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Estimating Price Elasticity using Market-Level Appliance Data

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Executive Summary

This report provides and update to and expansion upon our 2008 LBNL report "An Analysis of the Price Elasticity of Demand for Appliances," in which we estimated an average relative price elasticity of -0.34 for major household appliances (Dale and Fujita 2008).

Consumer responsiveness to price change is a key component of energy efficiency policy analysis; these policies influence consumer purchases through price both explicitly and implicitly. However, few studies address appliance demand elasticity in the U.S. market and public data sources are generally insufficient for rigorous estimation. Therefore, analysts have relied on a small set of outdated papers focused on limited appliance types, assuming long-term elasticities estimated for other durables (e.g., vehicles) decades ago are applicable to current and future appliance purchasing behavior. We aim to partially rectify this problem in the context of appliance efficiency standards by revisiting our previous analysis, utilizing data released over the last ten years and identifying additional estimates of durable goods price elasticities in the literature.

Reviewing the literature, we find the following ranges of market-level price elasticities: -0.14 to -0.42 for appliances; -0.30 to -1.28 for automobiles; -0.47 to -2.55 for other durable goods. Brand price elasticities are substantially higher for these product groups, with most estimates -2.0 or more elastic. Using market-level shipments, sales value, and efficiency level data for 1989-2009, we run various iterations of a log-log regression model, arriving at a recommended range of short run appliance price elasticity between **-0.4** and **-0.5**, with a default value of **-0.45**.

Contents

1 Introduction

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In this report we discuss and provide an estimated range of values for the consumer price elasticity of demand for common household appliances. The motivation for our current study is to improve the accuracy of shipments forecasting for federal appliance efficiency standards, but the elasticities we estimate could plausibly be used in a wider range of appliance market analyses.

While this analysis focuses on the purchase volume response to an appliance price change, we also emphasize the importance of considering the ceteris paribus impact of an efficiency level change on sales when projecting appliance shipments following a policy shock. All else equal, an appliance with higher efficiency is more desirable to consumers than one with lower efficiency; we provide an estimate of the “efficiency elasticity” of appliance demand that can be used to model this impact in shipments analysis.

In Section 2, we summarize estimates of price elasticity found in the literature. In Section 3, we describe our regression model and our data sources. We present the results of our regression analysis in Section 4 and discuss our recommendations in Section 5. Three appendices provide additional figures (Appendix A), regression results (Appendix B), and a discussion of our previous report (Appendix C).

2 Literature Review

Relatively few studies measure the effect of price on the sale of household appliances. This section briefly reviews available literature that relates to the demand for appliances, vehicles, and other durable goods, with particular attention to price and income elasticity estimates and the differences between short and long run elasticities and product and brand elasticities.

Price Elasticity

The price elasticity of demand is defined to be the percent change in quantity purchased given a 1% change in price (Varian 1999):

$$\epsilon_d = \frac{\frac{\Delta q}{q}}{\frac{\Delta p}{p}}$$

where:

ϵ_d = price elasticity of demand;

q = quantity;

p = price.

Reviewing the literature, we find the following ranges of market-level price elasticities: -0.12 to -0.42 for appliances; -0.30 to -1.28 for automobiles; -0.47 to -2.55 for other durable goods (see 2.1 for citations and individual study details).[1] Of particular relevance to our current analysis, Rapson (2014) calculates long run price elasticities of -0.12 and -0.24 for room air conditioners and central air conditioners, respectively.

Income Elasticity

The income elasticity of demand is defined to be the percent change in quantity purchased given a 1% change in income (Varian 1999):

$$\epsilon_I = \frac{\frac{\Delta q}{q}}{\frac{\Delta I}{I}}$$

where:

ϵ_I = income elasticity of demand;

q = quantity;

I = income.

Generally, appliances and other durables are normal goods, such that an increase in income leads to an increase in purchases. Accordingly, the literature provides a range of income elasticities between 0.26 and 0.79 for appliances and 0.22 to 3.08 for vehicles.

[1] Appendix C provides a discussion of our previous analysis of appliance price elasticity, in which we report an average value of -0.34 relative price elasticity across three household appliances.

Short Run and Long Run Price Elasticity

The impact of a price shock on purchase behavior is not uniform over time (Hymans et al. 1970). For the automobile market, Hymans et al. (1970) demonstrate that price elasticity of demand decreases dramatically within five to ten years of a price change. In the context of a price increase in the market for camcorders, Gowrisankaran and Rysman (2009) find that the market-wide long run price elasticity is approximately half of the magnitude of the short run elasticity.

This notion is also supported by Parker and Neelamegham's (1997) discussion of "technical competence," in which they expand on innovation diffusion concepts laid out in Rogers (1983). That is, as time passes and consumers gain familiarity with a product, they associate less risk with a price premium. Parker and Neelamegham (1997) find consistently decreasing price elasticity over time for many durable household goods, including refrigerators and freezers.[2]

Product and Brand Elasticity

In this analysis, we focus on the average response to an appliance price change across all market consumers of the given product; this is the "product" or "market" price elasticity. However, many existing studies focus on brand elasticity: the price response with regard to a particular brand within a product market. For example, if the price for a Brand A refrigerator increases, consumers may respond by forgoing a purchase altogether or by purchasing a similar refrigerator from Brand B.[3] Logically, the brand price elasticity will be higher (*i.e.*, more elastic) than the product price elasticity, as there are several major brands and numerous smaller brands producing all types of household appliances, and it is comparatively simple to substitute between brands rather than substituting for an appliance purchase in general. The studies we reviewed reveal this difference, with product price elasticities in the range of about -0.1 to -1 and brand price elasticities primarily greater than 1 in magnitude (Table 2.1).

Implicit Discount Rate

The concepts of price elasticity of demand and implicit discount rate are related in that both provide insight into the consumer's purchase decision. In some cases, a value must be assumed for the implicit discount rate before estimating price elasticity (*e.g.*, if present value of operating cost is used as a regression control, as we did in the 2008 report). In our current model specification, we avoid the necessity of selecting an appropriate implicit discount rate

[2] They also find no significant price response in room air conditioners, and price elasticities that first increase and then decrease over time for dishwashers. Note that the elasticity values calculated by Parker and Neelamegham (1997) appear to incorporate the influence of product brand and are thus expected to be more elastic than the aggregate product market elasticities we aim to estimate in this analysis.

[3] Brand elasticities are explored in depth in the market for consumer electronics in Gowrisankaran and Rysman (2009).

by including relative efficiency level rather than operating cost in our regressions, as described further in Section 3.1.[4]

[4]In the 2008 report, we calculate present value of energy costs using implicit discount rates of 20% and 37% (following Hausman (1979) and Revelt and Train (1998)); we found this led to slight differences in our estimate of relative price elasticity, but our estimates remained within the expected range based upon the literature.

Table 2.1: Price and Income Elasticities for Durable Goods

Product	Price Elasticity	Brand Elasticity	Income Elasticity	Model Type	Analysis Period	Time Period	Source
Automobiles	-1.07	–	3.08	Linear regression, stock adjustment	–	Short run	Hymans et al. [1970]
Automobiles	-0.36	–	1.02	Linear regression, stock adjustment	–	Long run	Hymans et al. [1970]
Automobiles	-1.63	–	0.26	Multiperiod, multiasset regression	1952-1972	Mixed	Hess [1977]
Automobiles	-0.93	–	0.22	Multiperiod, single asset regression	1952-1972	Mixed	Hess [1977]
Automobiles	-0.9	–	2.8	Linear regression, stock adjustment	1922-1941, 1948-1953	Long run	Nerlove [1957]
Automobiles	-0.3	–	–	Linear regression	1975-2007	Mixed	Klier and Linn [2012]
Automobiles	-1.86	–	–	Instrumental variables	1975-2007	Mixed	Klier and Linn [2012]
Automobiles	-1.28	–	–	Instrumental variables	1975-2007	Mixed	Klier and Linn [2012]
Automobiles	-0.85 to -0.87	-0.78 to -1.09	1.62 to 1.93	Multinomial logit	1989	Short run	McCarthy [1996]
Durable Goods [a]	–	-2.03	–	Multiplicative regression	–	Mixed	Tellis [1988]
Printers	-0.47 to -0.90	–	–	Nested discrete choice	1998-1999	Short run	Melnikov [2013]
Camcorders	-2.55	-2.59	–	Dynamic optimization	2003	Short run	Gowrisankaran and Rysman [2009]
Camcorders	-1.23	-2.41	–	Dynamic optimization	2003	Long run	Gowrisankaran and Rysman [2009]
Clothes Dryers	-0.14	–	0.26	Cobb-Douglas, diffusion	1947-1961	Mixed	Golder and Tellis [1998]
Clothes Dryers	–	-1.32	–	Non-linear diffusion	1949-1961	Short run	Jain and Rao [1990]
Dishwashers	-0.42	–	0.79	Cobb-Douglas, diffusion	1947-1968	Mixed	Golder and Tellis [1998]
Dishwashers	–	-0.4	–	Dynamic diffusion	–	Mixed	Parker and Neelamegham [1997]
Central AC	-0.24	–	–	Dynamic structural model	1990-2005	Long run	Rapson [2014]
Room AC	-0.37	–	0.45	Cobb-Douglas, diffusion	1946-1962	Mixed	Golder and Tellis [1998]
Room AC	-0.12	–	–	Dynamic structural model	1990-2005	Long run	Rapson [2014]
Room AC	–	-1.72	–	Non-linear diffusion	1949-1961	Short run	Jain and Rao [1990]
Refrigerators	-0.37	–	–	Logit probability, survey	1997	Short run	Revelt and Train [1998]
Refrigerators	–	-2.3	–	Dynamic diffusion	–	Mixed	Parker and Neelamegham [1997]
Refrigerators	–	-2.8	–	Conditional logit, market shares	2007-2009	Long run	Houde [2014]
Appliances	–	-2.25	–	Revealed preference model	2001-2011	Long run	Houde and Spurlock [2015]
Freezers	–	-2.8	–	Dynamic diffusion	–	Mixed	Parker and Neelamegham [1997]

[a] Average brand price elasticity in meta-analysis of 70 studies.

3 Description of Regression Model and Data Sources

We use time series shipments, price, and efficiency data for five household appliances, as well as household income, predicted appliance stock failures, and new residential construction, to estimate the average consumer price elasticity of demand through various log-log regression specifications.

3.1 Regression Model

Due to the limited nature of our available data set, we run a log-log regression model, such that the coefficient on price (β_1) provides an estimate of the price elasticity of demand. At its most simplistic, this regression takes form:

$$ln(Q_t) = \beta_0 + \beta_1 ln(\mathrm{p_t}) + \varepsilon_\mathrm{t}$$

where:

t = year;

Q_t = appliance shipments (1000 units);

p_t = average price (\$2014);

β_1= price elasticity (ϵ_p);

ε_t = residual (unobserved factors).

However, many factors beyond product price affect purchase decisions, so we posit that, given the data available, the following model formulation best suits our analytical goals.[5] In the following section, we provide further description of these variables.

$$ln(Q_t) = \beta_0 + \beta_1 ln(\mathrm{p_t}) + \beta_2 ln(\mathrm{e_t}) + \beta_3 ln(\mathrm{I_t}) + \beta_4 ln(\mathrm{H_t}) + \beta_5 ln(\mathrm{F_t}) + \beta_6 D_{DW} + \beta_7 D_{REF} + \beta_8 D_{RAC} + \beta_9 D_{CW} + \varepsilon_t$$

where:

t = year

Q_t = appliance shipments (1000 units)

p_t = average price (\$2014)

e_t = energy efficiency measure;

I_t = mean annual household income (\$2014);

H_t = new housing;

F_t = projected annual failures of products in existing stock;

D_i = dummy variable for each product type;

[5] We perform numerous intermediate regressions, adding one variable at a time (see Table 4.1). We also perform similar regressions for each product individually; although the data set for each individual product regression is quite small, we feel this exercise is a useful contribution to the conversation around the application of the elasticity estimated through the combined regression to other household appliances.

β_1= price elasticity (ϵ_p);

β_2= efficiency elasticity (ϵ_e);

ε_t = residual (unobserved factors).

3.2 Data Set: Variable Descriptions and Sources

In this section, we describe our data sources and the variables used in our regression analysis. Additional figures showing variable trends over time are provided in Appendix A.

3.2.1 Dependent Variable: Appliance Shipments

In our regression analysis, we define demand for appliances in terms of annual shipments. Appliance shipments data were procured from the Association of Home Appliance Manufacturers (AHAM 2010). Shipments are a measure of factory output or production, rather than final sales to the end user, but they provide a useful proxy for this harder to track variable. For all five of the appliances we study, shipments increased over much of the 1989-2009 time period, though all show some degree of relative decrease as the recent recession becomes apparent around 2007-2008 (Figure A.1).

3.2.2 Regressors

We expect a combination of economic variables and physical household and product features to influence the sales trends of home appliances. These include: retail price; product efficiency and operating cost; household income; new housing construction; failure of products in the existing stock; and additional factors such as product quality and consumer style preferences. Decreasing prices and/or operating costs and increasing household incomes will encourage appliance purchases by making appliances comparatively less expensive. As many household appliances are now considered necessities (*e.g.,* refrigerator, clothes washer, etc.), a replacement is generally purchased when an old appliance breaks.[6] Additionally, new appliances are often installed in new construction, so the annual number of completed housing units will influence shipments. While we currently focus on the impact of price on shipments, it is necessary to account for the potential influence of these other factors to arrive at an accurate estimate of price elasticity of demand.

Price

Mean annual product price is calculated from the total value of annual sales and total annual shipments; thus, it is a shipment-weighted average across the various sub-types among each product (*e.g.,* refrigerator door configurations, washer axes, etc.). As with our annual

[6]In some cases, repairs may extend the useful life of an appliance, but replacement will be necessary in the long run.

shipments data, the value of sales data used in this calculation were procured from AHAM (2009b). Between 1989 and 2009, there has been a general downward trend in terms of real appliance prices (Figure A.2).[7]

$$p_t = \frac{Q_t}{V_t}$$

where:

t = year;

p_t = average price ($2014);

Q_t = appliance shipments (1000 units);

V_t = total value of annual sales ($2014).

Energy Efficiency

Time series of shipment-weighted energy efficiency were also obtained from AHAM (2009a) for each product. Over the 1989-2009 time period, all five appliances have substantially increased in efficiency, as shown by the drop in average annual energy consumption and average energy consumption per cycle presented in Figure A.3.[8] The energy efficiency measure that we include in our regressions is the ratio of energy efficiency (as commonly defined for each product) in the current year to the energy efficiency in 1989 (the first year in our data set).[9]

$$e_t = \frac{E_t}{E_0}$$

where:

t = year;

e_t = energy efficiency measure;

E_t = energy consumption in year t;

E_0 = energy consumption in year 0 (*i.e.*, 1989).

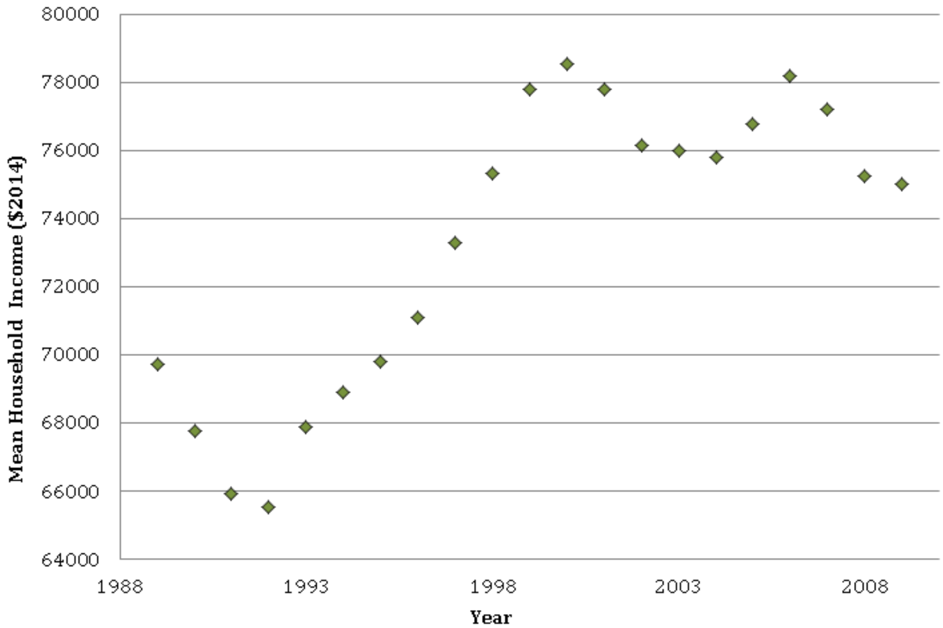
Given that we are using a log-log regression model, we can view the coefficient on $e_t$as the "efficiency elasticity" (ϵ_e): the percentage change in shipments caused by a 1% change in the current year to initial year energy efficiency ratio. When modeling the shipments change caused by an efficiency induced price change, the efficiency elasticity must be included along with the price elasticity to accurately account for policy impacts.

[7]This price decline has occurred in spite of increases in product quality (see, for example, Houde and Spurlock (2015) or Brucal and Roberts (2015)).

[8]Note that the units of energy consumption differ by product.

[9]This conversion is performed in order to include products with different common energy efficiency measures in the same regression without the additional complication and opportunity for error inherent in converting from energy efficiency to annual energy consumption or annual energy cost.

Figure 3.1: Mean Household Income



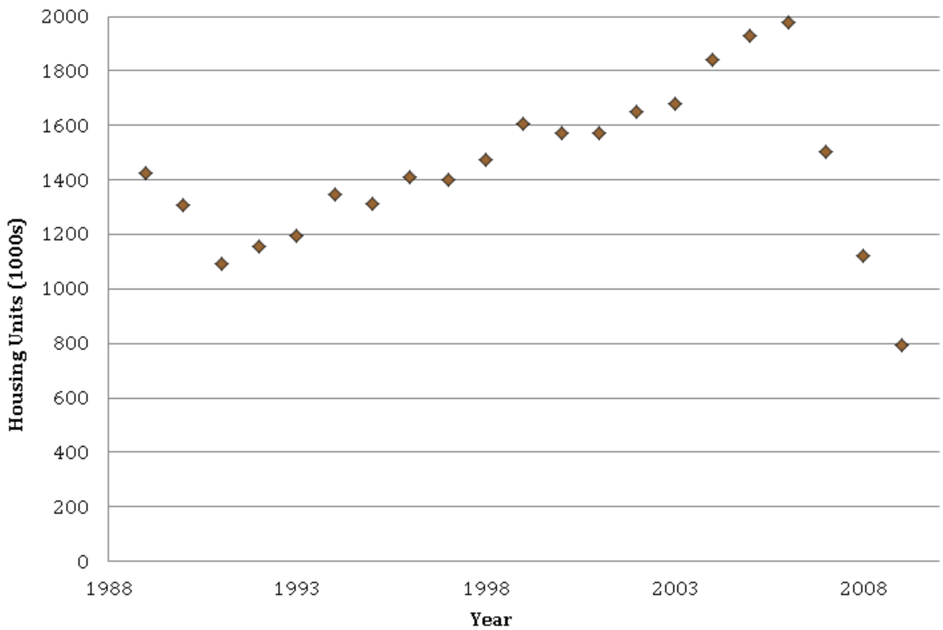
Income

We use mean annual household income to represent changes in consumers' ability to pay for appliances (U.S. Census 2014). We also tested median annual household income and aggregate national personal income as ability-to-pay variables, but as mean household income was significant in a greater number of regression specifications and the price coefficient was similar across the three different income variables, we primarily rely on mean household income (U.S. Census 2014, U.S. BEA 2015).

New Residential Housing

Appliances are often included in new homes at the time of sale. In cases where no appliances are included in the sale, home buyers tend to purchase new appliances for their new home, rather than moving older appliances. Thus, we expect appliance sales to scale with the annual number of completed housing units (Figure 3.2). Completed housing units are defined by the U.S. Census Bureau as single family housing that is occupied and/or has finished flooring installed or multifamily housing where at least half of the units are occupied or available for occupancy (U.S. Census 2015).

Figure 3.2: Completed Housing Units



Stock Failures

Current year demand for an appliance is expected to be influenced by the number of appliances in the operating stock that break this year. While some will be repaired, it is common practice to purchase a new appliance when one breaks or has become quite old. The number of appliance failures (and thus, replacements) in any given year depends on the volume of historical purchases and the probability of failure as a function of appliance age. To model appliance failures in a given year, we first calculate the failures of each previous annual purchase cohort (i.e., cohort C_T includes all shipments from year T).

$$f_{Ct} = \sum p\left(a_t\right) \times Q_C$$

where:

t = year;

C = shipments cohort;

a_t = product age in year t;

$p\left(a_t\right)$ = probability of product failure at age a;

Q_C = appliance shipments.

f_{Ct} = projected failures of cohort C products in year t.

Total appliance failures in a given year are then estimated by summing the annual failures across all previous cohorts:

$$F_t = \sum_{C=0}^{t} f_{Ct}$$

where:

t = year;

C = shipments cohort;

f_{Ct} = projected failures of cohort C products in year t;

F_t = total projected failures in year t.

We use Weibull functions to estimate our stock failure variable, relying on parameters developed for the current appliance efficiency standards for each product (U.S. DOE2011a, 2011b, 2012a, 2012b). The Weibull parameters we use for each product are listed in Table 3.1.

$$P(a_t) = e^{-\left(\frac{a-\theta}{\alpha}\right)^{\beta}}$$

where:

t = year;

$P(a_t)$ = probability of product failure at age a;

a_t = product age in year t;[10]

α = scale parameter (*i.e.,* decay length in an exponential distribution);

β = shape parameter (*i.e.,* change in failure rate through time);

θ = shape parameter (i.e., time before any failures occur).[11]

Table 3.1: Weibull parameters for stock failure estimation

Product	α	β	θ	Mean Age	Max Age
Clothes Washer	10.13	2.66	2	14.2	50
Dishwasher	16.29	2.31	1	15.4	50
Refrigerator	13.91	1.68	5	17.43	30
Freezer	19.49	2.4	5	22.28	30
Room AC	7.47	1.00	1	10.5	20

Other Factors Not Addressed by this Data Set

The residual term, ε_t, captures the impact of unobserved factors on the annual level of appliance shipments. While we attempted to include the primary relevant variables in our regressions, we note that numerous other factors influence the volume of appliance sales.

Capacity : We initially attempted to include this variable, but as it was not available for all products and came up insignificant in early regression attempts, it was dropped. However, this is a feature of most appliances that has been shifting over time and which may have some bearing on the consumer purchase decision or the price point at which consumers are willing to buy.

[10] When no maximum lifetime is provided in the documentation for the current efficiency standard, we use a value of 30.

[11] When no delay parameter is provided in the documentation for the current efficiency standard, we use a value of 1.

Energy Cost : Earlier regression model specifications included annual average retail electricity price (U.S. EIA 2012), but as there was not a clear trend in real electricity prices during the analysis time frame, this variable is insignificant in many of the model runs, and inclusion or exclusion of this variable makes little difference to the values of the coefficients of interest. Thus we do not include energy cost in the final regression model.

Quality : "Quality" is a somewhat ambiguous term, which is often used as a catch-all to describe such characteristics as energy efficiency, capacity, and durability, among other desirable product attributes. While it may be possible to capture some dimensions of quality directly in our regression equation, others are less tangible and unlikely to be available in the necessary time series. Recent research suggests appliance quality has been increasing alongside the current trends of real price decrease and sales volume increase. Brucal and Roberts (2015) find that when analyzed using a constant-quality price index, constant-quality prices for clothes washers fell over time, while quality increased.[12] Improved quality is expected to be associated with increased sales, all else equal, and in aggregated, market-level data, changes in price over time may in fact mask underlying changes in the cost of quality.

Other potential variables : Though we could not determine how to include such factors in our analysis, we recognize that additional appliance attributes will also impact consumer demand; such attributes include: product style, diversity of product offerings, and safety. Broader changes to consumer habits and preferences, such as an increase in environmental awareness, are also expected to influence the demand for appliances, but are difficult to account for in an analysis like ours.

[12]Similarly, analyzing point-of-sale data for clothes washers, dishwashers, room air conditioners, freezers, and refrigerators, Houde and Spurlock (2015) generally find an expansion of "quality" in non-energy related product attributes following the implementation of efficiency policy.

4 Regression Results

In this section, we present results for the combined model, in which all five appliances are included. Results for additional combined model specifications and individual regressions for each appliances are included in Appendix B.

Regressions presented in 4.1 increase in complexity from 1), a highly simplified regression in which price and appliance type dummy variables are the only regressors, to 6), a model including price, efficiency, income, predicted stock failures, and new housing.[13] Each of these models results in a price coefficient that is statistically significant ($p < 0.01$), has the expected sign, and is of a reasonable magnitude as compared to the values revealed in our review of the literature (see Section 2). Moreover, the coefficients on other regressors are of the expected sign.[14] Due to some multicollinearity among regressors, the R^2 values included in 4.1 may be somewhat inflated.[15]

We performed similar regressions of individual appliance shipments on price, efficiency, income, stock failures, and new housing (AppendixB). While these regressions yield, on average, similar estimates of price elasticity to the combined model, we focus on the combined model due to its substantially larger sample size. Individual product regressions may provide insight into whether a comparatively higher or lower elasticity value should logically be applied for a specific type of appliance.

[13]The coefficient on price (and other regressors) changes as additional variables are included in successive regressions due to initial omitted variable bias. However, once energy efficiency and income are accounted for in regression 3, the price coefficient becomes fairly stable in the -0.4 to -0.5 range. Though the price coefficient decreases in magnitude as additional regressors are included, it could potentially increase if new regressors are 1) negatively correlated with shipments and positively correlated with price or 2) positively correlated with shipments and negatively correlated with price. Based on the logical arguments laid out in Section 3.2, we do not believe that our model is mis- or over-specified. Considering the additional factors listed in Section 3.2.2, our data set does not allow us to identify quality or diversity of products. For the products for which we have a time series of capacity data, in two cases capacity and shipments appear positively correlated and in two cases capacity and shipments appear negatively correlated, and we reiterate that in an earlier model specification, capacity was not statistically significant.

[14]The negative sign on the energy efficiency ratio variable means that as efficiency improves, the quantity of shipments increases (review the definition of the energy efficiency variable in Section 3.2.2). Given that appliances are a normal good, we expect an increase in income to lead to more sales, as implied by the positive coefficient on the mean household income variable. Stock failures and new housing construction also increase demand for appliances, so we expect positive coefficients on these variables.

[15]The presence of multicollinearity does not necessarily indicate that our estimates of the price coefficient are biased. In A.1 we provide correlation statistics for all regressors. The correlation between price and the other regressors is generally quite low.

Table 4.1: Combined Model Regression Results

Regression (N=105)	Value	Price	CW	REF	RAC	FRE	Energy Efficiency	Mean House-hold Income	Stock Failures	New Housing	R^2
1	β_i	**-0.79**	0.79	1.10	-0.10	-2.33	–	–	–	–	0.940
	t-stat	-15.42	14.26	18.32	-2.04	-24.75	–	–	–	–	
2	β_i	**-0.67**	0.72	0.90	-0.08	-2.21	-0.32	–	–	–	0.956
	t-stat	-13.73	14.59	14.59	-1.96	-26.46	-5.96	–	–	–	
3	β_i	**-0.48**	0.60	0.80	-0.05	-1.87	-0.19	1.63	–	–	0.966
	t-stat	-8.72	12.63	14.03	-1.34	-19.72	-3.67	5.51	–	–	
4	β_i	**-0.45**	0.51	0.71	-0.05	-1.71	-0.16	1.60	0.12	–	0.966
	t-stat	-6.94	4.79	6.49	-1.45	-8.78	-2.44	5.39	0.94	–	
5	β_i	**-0.47**	0.60	0.78	-0.05	-1.88	-0.24	1.13	–	0.20	0.969
	t-stat	-9.03	13.15	14.17	-1.40	-20.67	-4.63	3.47	–	3.13	
6	β_i	**-0.40**	0.39	0.57	-0.06	-1.51	-0.18	0.95	0.29	0.25	0.970
	t-stat	-6.49	3.70	5.18	-1.70	-7.89	-2.89	2.87	2.20	3.75	

5 Discussion and Additional Considerations

In future appliance market projections, we generally recommend using a price elasticity of demand of **-0.45**.

If the specific product in question is suspected to be somewhat more or less elastic than household appliances in general, we recommend anchoring the price elasticity value in the range of -0.4 to -0.5 (see regressions 3-6 in Table 4.1). For the five appliances examined in this analysis, the product-specific values presented in Appendix B may alternatively be used, but we caution that these elasticities were estimated using small data sets.

It is important to note that price elasticity is not necessarily linear with the magnitude of price change; as such, the above price elasticities will be most accurate for predicting the demand impact of a small shift from the data set's mean values. Though we generally recommend applying elasticities in the ranges presented in Table 5.1, we recognize that analytical situations may arise in which it is appropriate to use a higher or lower elasticity to represent the nature of the market for a particular product. In certain cases, it may be appropriate to use a very low or potentially zero price elasticity for a product like a cable set-top box; the purchase price of these products are bundled with a customer's cable subscription package, such that any change in the price of the set-top box will be highly obscured by the cost of the cable fee. On the other hand, for a product that is more of a luxury than a necessity (such as, perhaps, an air purifier), it is reasonable to anticipate that the price elasticity could be higher. However, unless there is strong evidence that the elasticity ought to be modified for a particular product, we recommend staying within the -0.4 to -0.5 range, with a default value of -0.45.

The coefficients presented in Table 4.1 are short run price elasticities. As we do not have information indicating short-run and long-run price elasticity differences specific to appliances we rely on the trend revealed by the Hymans et al (1970) study on the changes to the price elasticity of demand for automobiles in the years following a change in purchase price; the price elasticity is expected to become more inelastic until it reaches a terminal value in approximately the 10th year following the price change.[16][17] Applying this trend to our short run elasticities, we arrive at long run price elasticities for appliances in the range of -0.13 to -0.17 (Table 5.1).

Table 5.1: Short and Long Run Elasticity Values

Factor	Years Following Price Change					
	1	2	3	5	10	20
Automobile ϵ_p	-1.20	-0.93	-0.75	-0.55	-0.42	-0.40
Impact relative to Year 1	1.00	0.78	0.63	0.46	0.35	0.33
Appliance ϵ_p	-0.40 to -0.50	-0.31 to -0.39	-0.25 to -0.32	-0.18 to -0.23	-0.14 to -0.18	-0.13 to -0.17
Efficiency ϵ_e	-0.16 to -0.24	-0.12 to -0.19	-0.08 to -0.12	-0.04 to -0.05	-0.01 to -0.02	-0.01

[16] We reiterate that Parker and Neelamegham (1997) report the existence of time trends in price elasticity for appliances and other durables, but do not provide the level of detail of the Hymans et al (1970) study.

[17] Note that Hymans et al (1970) find virtually no further decrease in elasticity between year 10 and year 20.

We also reiterate that to accurately model the change in shipments due to appliance efficiency policy, it is necessary to account for the shipments impact associated with both the price change and the efficiency change. As shown by the coefficients on the energy efficiency variable (Table 4.1), a 1% decrease in the current-to-initial energy use ratio, all else equal, will lead to approximately a 0.16% to 0.24% increase in units sold (bottom row, Table 5.1). The shipments impact of a price increase that is linked to an efficiency increase will be partially offset once the "efficiency elasticity" is taken into account.

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A Additional Tables and Figures

In this appendix, we provide additional figures referenced in the above text, including time series of appliance shipments (Figure A.1), appliance prices (Figure A.2), and appliance energy consumption (Figure A.3). We also provide a table of correlation coefficients for all regressors (Table A.1).

Figure A.1: Appliance Shipments 1989-2009 (1000 units)

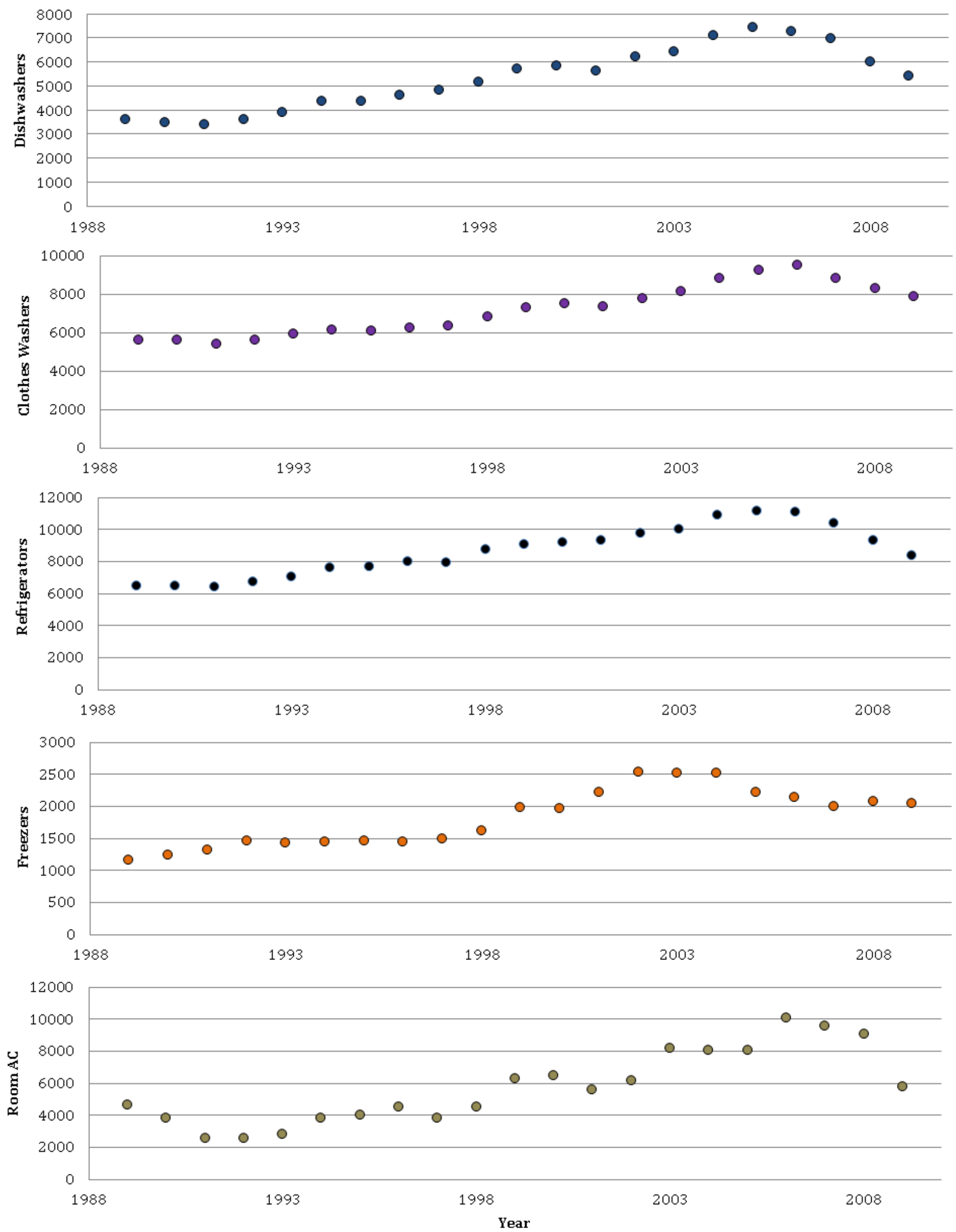

Figure A.2: Average Appliance Price ($2014)

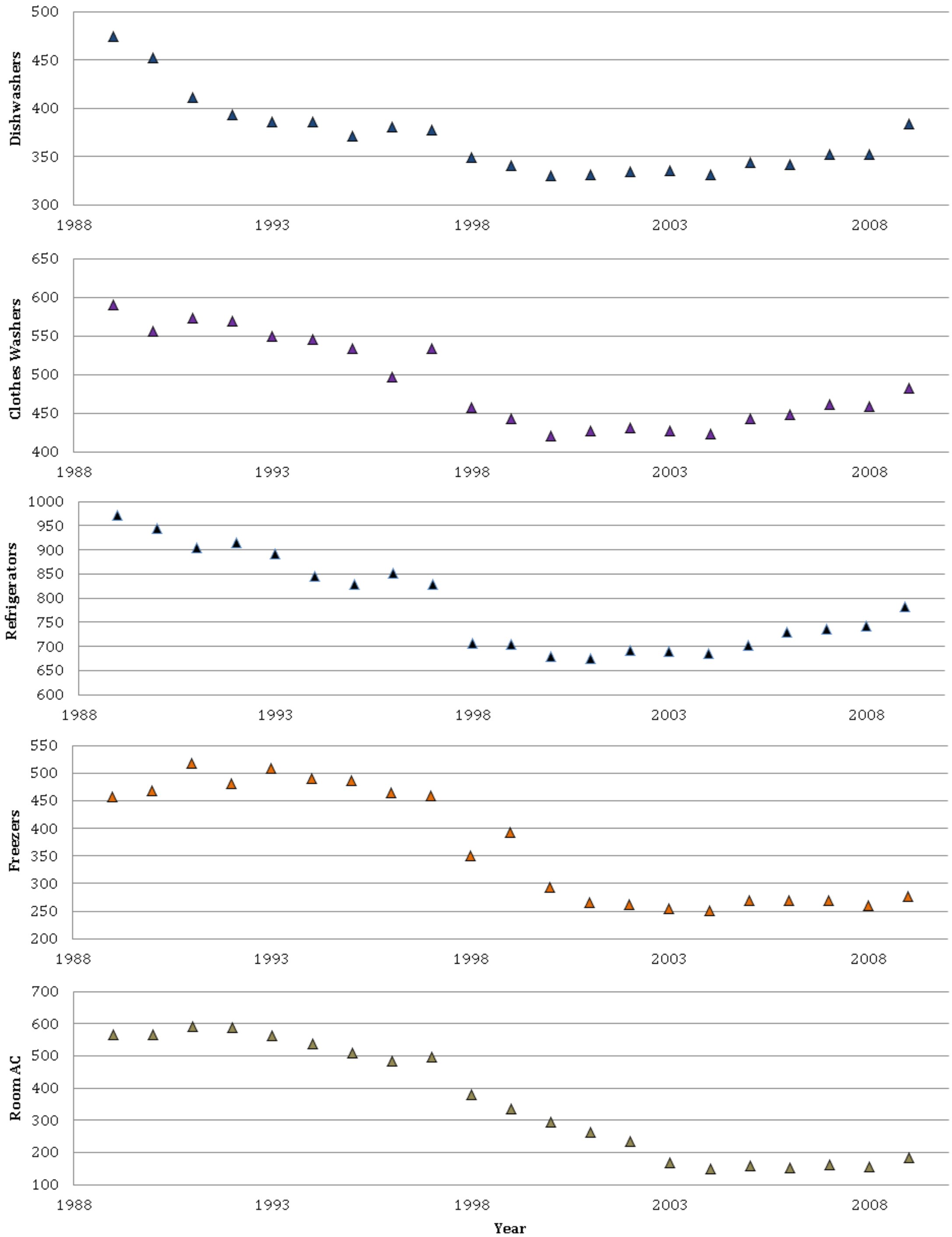

Figure A.3: Appliance Energy Consumption

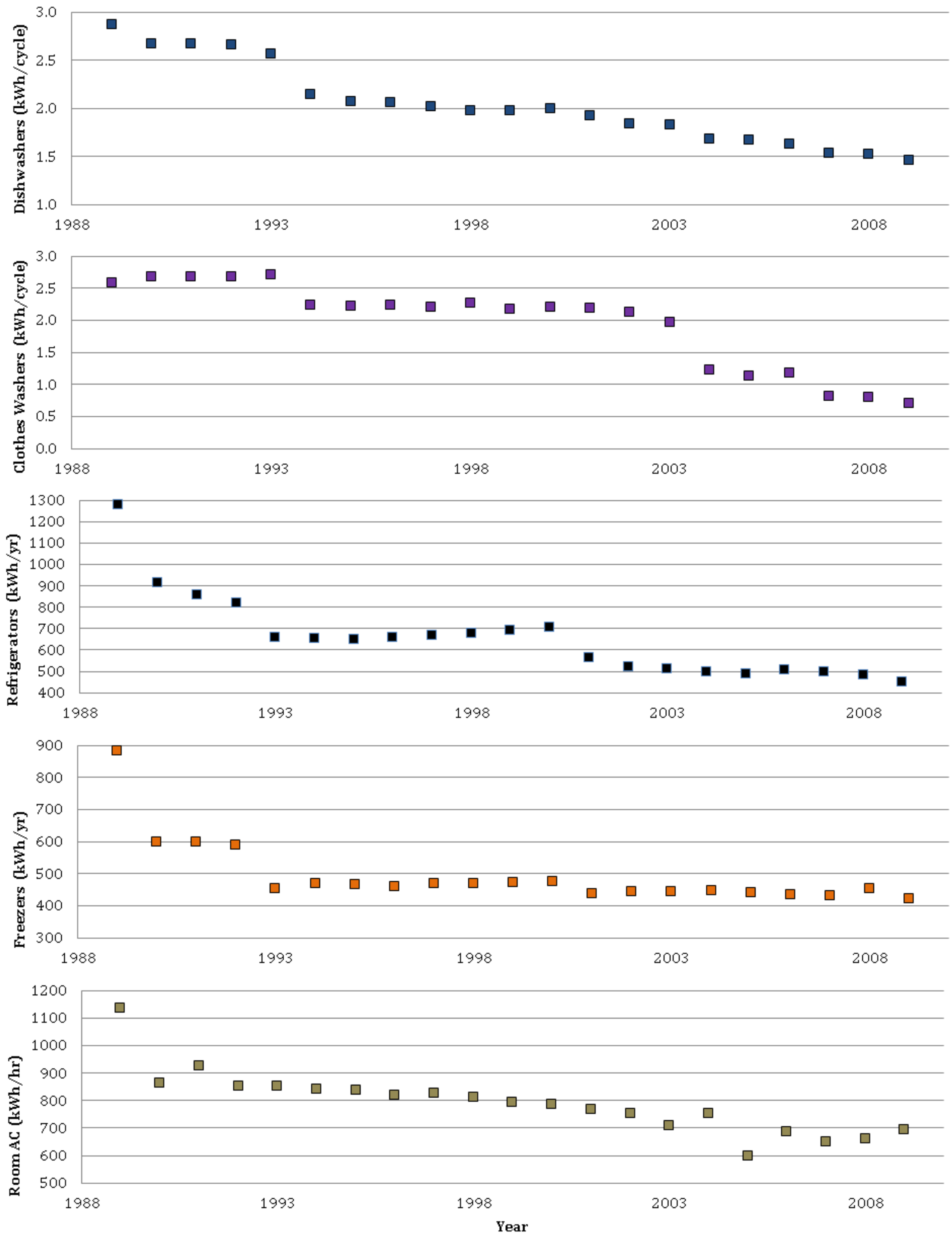

Table A.1: Correlation of Explanatory Variables

	Price	Energy Efficiency	Personal Income	New Housing	House -holds	Stock Failures	Median Income	Mean Income
Price	1.00	0.20	-0.29	-0.19	-0.29	0.73	-0.24	-0.30
Energy Efficiency	0.20	1.00	-0.68	-0.19	-0.69	-0.20	-0.33	-0.53
Personal Income	-0.29	-0.68	1.00	0.38	0.99	0.32	0.71	0.87
New Housing	-0.19	-0.19	0.38	1.00	0.36	0.07	0.57	0.60
House -holds	-0.29	-0.69	0.99	0.36	1.00	0.32	0.65	0.84
Stock Failures	0.73	-0.20	0.32	0.07	0.32	1.00	0.19	0.25
Median Income	-0.24	-0.33	0.71	0.57	0.65	0.19	1.00	0.90
Mean Income	-0.30	-0.53	0.87	0.60	0.84	0.25	0.90	1.00

B Detailed Regression Results

In this appendix, we provide the full Stata outputs for additional combined model specifications (Table B.1) and for all of the individual product regressions: clothes washers (Table B.2); dishwashers (Table B.3); refrigerators (Table B.4); freezers (Table B.5); room air conditioners (Table B.6).

Table B.2: Regression Results - Clothes Washers

Regression (N=21)	Value	Price	Energy Efficiency	Median Household Income	Stock Failures	New Housing	R^2
1	β_i	**-0.78**	–	–	–	–	0.720
	t-stat	-7.24	–	–	–	–	
2	β_i	**-0.58**	-0.21	–	–	–	0.925
	t-stat	-9.33	-7.28	–	–	–	
3	β_i	**-0.34**	-0.25	0.12	–	0.23	0.959
	t-stat	-2.80	-9.71	0.31	–	4.09	
4	β_i	**-0.34**	-0.27	0.29	-0.42	–	0.922
	t-stat	-3.21	-3.91	0.51	-1.10	–	
5	β_i	0.08	-0.15	-0.11	0.35	0.82	0.968
	t-stat	0.38	-2.88	-0.29	4.87	2.31	

Table B.3: Regression Results - Dishwashers

Regression (N=21)	Value	Price	Energy Efficiency	Median Household Income	Stock Failures	New Housing	R^2
1	β_i	**-2.14**	–	–	–	–	0.699
	t-stat	-6.89	–	–	–	–	
2	β_i	**-1.07**	-0.75	–	–	–	0.865
	t-stat	-3.56	-4.93	–	–	–	
3	β_i	-0.26	-0.81	0.62	0.40	–	0.971
	t-stat	-1.51	-8.26	1.66	6.14	–	
4	β_i	**-0.61**	-0.27	1.76	0.29	–	0.904
	t-stat	-2.07	-0.65	3.02	0.60	–	
5	β_i	**-0.22**	-0.13	0.37	0.47	0.92	0.991
	t-stat	-2.27	-1.00	1.69	12.08	5.83	

Table B.1: Combined Model - Alternative Income and Housing Regressors

Regression (N=105)	Value	Price	CW	REF	RAC	FRE	Energy Efficiency	Median Household Income	Personal Income	Number Households	R^2
A	β_i	**-0.55**	0.64	0.82	-0.06	-2.01	-0.28	1.79	–	–	0.963
	t-stat	-10.59	13.56	13.97	-1.61	-22.75	-5.67	4.54	–	–	
B	β_i	**-0.48**	0.60	0.80	-0.05	-1.87	-0.19	–	1.63	–	0.965
	t-stat	-8.72	12.63	14.03	-1.34	-19.72	-3.67	–	5.51	–	
C	β_i	**-0.40**	0.56	0.79	-0.04	-1.73	-0.06	1.11	–	0.99	0.970
	t-stat	-6.46	11.05	14.08	-1.00	-15.19	-0.81	3.01	–	2.28	

Table B.4: Regression Results - Refrigerators

Regression (N=21)	Value	Price	Energy Efficiency	Median House-hold Income	Stock Failures	New Housing	R^2
1	β_i	**-1.37**	–	–	–	–	0.816
	t-stat	-9.46	–	–	–	–	
2	β_i	**-1.01**	-0.23	–	–	–	0.859
	t-stat	-5.42	-2.60	–	–	–	
3	β_i	-0.03	-0.36	1.11	–	0.29	0.967
	t-stat	-0.16	-7.71	3.61	–	6.44	
4	β_i	-0.47	-0.18	1.09	0.12	–	0.882
	t-stat	-1.28	-1.18	1.33	0.42	–	
5	β_i	**-0.34**	-0.11	-0.14	0.36	0.61	0.993
	t-stat	-3.69	-2.89	-0.65	15.77	7.69	

Table B.5: Regression Results - Freezers

Regression (N=21)	Value	Price	Energy Efficiency	Median House-hold Income	Stock Failures	New Housing	R^2
1	β_i	**-0.80**	–	–	–	–	0.588
	t-stat	-5.43	–	–	–	–	
2	β_i	**-0.60**	-0.57	–	–	–	0.699
	t-stat	-4.19	-2.84	–	–	–	
3	β_i	-0.30	-0.45	1.57	–	–	0.718
	t-stat	-1.24	-2.12	1.47	–	–	
4	β_i	-0.46	-0.32	0.87	0.71	–	0.708
	t-stat	-1.35	-1.13	0.58	0.67	–	
5	β_i	-0.44	-0.34	0.88	0.02	0.66	0.689
	t-stat	-1.20	-1.06	0.56	0.13	0.55	

Table B.6: Regression Results - Room Air Conditioners

Regression (N=21)	Value	Price	Energy Efficiency	Median House-hold Income	Stock Failures	New Housing	R^2
1	β_i	**-0.71**	–	–	–	–	0.844
	t-stat	-10.43	–	–	–	–	
2	β_i	**-0.85**	0.62	–	–	–	0.847
	t-stat	-6.57	1.21	–	–	–	
3	β_i	**-0.62**	0.55	2.40	–	–	0.885
	t-stat	-4.36	1.25	2.61	–	–	
4	β_i	**-0.71**	0.48	2.08	-0.21	–	0.878
	t-stat	-3.30	1.03	1.90	-0.59	–	
5	β_i	-0.34	0.59	2.09	0.53	0.63	0.894
	t-stat	-1.14	1.33	2.04	1.76	1.07	

C “An Analysis of the Price Elasticity of Demand for Appliances”

Our original report, “An Analysis of the Price Elasticity of Demand for Appliances” (hereafter, the “2008 report”), included the results of a literature review, tabular analysis, and regression analysis of the impact of price and other variables on appliance shipments (Dale and Fujita 2008). At the time of our analysis, we found few relevant studies of appliance markets, and no studies using time series price and shipments data after 1980. The literature we found in aggregate suggested that appliance demand is price inelastic. Other information in the literature suggested that appliances are a normal good, such that rising incomes increase the demand for appliances, and that consumers purchase decisions reveal relatively high implicit discount rates, given current appliance prices and appliance operating costs.

As there was little appliance price and operating cost data available, we used time series data for refrigerators, clothes washers and dishwashers to evaluate broad market trends and to perform simple regression analysis. It was necessary to interpolate price and efficiency in several years of the analysis period. These data indicated that there was a rise in appliance shipments, a decline in appliance price and operating cost, and an increase in household income over the 1980-2002 period. To simplify the analysis, we combined the available economic information into one variable, termed relative price (*i.e.*, retail price plus present value of energy cost, divided by income), and used this variable in a tabular analysis of market trends and a regression analysis. Regression analysis of the combined data set of all appliances resulted in a relative price elasticity of demand estimate of -0.34. We also computed a simple price elasticity, relying only on first year and final year shipments and price, finding price elasticities of -0.32, -0.37, and -0.48 for clothes washers, dishwashers, and refrigerators, respectively. While these estimates largely agree with those we found in the literature, the measures are based on a small data set, using very simple statistical analysis. More important, the measure is based on the assumption that economic variables, including price, income and operating costs, explain most of the trend in appliance purchases since 1980. Changes in appliance quality and consumer preferences may have occurred during this period, but they are not accounted for in this analysis. The capacity of most appliances has increased since 1980, and it is likely that there have been increases in quality and durability as well. Some of the increases in sales over the 1980-2002 time period may have been driven by changing preferences rather than decreasing prices.