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ENERGY STAR APPLIANCES AND ENERGY EFFICIENCY

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ABSTRACT
This paper reviews the results of a detailed assessment of U.S. lighting markets. The study approach was as follows. First, information from annual surveys of sales of lighting products was used to build a database of product sales and drivers of product sales by efficiency type. Second, ordinary least squares regression analysis was used to model the impact of gross domestic product, electricity prices and demand side management on product sales for energy efficient and standard products. Third, the regression output was combined with the database information to estimate the impact of changes in electricity prices, gross domestic product and demand side marketing activity on sales of energy efficient and standard products.

KEY WORDS
Identification and estimation, lamp market, compact fluorescent lamp, linear fluorescent lamp.

1. Introduction

Econometric methods have been used in previous studies to analyze the impact of market transformation programs. Duke and Kammen [1] found that accounting for interaction between the demand response and production response for electronic ballasts increases the consumer benefit cost ratio. Horowitz [2] found that coordinated national electronic ballast programs were more cost effective than local efforts. Horowitz and Haeri [3] found that the cost of energy efficiency investments was fully capitalized in housing prices and that purchasing an energy efficient house was cost effective. Jaffe and Stavins [4] found that insulation levels in new residential housing appropriately reflect energy prices. Tiedemann [5] applies an econometric approach similar to that used here to an analysis of the China Green Lights program. This paper develops and applies the interrupted time-series model to measure market transformation in the U.S. markets for screw-type lighting and linear fluorescent lamps.

Through the late 1980's a number of utilities began to offer demand side management (DSM) programs in response to changes in the incentive mechanisms they were offered by Public Utility Commissions. The intent of these mechanisms was to put supply-side and demand-side options on an equal footing given evidence that it was sometimes more cost effective, at the margin, to change-out current technologies for new ones than to increase energy system capacity to handle ever larger energy loads. The development of integrated resource planning formalized the insights of DSM planners, provided a consistent framework in which the range of relevant energy supply options could be fairly compared, and led to the development of market-based and policy initiatives to address energy efficiency concerns.

Although the utility DSM initiatives laid the groundwork for future activity, the launch of the modern era in energy conservation in the United States can perhaps most appropriately be linked to the launch of the Green Lights Program in 1991. The Environmental Protection Agency (EPA) Green Lights initiative was a voluntary partnership between the government and the private sector aimed at promoting energy efficient lighting in commercial and industrial establishments. Program emphasis was initially on electronic ballasts, T8 fluorescent tubes, CFLs and lighting controls. The Green Lights Program formed the initial component of the Energy Star program.

2. Method

This paper uses market analysis to understand the impact of energy conservation policy developments on sales of energy efficient screw-type lamps and linear fluorescent lamps. The basic approach is straightforward: first, publicly available information is used to build a database of sales and drivers of sales; second, econometric models are used to estimate the determinants of sales; and, third, the regression results are used to estimate the individual impacts of prices, GDP and energy conservation policies on sales.

It is convenient to view a single lamp market in isolation and abstract from linkages to other markets or from general equilibrium effects. Consider the following simple two-equation model, where (1) is the demand curve for a standard product, say type-A incandescent lamps, and (2) is the demand curve for an efficient product, say compact fluorescent lamps, where the standard and efficient products comprise the whole market. In these equations, $quantity_{it}$ is the residential and small commercial demand for product i in year t, $price_t$ is

the average price of electricity in year t, GDP_t is the gross domestic product in year t (as a proxy for income), $dummy_t$ is a dummy variable that takes on the value 0 for the years up to the energy crisis (1997 through 2001) and the value 1 for the post-crisis years (2001-2004), ε_{it} is an error term and the symbols α, β, γ, and δ are parameters.

(1) $quantity_{1t} = \alpha_1 + \beta_1\ price_t + \gamma_1\ GDP_t + \delta_1\ dummy_t + \varepsilon_{1t}$

(2) $quantity_{2t} = \alpha_2 + \beta_2\ price_t + \gamma_2\ GDP_t + \delta_2\ dummy_t + \varepsilon_{2t}$

Equation (1) represents the demand for the first product in year t and says that demand for the first product is a linear function of the electricity price, gross domestic product and a preference variable which reflects a shift in consumer demand as a result of marketing and related activity. It would be desirable to include the prices of the first product and the second product as arguments on the right hand side of equation (1), but these are not available. Note that all of the right-hand side variables are exogenous, so that equation (1) is identified.

Equation (2) represents the demand for the second product in year t and says that demand for the second product is a linear function of the electricity price, gross domestic product and a preference variable which reflects a shift in consumer demand as a result of marketing and related activity. It would also be desirable to include the prices of the first product and the second product as arguments on the right hand side of equation (2), but these are not available. The information used in the regressions comes from the annual Itron surveys of sales of lighting products and Bureau of Economic Analysis (BEA) information on energy prices and GDP.

Next, using the estimated parameters from the regressions, we take first differences of (1) and (2) in order to decompose the change in sales in a given year into price-related, GDP-related and DSM-related components. Noting that the first difference of a constant is zero and the first difference of the dummy variable is 1, we have (3) and (4) as follows.

(3) $\Delta quantity_{1t} = \beta_1\ \Delta price_t + \gamma_1\ \Delta GDP_t + \delta_1$

(4) $\Delta quantity_{2t} = \beta_2\ \Delta price_t + \gamma_2\ \Delta GDP_t + \delta_2$

3. Hypotheses

Next we consider hypotheses for this study. If product 1 and product 2 are normal goods, then consumption of product 1 increases with an increase in gross domestic product, and the consumption of product 2 increases with an increase in gross domestic product. This then gives Hypothesis 1.

Hypothesis 1. An increase in GDP increases sales of the energy efficient product and reduces sales of the inefficient product.

In this study, efficient products include compact fluorescent lamps and T8 fluorescent tubes, while less efficient products include type-A incandescent lamps and T12 fluorescent tubes.

We assume that consumers base purchase decisions, at least in part, on the assessment of some financial criteria such as pay-back period or life cycle costs. This might be done directly by the consumer, but is more likely to be based on information from trade allies, consumer organizations or governments, such as Energy Guide labels. Because comprehensive information on customer costs and befits is not available by year, we apply a modified analysis in which consumers consider the cost of electricity in making purchase decisions on energy using products. An increase in the price of electricity shifts purchases towards more energy efficient products, and a decrease in the price of electricity shifts purchases towards less energy efficient products. This then gives Hypothesis 2.

Hypothesis 2. An increase in the price of electricity increases sales of the energy efficient product and reduces sales of the inefficient product.

Barriers to increased sales of energy efficient products include inadequate consumer and trade ally awareness and knowledge of the features, benefits and cost effectiveness of energy efficient products. Demand side management marketing efforts are aimed, in part, at overcoming these barriers and thereby increasing demand for more energy efficient products (shifting the demand curve upwards and to the right) and reducing demand for less energy efficient products (shifting the demand curve down and to the left). This then gives Hypothesis 3.

Hypothesis 3. An increase in demand side management marketing increases sales of more energy efficient products and reduces sales of less energy efficient products.

4. Screw-type Lamps

Table 1 shows annual sales and market share information for screw-type lamps purchased by residential and small business customers. The market is defined to include only compact fluorescent lamps and type-A incandescent lamps, because they are the main products that occupy medium-base, screw-type fixtures. Some halogen lamps also fit medium-base, screw-type fixtures but they are not viewed as meeting the same lighting needs, and so they are excluded from this analysis.

Sales of compact fluorescent lamps increased from 4.8 million units in 1997 to 6.8 million units in 2000 (just before the energy crisis) and to 31.4 million units in 2004. Sales of incandescent lamps increased from 1,169.2 million units in 1997 to 1,355.2 million units in 2000 and then fell to 1,179.5 million units in 2004. Market share of

compact fluorescent lamps rose from 0.4% in 1997 to 0.5% in 2000 and to 2.6% in 2004, while market share of incandescent lamps fell from 99.6% in 1997 to 99.5% in 2000 and to 97.4% in 2004. It should be noted that quality compact fluorescent lamps typically last for ten times as many hours as incandescent lamps.

Table 1. Sales and market share for screw-type lamps

	Compact fluorescent		Incandescent		Total	
	Number (000)	Share (%)	Number (000)	Share (%)	Number (000)	Share (%)
1997	4,759	0.41	1,169,200	99.59	1,173,959	100.00
1998	5,438	0.44	1,231,210	99.56	1,236,648	100.00
1999	6,117	0.47	1,293,220	99.53	1,299,337	100.00
2000	6,796	0.50	1,355,230	99.50	1,362,026	100.00
2001	22,043	1.67	1,301,780	98.33	1,323,823	100.00
2002	27,036	2.07	1,277,200	97.93	1,304,236	100.00
2003	33,957	2.68	1,231,570	97.32	1,265,527	100.00
2004	31,362	2.59	1,179,470	97.41	1,210,832	100.00

Source: RER and Itron, California Lamp Report (various)

Table 2 presents the results of the ordinary least squares regression modelling for screw-type lamps. Coefficient standard errors are shown in parentheses below the coefficients and the significance of a linear regression is shown below the F-test value.

Model (1) shows the impact of gross domestic product (GDP in billions of US dollars at 2000 prices) and electricity price (price in US cents) on sales of compact fluorescent lamps in thousands of units. Model (2) shows the impact of gross domestic product, electricity price and the demand side management dummy variable on sales of compact fluorescent lamps in thousands of units. The DSM dummy variable takes the value 0 for the years 1997-2001 and the value 1 for the years 2002-2004 as explained above. Model (3) shows the impact of gross domestic product (GDP) and electricity price (price) on sales of incandescent lamps in thousands of units. Model (4) shows the impact of gross domestic product, electricity price and the demand side management dummy variable on sales of compact fluorescent lamps in thousands of units.

Table 2. Lamp sales regressions (000)

	Compact fluorescent lamps		Incandescent lamps	
	(1)	(2)	(3)	(4)
Con	-263,133*** (61,690)	-171,970** (72,430)	2,715,190*** (381,700)	2,059,020*** (536,300)
GDP	0.010*** (0.0027)	0.0056** (0.0025)	0.089*** (0.014)	0.12*** (0.014)
Price	21,324** (8,501)	15,396** (7,551)	-274,975*** (55,040)	-232,304*** (56,630)
DSM	-	10,605** (4,950)	-	-76,336** (35,770)
Adj R^2	0.79	0.85	0.56	0.70
F	13.8 (0.01)	14.6 (0.01)	5.5 (0.06)	6.4 (0.05)
DW	1.60 (0.20)	2.00 (0.01)	1.45 (0.28)	1.07 (0.46)

Note: One, two or three asterisks indicate the coefficient is significant at the 10%, 5% or 1% level respectively.

The regression modelling is successful since each equation explains at least 56% of the variance or more, as given by the adjusted R-squared values, although the low values of the Durbin-Watson statistic suggest possible auto-correlated residuals in several equations, and this was not improved by using a first-order auto-regressive scheme. All the coefficients have the expected signs, and they are all statistically significant at the 10% level or better. An increase in gross domestic product increases sales of compact fluorescent lamps and of incandescent lamps. An increase in the residential price of electricity increases the sales of energy efficient compact fluorescent lamps and reduces the sales of less efficient incandescent lamps. Energy crisis motivated DSM activities increase the sales of compact fluorescent lamps and decrease the sales of incandescent lamps.

Table 3 uses the regression results to provide an analysis of the changes in gross domestic product, residential electricity prices and demand side management on annual sales of compact fluorescent lamps.

The price effect is the product of the price coefficient from equation (2) above times the incremental price change calculated in the third row using the information in the second column of the table. The price effect is an increase in compact fluorescent lamp sales by 1.8 million units in 2002, 5.5 million units in 2003 and 9.7 million units in 2004. The GDP effect is the product of the GDP coefficient from equation (2) times the change in GDP calculated in the sixth row from the information in the fifth row of the table. The GDP effect is an increase of compact fluorescent sales of 0.9 million units in 2002, 1.5 million units in 2003 and 2.4 million units in 2004. The DSM effect is just the coefficient of the DSM term from equation (2). The DSM effect is an increase in sales of compact fluorescent lamps of 10.6 million units in each of 2002, 2003 and 2004. Finally, the total effect is the sum of the price effect plus the GDP effect plus the DSM effect. The total effect is an increase in sales of compact fluorescent lamps of 13.3 million units in 2002, 17.7 million units in 2003 and 22.7 million units in 2004.

Table 3. Compact fluorescent lamp sales analysis

	2001	2002	2003	2004
Price (US$)	8.34	8.46	8.70	8.97
Δ Price (US$)	-	0.12	0.36	0.63
Price effect (000)	-	1848	5543	9699
GDP (US$M)	9891000	10049000	10321000	10756000
Δ GDP (US$M)	-	158000	272000	435000
GDP effect (000)	-	885	1523	2436
DSM effect (000)	-	10605	10605	10605
Total effect (000)	-	13338	17671	22740

Table 4 uses the regression results to provide an analysis of the changes in gross domestic product, residential electricity prices and demand side management on annual sales of type-A incandescent lamps. The price effect is a reduction in incandescent lamps sales by 27.9 million units in 2002, 83.6 million units in 2003 and 146.4 million units in 2004. The GDP effect is an increase of incandescent lamp sales of 19.0 million units in 2002, 32.6 million units in 2003 and 52.2 million units in 2004. The DSM effect is a decrease in sales of incandescent lamps of 76.3 million units in each of 2002, 2003 and 2004. The total effect is a decrease in sales of incandescent lamps of 85.2 million units in 2002, 127.3 million units in 2003 and 170.5 million units in 2004.

Table 4. Incandescent lamp sales analysis

	2001	2002	2003	2004
Price (US$)	8.34	8.46	8.70	8.97
Δ Price (US$)	-	0.12	0.36	0.63
Price effect (000)	-	-27877	-83629	-146352
GDP (US$M)	9891000	10049000	10321000	10756000
Δ GDP (US$M)	-	158000	272000	435000
GDP effect (000)	-	18960	32640	52200
DSM effect (000)	-	-76336	-76336	-76336
Total effect (000)	-	-85253	-127325	-170488

5. Linear Fluorescent Tubes

Table 5 shows annual sales and market share information for linear fluorescent tubes purchased by residential and small business customers. The market is defined to include only T8 and T12, because they are the main competing linear fluorescent products. Sales of T8 tubes increased from 36.4 million units in 1997 to 43.6 million units in 2000 and to 52.1 million units in 2004. Sales of T12 tubes increased from 91.1 million units in 1997 to 65.4 million units in 2000 and then fell to 42.6 million units in 2004. Market share of T8 tubes was stable at 40.0% in 1997 through 2000 and rose to 55.0% in 2004, while market share of T12 was stable at 60.0% in 1997 through 2000 and fell to 45.0% in 2004.

Table 5. Sales and market share for linear fluorescent tubes

	T8 fluorescent tubes		T12 fluorescent tubes		Total	
	Number (000)	Share (%)	Number (000)	Share (%)	Number (000)	Share (%)
1997	36,432	39.99	54,650	60.01	91,082	100.00
1998	38,816	39.99	58,225	60.01	97,041	100.00
1999	41,200	40.00	61,800	60.00	103,000	100.00
2000	43,584	40.00	65,375	60.00	108,959	100.00
2001	46,979	50.00	46,978	50.00	93,957	100.00
2002	49,282	50.00	49,482	50.00	98,964	100.00
2003	50,866	55.00	41,617	45.00	92,483	100.00
2004	52,051	55.00	42,587	45.00	94,638	100.00

Source: RER and Itron, California Lamp Report (various)

Table 6 presents the results of the ordinary least squares regression modelling for linear fluorescent tubes. Model (5) shows the impact of gross domestic product and electricity price on sales of T8 tubes in thousands of units. Model (6) shows the impact of gross domestic product, electricity price and the demand side management dummy variable on sales of T8 tubes in thousands of units. Model (7) shows the impact of gross domestic product (GDP) and electricity price (price) on sales of T12 tubes in thousands of units. Model (8) shows the impact of gross domestic product, electricity price and the demand side management dummy variable on sales of T12 tubes in thousands of units. The explanatory power of the regressions is very good, and all coefficients have the expected signs. An increase in gross domestic product increases sales of T8 and T12 tubes. An increase in the residential price of electricity increases the sales of T8 tubes and reduces the sales of less efficient T12 tubes. Energy crisis motivated DSM activities increase the sales of compact fluorescent lamps and decrease the sales of incandescent lamps.

Table 6. Linear fluorescent tubes sales regressions (000)

	T8 fluorescent lamps		T 12 fluorescent lamps	
	(5)	(6)	(7)	(8)
Con	-50,639*** (16,300)	-30,519 (23,830)	307,335*** (46,290)	254,153*** (52,120)
GDP	0.0078*** (0.00070)	0.0068*** (0.00068)	0.00076 (0.0022)	0.0034 (0.0026)
Price	2,273 (2243)	965 (2,422)	-30,909*** (6,766)	-27,451*** (6,050)
DSM	-	2,341 (1,684)	-	-6,187* (3,773)
Adj R^2	0.93	0.94	0.78	0.80
F	45.3 (0.00)	35.4 (0.00)	13.0 (0.01)	10.5 (0.02)
DW	1.35 (0.32)	1.35 (0.32)	1.91 (0.05)	2.51 (-0.26)

Note: One, two or three asterisks indicate the coefficient is significant at the 10%, 5% or 1% level respectively.

Table 7 uses the regression results to provide an analysis of the changes in gross domestic product, residential electricity prices and demand side management on annual sales of T8 tubes. The price effect is an increase in T8 sales by 0.1 million units in 2002, 0.3 million units in 2003 and 0.6 million units in 2004. The GDP effect is an increase of T8 sales of 1.1 million units in 2002, 1.9 million units in 2003 and 3.0 million units in 2004. The DSM effect is an increase in T8 sales of 2.3 million units in each of 2002, 2003 and 2004. The total effect is an increase in sales of T8 tubes of 3.5 million units in 2002, 4.5 million units in 2003 and 5.9 million units in 2004.

Table 7. T8 fluorescent tube sales analysis

	2001	2002	2003	2004
Price (US$)	8.34	8.46	8.70	8.97
Δ Price (US$)	-	0.12	0.36	0.63
Price effect (000)	-	116	347	608
GDP (US$M)	9891000	10049000	10321000	10756000
Δ GDP (US$M)	-	158000	272000	435000
GDP effect (000)	-	1074	1850	2958
DSM effect (000)	-	2341	2341	2341
Total effect (000)	-	3531	4538	5907

Table 8 uses the regression results to provide an analysis of the changes in gross domestic product, residential electricity prices and demand side management on annual sales of T12 tubes. The price effect is a reduction in T12 sales by 3.3 million units in 2002, 9.9 million units in 2003 and 17.3 million units in 2004. The GDP effect is an increase of T12 sales of 0.5 million units in 2002, 0.9 million units in 2003 and 1.5 million units in 2004. The DSM effect is a decrease in sales of T12 tubes of 6.2 million units in each of 2002, 2003 and 2004. The total effect is a decrease in sales of T12 tubes of 8.9 million units in 2002, 15.1 million units in 2003 and 22.0 million units in 2004.

Table 8. T12 Fluorescent tube sales analysis

	2001	2002	2003	2004
Price (US$)	8.34	8.46	8.70	8.97
Δ Price (US$)	-	0.12	0.36	0.63
Price effect (000)	-	-3924	-9882	-17294
GDP (US$M)	9891000	10049000	10321000	10756000
Δ GDP (US$M)	-	158000	272000	435000
GDP effect (000)	-	537	925	1479
DSM effect (000)	-	-6187	-6187	-6187
Total effect (000)	-	-8944	-15144	-22002

6. Conclusion

This paper reviews the results of a detailed assessment of U.S. lighting markets. The study approach was as follows. First, information from annual surveys of sales of lighting products was used to build a database of product sales and drivers of product sales by efficiency type. Second, ordinary least squares regression analysis was used to model the impact of gross domestic product, electricity prices and demand side management on product sales for energy efficient and standard products. Third, the regression output was combined with the database information to estimate the impact of changes in electricity prices, gross domestic product and demand side marketing activity on sales of energy efficient and standard products.

The main purpose of this study is to estimate the total effect of GDP changes, electricity price changes and energy conservation measures on eth sales of lighting products. The main study results are follows. First, the total effect is an increase in sales of compact fluorescent lamps of 13.3 million units in 2002, 17.7 million units in 2003 and 22.7 million units in 2004. Second, the total effect is a decrease in sales of incandescent lamps of 85.2 million units in 2002, 127.3 million units in 2003 and 170.5 million units in 2004. Third, the total effect is an increase in sales of T8 tubes of 3.5 million units in 2002, 4.5 million units in 2003 and 5.9 million units in 2004. Fourth, the total effect is a decrease in sales of T12 tubes of 8.9 million units in 2002, 15.1 million units in 2003 and 22.0 million units in 2004.

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