Quantifying Market Transformation: the Case of Technology Procurement of Refrigerator-Freezers

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1. ABSTRACT

An increasing number of energy efficiency programs are aimed at transforming the market by inducing structural changes that favor more energy-efficient products. Because this involves institutional and organizational changes as well as technological and economic changes, quantifying market transformation has generally been elusive or inappropriate. Yet without some quantitative measures of market impacts, it will be difficult to incorporate the goal of market transformation into broader policies and translate knowledge across similar programs.

In this paper, we look at empirical evidence from a market transformation program involving technology procurement of refrigerator/freezers in Sweden that was completed in late 1991. We use historical model and sales data to analyze market impacts with respect to energy-efficiency. Expected future impacts of the program are modeled using the current appliance stock, a characterization of consumer choice, and estimated changes in the availability and price of refrigerator-freezers. The analysis suggests that the benefits to consumers resulting from the program are quite high in comparison to the costs.

2. INTRODUCTION

Market transformation programs are aimed at inducing lasting changes to the market such that energy-efficient products are more likely to be purchased due to greater availability, decreased price, easier implementation, or some other effect that improves their standing in the market. The Technology Procurement (TU) program in Sweden brings new energy-efficient products to market via a competition organized through the co-ordination of buyers and sellers. The co-ordinating role is played by the Department of Energy Efficiency at the Swedish National Board for Industrial and Technical Development (NUTEK). The TU program was initiated in 1988 and one of the first competitive procurements, for refrigerator-freezers, was completed in late 1991 (Nilsson 1992).

It is difficult to quantify the impacts of market transformation programs such as TU. The market as a whole must be analyzed rather than a small group of customers as might be the case in a demand-side management program. There are often many changes occurring simultaneously, as manufacturers develop new models, retailers change the mix of models in their stock, buyers change their specifications, and consumer preferences change. In this paper, we focus on impacts that can be quantified, such as the availability and price of models. By drawing on both model and sales data, we attempt to develop some measures of market transformation, and assess the TU program for refrigerator-freezers based on these measures.

3. DATA AND METHODOLOGY

A quantitative evaluation of market transformation requires data on the entire market for a particular product or at least some reasonable portion of that market. This is in contrast to demand-side management programs or programs aimed at a particular group of consumers, for which data is needed only for the targeted segment of the market. Furthermore, there has to be some way of characterizing changes in the market over time such that the impacts of the program can be revealed. Both model and sales data are needed in assessing such changes. Model data provides detail on the characteristics of different models while sales data gives the market shares of particular models or groups of models.

The Swedish Consumer Board (Konsumentverket) maintains data on a number of different appliances, and we gathered the data available between 1984-1994. For refrigerator-freezers, this data includes most of the models commonly available and gives important characteristics such as energy consumption, dimensions, features, volume, and average retail price (Carlsson 1994). Most refrigerator-freezers have separate compartments only for the refrigerator (kyl) and freezer (frys). There are also a few models that have chiller compartments (sval) and/or additional freezer compartments (0-fack). We calculate the adjusted volume (ADJVOL) in liters according to standard conventions based on temperature differentials:

$$ADJVOL = VOL_{kyl} + 2,15*VOL_{frys} + 0,75*VOL_{sval} + 1,25*VOL_{0\text{-}fack} \quad (1)$$

The specific energy consumption (E-SPEC) is simply the annual energy consumption (AEC) divided by the adjusted volume:

$$E\text{-}SPEC = AEC\ (kWh) / ADJVOL\ (liters) \quad (2)$$

The purchase prices are subject to variations according to such factors as geographical region, bulk discounts, retailer pricing conventions, and sale prices. Of course, this is generally the case unless a comprehensive set of point-of-purchase data is available. Nevertheless, the purchase price data can be used to discern general trends while recognizing that individual purchases cannot be analyzed directly. Where necessary for purposes of comparison, we adjusted the prices by the consumer price index for the appropriate month and year.

A major manufacturer provided sales data for its models for the years 1985-1994, representing between 55-70% of total sales in Sweden (Salminen 1993). Consequently, the sales data gives a fairly accurate picture of purchasing patterns and changes over time in the energy efficiency profile for refrigerator-freezers in Sweden. Since our focus is on energy efficiency choices, the use of sales data from only one manufacturer is also advantageous in that it eliminates some of the effects of brand names on consumer choices. The model data was used to attach the relevant characteristics for each model sold, including volume, energy consumption, and purchase price.

One adjustment had to be made to the sales data in order to make it a better indicator of market trends. One particular model has commanded a disproportionate share of sales throughout this time period and thus tends to dominate the statistics. It has been popular with housing companies that buy in large quantities for apartments and require certain exterior dimensions. Since its share has not changed very much over this period, varying between 18-20%, we have excluded it as an outlier for this study, the model effectively representing a "sticky" portion of the market. This adjustment, however, must carry the recognition that there is a potential for a big shift in the market in future years if housing companies switch their specification away from this model.

4. ANALYSIS

It is difficult to separate the various changes occurring in the market over time with generalized quantitative techniques. The actions of manufacturers, retailers, consumers, government officials, and other actors all become intertwined. Manufacturers change the mix of models they offer, retailers promote or display these models differently, large buyers fix their purchasing orders based on certain criteria, and so forth. While it is not possible to break out all or even most of these changes, we can at least consider some market shifts based on the distribution of models and sales and the purchasing patterns thereby implied. The availability and sales of energy-efficient models are particularly relevant to market transformation, and we consider changes between 1984-1994. Over the same time period, we assess structural changes in the market for refrigerator-freezers based on adjusted volume, energy consumption and specific energy consumption. We then analyzed expected future impacts of technology procurement by configuring the REEPS model (EPRI 1987) with the refrigerator-freezer data for Sweden.

4.1. Availability

Perhaps one of the most tangible benefits from Technology Procurement is the increased availability of energy-efficient models on the market. Those manufacturers that participated and did not win, having sunk costs and effort in the competition, will want to market their own products in ensuing years. Although these models will likely not be as efficient as the winning model, especially if they differ in volume or features, there is nonetheless a shift toward a more efficient mix of models on the market. There is also the possibility that the most inefficient models are driven off the market by the combined effects of increased competition and increased awareness of energy efficiency. Changes in the mix of models available can significantly transform the market for energy efficiency.

We divided the models into five groups, with models under 1,1 kWh/l constituting the most efficient group and models over 2,0 kWh/l making up the least efficient group. Table 1 shows the number and percentage of energy-efficient models for various years before and after the 1991 competition. Before the competition, there was only one model under 1,1 kWh/l. This was the case until the procurement was completed in 1991. After the competition, the number of such models increased markedly each year. Thus, the share of energy-efficient models went from 0,8% of the market in 1991 to 22% of the market in 1994. At the same time, there were declines in the least efficient group of models after 1991. Indeed, the number and share of inefficient models had been increasing until 1991. By 1994, the share of these models had dropped to 7,7% from 15,3% in 1991. The shifts in model offerings thus represent significant changes in market availability rather than just marginal improvements in efficiency.

*Table 1a: **Number of models by year and specific energy group***

Specific Energy (kWh/l)	1984	1985	1987	1988	1990	1991	1992	1993	1994
< 1.1	1	1	1	1	1	1	10	15	26
< 1.4	13	19	24	33	28	39	44	44	43
< 1.7	22	24	22	27	34	38	43	41	25
< 2.0	13	11	8	9	16	27	23	21	14
>= 2.0	3	2	4	7	13	19	13	11	9
	52	57	59	77	92	124	133	132	117

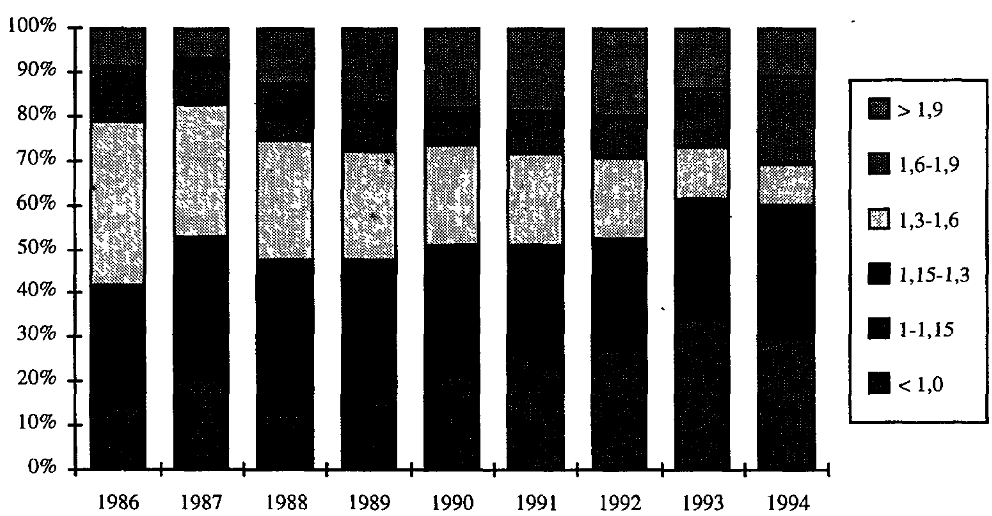
***Table 1b:** Shares of models by year and specific energy group*

Specific Energy (kWh/l)	1984	1985	1987	1988	1990	1991	1992	1993	1994
< 1.1	1.9%	1.8%	1.7%	1.3%	1.1%	0.8%	7.5%	11.4%	22.2%
< 1.4	25.0%	33.3%	40.7%	42.9%	30.4%	31.5%	33.1%	33.3%	36.8%
< 1.7	42.3%	42.1%	37.3%	35.1%	37.0%	30.6%	32.3%	31.1%	21.4%
< 2.0	25.0%	19.3%	13.6%	11.7%	17.4%	21.8%	17.3%	15.9%	12.0%
>= 2.0	5.8%	3.5%	6.8%	9.1%	14.1%	15.3%	9.8%	8.3%	7.7%

4.2. Sales

Technology Procurement brings a more energy-efficient product to the market earlier than would have been the case in the absence of the program. We have already observed that in the case of refrigerator-freezers, this led rather quickly to the introduction of several more models with improved energy efficiency. But the question of whether these models gain market share is ultimately what will determine the tangible benefits from the program through decreased energy consumption. Since our sales data is only for one manufacturer, we cannot fully ascertain the market shares of the most efficient models. However, by looking at the distribution of sales over time, we can gain a reasonable picture of the shifts in market shares. This distribution is shown as bar graphs in Figure 1.

Figure 1: Market Shares by Specific Consumption Segment



The most efficient models (< 1,1 kWh/liter), those which were introduced subsequent to the procurement, gained market share rather quickly, increasing to 7,5% in 1993. Partly as a result of this, the average energy consumption for all refrigerator-freezers decreased to its lowest point in 1994. However, the least efficient models have also gained market share during this period, in spite of the fact that the availability of these models decreased (see Table 1). It is somewhat difficult to interpret this shift without further market segmentation because of the interdependency between energy consumption and volume, as well as other features such as automatic defrost. We attempt to address the issue of changes in volume in the next section, but we do not consider other features in this analysis.

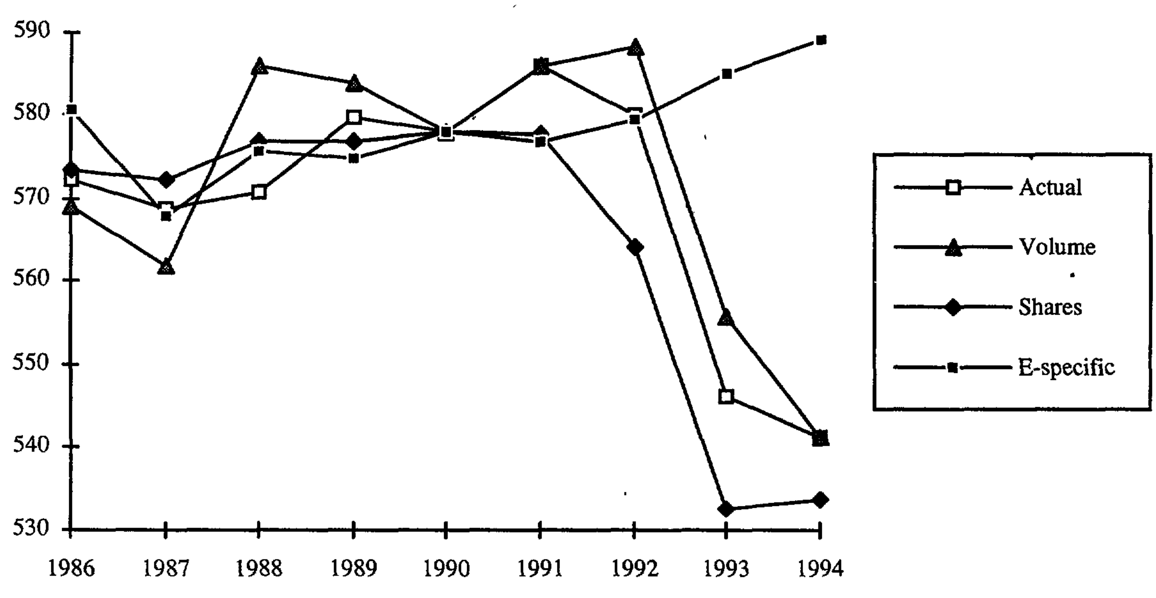
4.3. Structural Shifts

The average sales-weighted annual energy consumption is the statistic of most interest for a simple characterization of energy consumption impacts. Using energy efficiency bins or segments, we can think of this annual energy consumption as the product of shares, volumes, and specific consumption. The shares of the energy efficiency segments are multiplied by the average adjusted volume and specific consumption of each segment. In some respects, this is equivalent to thinking of each segment as being a single model or product, while the volume and specific consumption provide the specification of the model. This simplification allows us to separate changes in shares from changes in volume and specific consumption. This is the most relevant with respect to market transformation because the shares are presumably the result of preferences for more or less efficient models. Average annual consumption (AEC) is equivalent to the sum of the product of specific consumption and adjusted volume across the energy efficiency segments:

$$AEC = S\ (SHARE_i * E\text{-}SPEC_i * ADJVOL_i) \qquad (3)$$

Since the TU program was completed in 1991, we use 1990 as the base year for comparing the impacts of changes in shares, volume, and specific consumption. This means that for each of the three variables, we interpret the resulting annual energy consumption as that which would have occurred given the 1990 values for the other 2 variables. Figure 2 shows the results of this calculation for 1986-1994. Until 1991, there was little change in the market, but between 1990 and 1994, actual average energy consumption decreased from 578 kWh/year in 1990 to 540 kWh/year in 1994. After 1991, we can see that the shifts in the shares of the energy efficiency segments had the greatest impact in decreasing energy consumption. If volume and specific consumption had remained constant, the shift in shares would have pushed average consumption even lower, to 530 kWh/year. Specific energy consumption would have pushed up the annual energy consumption if the shares and volume had not changed from their 1990 values. Volume changed roughly in tandem with energy consumption.

Figure 2: Structural Shifts in Refrigerator-Freezer Market



4.4. Modeling Future Impacts

Using the REEPS model, we estimated energy and economic impacts of the technology procurement program. This required first developing a reference (or business-as-usual) case and then adjusting the input set to create the TU case. We developed the model with data on the existing stock of refrigerator-freezers in Sweden (Salminen 1993) and the statistics for currently available models and market shares. The REEPS model permits specification of specific technologies, for which we configured eight representative models spanning the range of available energy efficiency levels (see table 3). The upper two models describe products made available as a result of the procurement, and thus the market availability variables differ from the reference case, for which these technologies were not available. The variables for availability were set to reflect the increased availability of energy-efficient models, using the percentages of available models in 1992 (from table 1). Exogenous assumptions for the model are given in table 4, including future electricity prices, number of households, and saturation of refrigerator-freezers.

***Table 2**: 1992 Summary of refrigerator-freezer options*

Bin	*Number of Models*	*Purchase Price (SEK/ECU))*	*Temperature-Corrected Volume (liters)*	*Specific Energy Consumption (kWh/liter)*	*New Home Shares (in 1992)*
< 0.85	2	7970/835	406	0.78	1.68%
0.85-1.0	7	6741/707	423	0.93	0.66%
1.0-1.15	9	7282/763	476	1.13	24.99%
1.15-1.3	16	7088/743	457	1.23	25.08%
1.3-1.45	27	7815/819	428	1.37	17.83%
1.45-1.9	51	7361/772	385	1.66	9.74%
2.05	9	7655/802	350	1.96	11.60%
>= 2.05	12	7308/766	306	2.28	8.41%

***Table 3**: Exogenous Assumptions*

YEAR	*Elec. Price (SEK/ECU) (per kWh)*	*Multi-Family (1000s)*	*Single-family (1000s)*	*Multi-Family Saturation*	*Single-family Saturation*
1991	0.841/0.088	2220	1924	0.48	0.25
1995	0.859/0.090	2274	1971	0.59	0.33
2000	0.882/0.092	2343	2030	0.73	0.44
2005	0.906/0.095	2414	2092	0.82	0.54
2010	0.930/0.970	2487	2156	0.90	0.63
2015	0.955/0.100	2563	2221	0.90	0.67
2020	0.980/0.103	2641	2288	0.90	0.70

Yearly choices among the technology options are modeled in REEPS, based on the current-year value of relevant variables such as electricity price and availability. The resulting choices among the different options in the TU or efficiency case are shown in Figure 3 for the time period 1992-2020. Since the price of electricity is rising over time, there is a trend toward the more efficient options. There are many other changes that affect the projected yearly energy consumption, such as the rate of stock turnover, the change in the mix of housing types, and the vintage profile of the stock of installed refrigerator-freezers. The average annual energy consumption of refrigerator-freezers over the same time period is shown in Figure 4.

Figure 3: Specific Technology Shares under Technology Procurement

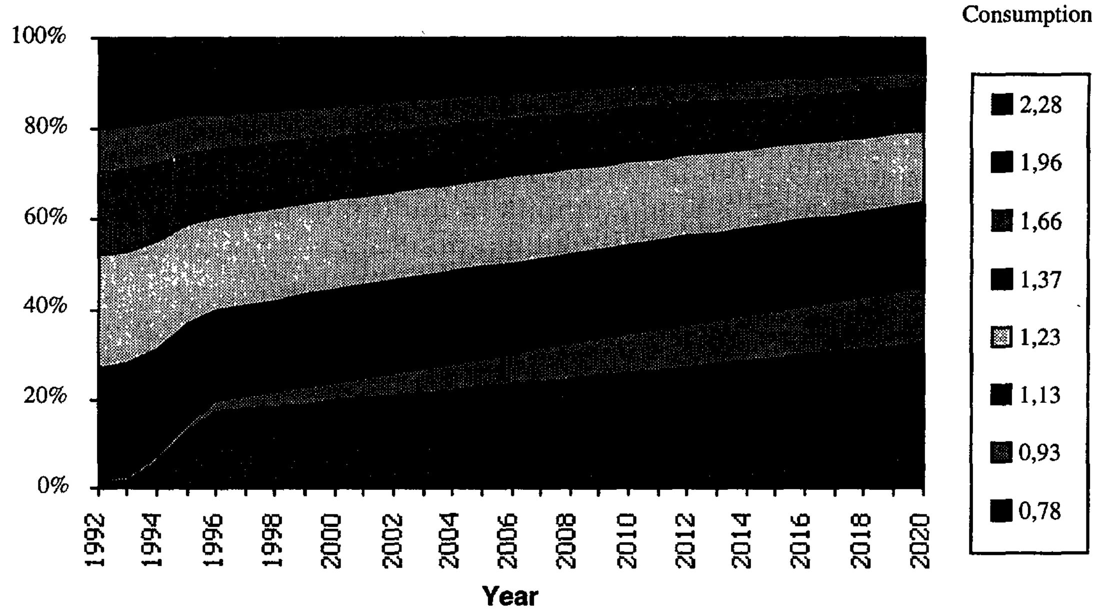
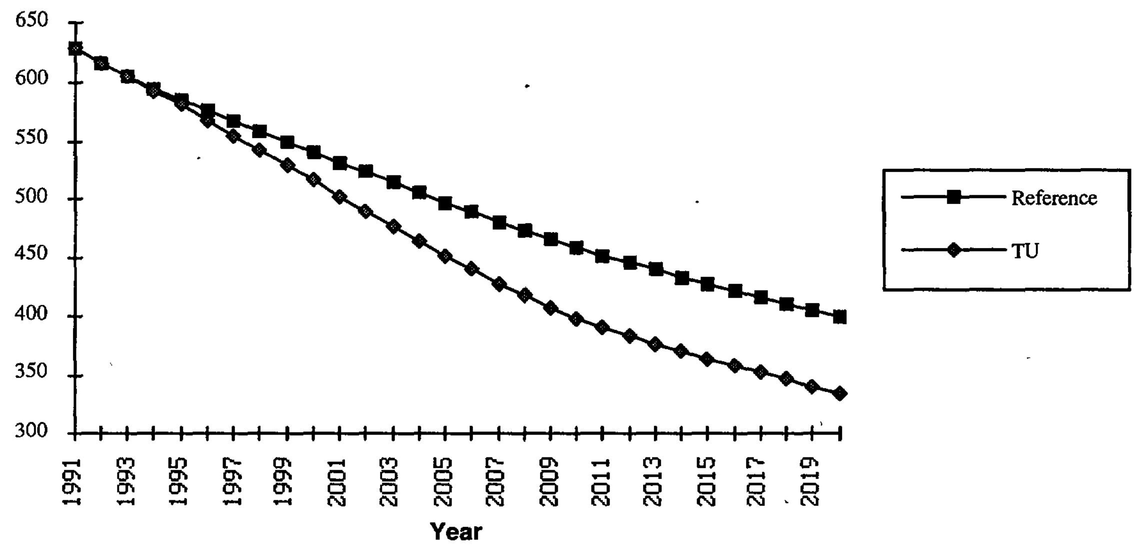


Figure 4: Average Annual Energy Consumption of Refrigerator-Freezers



Since REEPS allows modeling of specific technologies (Hummel 1992), it is possible to make a rough benefit-cost calculation for the TU program. The benefit is the reduction in electricity costs for those consumers who purchase the more efficient products. The costs are the additional purchase costs incurred by consumers, and the program's administrative and incentive costs. Table 4 gives the estimated value of these costs based on the results of the model runs along with the benefit-cost ratio.

Table 4: Costs and benefits (savings) from refrigerator-freezer TU program

	Electricity Savings	*Additional First Costs*	*Program Costs*	*Benefit-Cost Ratio*
SEK	3.97E+09	4.37E+08	2.00E+06	9.04
ECU	4.16E+08	4.58E+07	2.10E+05	

5. DISCUSSION

In the three years after the procurement was completed (1992-1994), a number of shifts occurred in the market which are at least partly attributable to the program. The availability of energy-efficient models increased dramatically as other manufacturers brought forth competing models. The average premium paid for energy-efficiency in the refrigerator-freezer market decreased over this period. Sales of energy-efficient models have increased, although not dramatically, while average energy consumption and adjusted volume have decreased. Structural changes in the market, when considered in terms of the energy efficiency distribution of sales, were more important in decreasing energy consumption than the decrease in volume.

The decrease in volume of refrigerator-freezers deserves special attention in this case. As noted previously and as the graph in Figure 2 shows, volume moved roughly in tandem with actual consumption and would have had little impact on energy consumption in the absence of changes in shares and specific consumption. However, the model introduced through the procurement program and the subsequent energy-efficient models that appeared on the program had lower volume than the average on the market. These models averaged 400 liters in adjusted volume while the market average was 427 kWh/year. Thus, the procurement program had an impact not only in terms of efficiency, but also on volume, so that the total impact on energy consumption was even greater. While it is common practice for designers of energy efficiency programs to avoid questions of changes in "activity," this result shows the significance of the interdependencies between activity and energy consumption.

The REEPS model results provide a direct quantitative estimate of the impacts of the program. The efficient models gain market share in future years (figure 3) due to the rise in electricity prices as well as changes in the cost of these models in the early years after TU due to increased volume and competition. The resulting impacts on annual energy consumption (figure 4) result in increasing levels of savings throughout the forecast period, by the end of which they begin to level off. As the figure shows, the reference case also has considerable reductions in annual energy consumption. The main reason is actually the increasing saturation of refrigerator-freezers. As table 3 showed, saturation will double in multi-family housing and will nearly triple in single-family households by 2020. In Sweden, consumers are increasingly turning towards combined units rather than separate refrigerators and freezers. Thus, with an expanding market, the share of new units in the stock is increasing a great deal over time, thereby building in a lot of savings.

The estimates of costs and benefits shown in table 4 offer perhaps the bottom-line with regard to the value of the technology procurement program to consumers. The high benefit-cost ratio suggests that even under different assumptions or much less optimistic market shares, the program would still be quite beneficial to consumers. Furthermore, the program had spin-off effects in the market for related products such as stand-alone refrigerator and freezer units. Similar technologies have been applied for these products without the incentives provided in the original procurement. If these impacts had been included, the benefit-cost ratio would have been much higher. The estimate of costs and benefits also shows how small the administrative and incentive costs are in comparison to the purchase and electricity costs borne by consumers

The quantitative measures employed here give some indication of the nature of the market transformation resulting from the Technology Procurement program. These or similar measures might prove useful in the evaluation of other programs aimed at market transformation where model and sales data are available to support the analysis. It does appear that detailed end-use modeling is a useful tool for evaluating the impacts of some types of market transformation programs. In the case of Technology Procurement, a number of indicators and variables can be employed in the analysis, including availability, cost, and the specific characteristics of technologies. This is not to suggest that energy efficiency programs should be analyzed solely on a quantitative basis alone. The complexity and dynamic interaction of market actors means that judgments about the efficacy of energy efficiency programs will also require considerable qualitative analysis when the programs are aimed at market transformation.

6. ACKNOWLEDGMENTS

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