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Appliance Choices and the Energy Efficiency Gap

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Abstract

The benefits of an investment in an energy efficient durable good depend on the life of the investment. If the expected length of ownership is mis-estimated, this will bias calculations of the benefits of energy efficiency, including estimates of the energy efficiency gap. This paper estimates how expected ownership length affects household appliance choices. I leverage the fact that some types of appliances are expected to convey (be included) with the sale of a house, while other appliances may or may not convey depending on local customs that vary at the state level. An appliance that conveys will be left behind when a homeowner moves, while an appliance that does not convey may be kept until the end of its useful life. I estimate the effect of an appliance conveying using a difference-in-differences across states and appliance types, allowing me to control for state-level trends using fixed effects. I find that consumers purchase less expensive refrigerators and clothes washers when those appliances convey. I show that accounting for whether an appliance conveys can substantially reduce or eliminate apparent undervaluation of energy efficiency benefits.

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1 Introduction

There has been considerable debate in the economics literature as to why consumers appear to undervalue energy efficiency when choosing durable goods. Proponents of the "energy efficiency gap" or "energy paradox" hypothesis argue that consumers and firms forego billions of dollars a year in energy savings in the form of investments that would pay for themselves over a short time frame (Jaffe and Stavins, 1994; McKinsey & Company, 2009). If consumers undervalue future energy costs when making a purchase, efforts to encourage energy efficiency present a "win-win" scenario for policy makers. Investments in energy efficiency would save consumers money and reduce the externalities of energy consumption, improving both private and social welfare.

Most explanations for the apparent energy efficiency gap draw on the findings of behavioral economics, such as time-inconsistent preferences.[1] Some works also point to conventional market failures.[2] A more prosaic explanation from recent literature is that the calculations suggesting the existence of an energy efficiency gap are simply wrong. A typical analysis of the benefits of energy efficiency compares the net present value of the energy savings to the upfront cost of an efficient car, appliance or home improvement, taking as given engineering estimates of per-period energy savings over the lifetime of the good. Such analyses often find that consumers would need incredibly high discount rates to rationalize failing to adopt the investments in question.

If the engineering estimates underlying the calculations are too high, the extent or even existence of an energy efficiency gap will be over-estimated. Hassett and Metcalf (1993) show that if the benefits of energy efficiency are uncertain and investments are irreversible, a failure to adopt energy efficient appliances can be a rational response to the uncertainty.[3] Metcalf and Hassett (1999) find that the engineering estimates of energy savings for attic insulation are overestimated. Fowlie et al. (2015) find that engineering estimates of energy savings from a weatherization program were more than double the

[1] For instance Tsvetanov and Segerson (2013) model how self control problems could lead to an energy efficiency gap. Allcott and Wozny (2014) find evidence suggesting consumers undervalue future fuel savings when buying cars. Gillingham and Palmer (2014) review the potential behavioral explanations for the energy efficiency gap, while DellaVigna (2009) reviews recent findings in behavioral economics more generally.

[2] Golove and Eto (2009) discuss several market barriers, including credit constraints and imperfect information. Davis (2012) shows evidence of a principal-agent problem between renters and landlords that leads to lower investments in energy efficient appliances.

[3] Sanstad et al. (1995) argues this only holds for very low discount rates, but Ansar and Sparks (2009) show that accounting for the experience curve effect (i.e. consumers rationally expecting energy efficiency options to improve with time, creating an incentive to delay investing) reconciles Sansad's results with Metcalf and Hassett, and points to a smaller energy efficiency gap. Metcalf and Rosenthal (1995) show empirically that uncertainty this is a factor in the markets for refrigerators and light bulbs.

actual average energy savings experienced by homeowners. Relatedly, Sallee (2014) shows that to the extent that consumers do not fully evaluate future energy savings, this may reflect rational inattention, rather than an irrational bias.

One element of energy efficiency calculations that has not been considered in previous literature is the expected life of the investment.[4] The simplest approach for these calculations is to assume that energy savings continue for the entire useful life of the good. However, if the good has limited resale or scrap value and consumers tend to replace their goods before the end of life, this will overestimate the benefits of energy efficiency. Similarly, useful life may itself be uncertain or mis-estimated, leading to a further bias.

In this paper, I estimate the impact of expected length of ownership on consumer appliance choices by exploiting a previously undocumented feature of the U.S. real estate market that creates exogenous variation in the expected length of ownership for certain types of appliances. U.S. real estate law requires that "fixtures" convey (be included) with a sale of real estate in the absence of a contract specifying otherwise. The definition of a fixture is sufficiently vague that the status of certain major home appliances is unclear, in particular refrigerators, clothes washers and dryers. As a result, the default for whether one of these appliances conveys depends on local real estate norms that are consistent within states, but vary across states. For instance, a homeowner in California purchasing a new refrigerator can expect to keep it when moving to a new house, while homeowners in Maryland and Virginia almost always leave appliances with the house. In a perfectly efficient housing market we would expect the value of any appliance to be capitalized into the house price. However, given that even major appliances are a small fraction of the overall price of a house, there is reason to believe that additional spending on these goods might not be recouped when selling the house.[5]

Using a rich survey dataset capturing more than 200,000 consumer appliance choices, I estimate the effect of an appliance conveying by default on the price of the appliance chosen, estimated energy use, and the probability of choosing an EnergyStar certified appliance. I compare refrigerators and clothes washers, which convey in some states but not others, to dishwashers and water heaters, which always convey in all states. I use MLS real-estate listings to determine the proportion of home sales in each state where a

[4]Jacobsen et al. (2016) estimate that ignoring heterogeneity in the longevity of motor vehicles undermines the potential efficiency gains of regulating fuel economy. This paper differs in its focus on individual choice, rather than policy optimality, although the two questions are closely related.

[5]Possible explanations of this include thin resale markets for appliances, differing preferences for appliance characteristics, and "lumpy" prices for homes (e.g. house prices rounding to the nearest $5,000). Although there is a recent literature showing that energy efficiency improvements are fully capitalized (Harjunen and Liski, 2014; Aydin et al., 2015; Margaret Walls and Bak, 2016), these works are all in the context of major, expensive upgrades to heating or insulation systems.

refrigerator or clothes washer conveys. By using an always-conveying appliance type as a control group, I am able to estimate a continuous differences-in-differences model with the proportion conveying as the treatment variable. This approach essentially entails comparing across states and appliance types with flexible controls for unobserved state-specific level effects and trends.

I estimate that having an appliance convey by default causes consumers to choose refrigerators that are 12% less expensive and clothes washers that are 7% less expensive. This is consistent with a shorter expected length of ownership when the appliances convey, and thus a lower return to investing in a model with lower per-period energy costs. The effect on upfront costs does not directly translate into choosing less energy efficiency, however. When appliances convey by default, consumers choose refrigerators that are on average *more* energy efficient, with smaller effects or zero effect on chosen energy efficiency for clothes washers. I estimate the effect of an appliance conveying on EnergyStar adoption, and find a tightly estimated zero effect. Similar to findings in Davis (2008), consumers may respond to appliances conveying in part by selecting smaller appliances with fewer features, leading coincidentally to less energy consumption. I find suggestive evidence that consumers choose smaller and less-fully featured appliances in states where those appliances convey.

My estimates of the effect of an appliance conveying on up front expenditures imply a substantial reduction in the expected length of ownership. I show that failing to account for the shorter effective life of a new energy efficient appliance can substantially bias estimates of the energy efficiency gap. For example, I show that a failure to account for the fact that refrigerators convey could cause a researcher to estimate that consumers undervalue future energy savings by as much as 40% when in fact consumers fully value future savings. For more extreme undervaluations, accounting for the fact that refrigerators convey still reduces a substantial portion of the apparent gap. The bias is smaller for clothes washers, consistent with the smaller effect on upfront costs for that appliance.

The remainder of the paper proceeds as follows: Section 2 provides a short background on the legal framework driving which appliances convey. Section 3 then lays out a simple model to motivate the empirical results. Section 4 describes the data, and section 5 presents my difference in difference results on the effect of appliances conveying. Section 6 presents analysis on how much of a naïve energy efficiency gap can be explained by ignoring which appliances convey, and section 7 concludes.

2 Background: The Law of Fixtures in the U.S.

The variation in which home appliances convey with the sale of a house stems from a legal gray area known as the Law of Fixtures (Horowitz, 1952). The purchase contract for a the sale of a house will by default specify that it covers only real property and not personal property. Real property is generally defined as land and things such as buildings and trees which are attached to the land, while personal property is everything else. Complicating matters, real property also includes objects which are attached to other real property. These are termed fixtures, and would also be expected to convey with a sale. However there is no bright line separating fixtures from personal property (Morris, 2010).

The legal test for whether an object is a fixture and should convey is whether the object is attached to the real property in question, with the intention of permanently attaching the object, and the object is adapted to use with the real property. While a dishwasher or a water heater is clearly attached to a house and should be considered a fixture, ranges are almost always considered fixtures even if they are freestanding electric models that could in principle be unplugged and removed. Legal disputes between buyers and sellers of real estate over these issues are common, especially with items such as chandeliers, custom draperies, and built-in speakers. The status of refrigerators and clothes washers and dryers varies from state to state according to local laws, customs and circumstances.

Although the buyer and seller in a real estate transaction are free to include or exclude any item from the sale, regardless of the legal distinction, there is reason to believe that the norms governing whether refrigerators and clothes washers convey do influence behavior. First, the law of fixtures is such that in absence of a contract provision, the local regime will be binding and the seller could be legally liable if an appliance that normally conveys is removed. Second, the local regime determines the default that occurs if the buyer and seller do not specify particular items to convey or not. The behavioral economics literature clearly shows that the default option has a strong influence on behavior.[6] Third, there is anecdotal evidence that the defaults for which appliances convey are binding. For instance, one can find national real estate forums online where a potential homebuyer asks whether refrigerators convey, and is met by confident but opposite responses from real estate agents based in different parts of the country.[7] Finally, for purposes of my analysis, it does not matter whether the local regime is perfectly binding, only that it influences consumers' expectations regarding the length of ownership at the time an appliance is purchased.

[6]Madrian and Shea (2001) is a seminal work, and DellaVigna (2009) reviews this literature.

[7]See for instance `http://www.trulia.com/voices/Home_Buying/When_purchasing_a_home_does_the_refrigerator_and_-231641` (accessed September 24, 2015).

3 A Simple Model of Appliance Choice

I consider a simple model of consumer choice of an energy-consuming durable good, and use this to generate empirical predictions for the reduced form analysis in section 5. The basic outlines of the model are drawn from Allcott and Greenstone (2012), which is in turn a simplified version of the model of Allcott et al. (2014).

A consumer chooses between two models of a durable good, with an expected lifetime of T periods. Index the models by $j \in \{E, I\}$, where E denotes the more energy efficient model, and I a less energy efficient model. The consumer pays p^j up front, and then receives a stream of benefits b^j each period, while paying energy cost e^j.[8] By construction $e^E < e^I$, but b^E may be greater than or less than b^I. That is, the energy efficient model uses less energy, but may be more pleasant to use, less pleasant to use, or the same. For instance, a smaller capacity refrigerator will use less energy, but also provides a lower level of benefits to the consumer. Conversely, a front-loading clothes washer may be more desirable and use less energy. Consumers discount utility in future periods by $\delta < 1$ and have an idiosyncratic preference for good E, such that they receive additional utility of ϵ for choosing E. Finally, let S_T denote the discounted present value of the difference in scrap or resale value between E and I at time T.

With these preferences, a consumer will optimally choose model E if and only if

$$\sum_{t=0}^{T} \left((b^E - b^I) - (e^E - e^I) \right) \delta^t + S_T > (p^E - p^I) - \epsilon.$$

In other words, the consumer buys E if the discounted present value (DPV) of the difference in the stream of net benefits from choosing E is larger than the difference in purchase price, plus the idiosyncratic utility or disutility that consumer gains from E. For purposes of this section I assume consumers fully value future benefits—there is no energy efficiency gap. Allcott and Greenstone (2012) create the possibility of an energy efficiency gap by multiplying the left hand side of the inequality above by a scaling parameter λ, where $\lambda < 1$ implies that consumers undervalue energy efficiency in some way. In section 6 I modify the decision rule to allow for undervaluation of future net benefits.

Now consider the effect of shortening the duration of ownership, as in the case where the durable good conveys with the sale of the consumer's home, and the consumer expects to move during the useful life of the good. This will reduce the number of terms on the

[8] The results of this analysis are unchanged if the consumer finances the purchase instead. In this case p^i would be replaced by the discounted present value of the total principle and interest payments. Even if financing terms differ between the efficient and inefficient models, this simply alters the price differential.

left hand side of the inequality, lowering DPV of ownership in absolute value. How this effects the probability of choosing the energy efficient model E depends on the sign of the per-period net benefits $(b^E - b^I) - (e^E - e^I)$ and the sign of the price differential $p^E - p^I$. If the per-period net benefits are positive (either $b^E > b^I$ or $|e^E - e^I| > |b^E - b^I|$), reducing T increases the probability that the consumer chooses I, as the DPV decreases relative to the price differential. Conversely, if the per-period net benefits are negative, such that choosing E is more costly each period, reducing T reduces the number of periods the cost must be paid, which increases the probability that the consumer chooses E. Thus, reducing the duration of ownership will decrease purchases of the energy efficient good in four cases:

1. The energy efficient characteristic is desirable and more expensive ($b^E > b^I$ and $p^E > p^I$)

2. The energy efficient characteristic is less desirable and more expensive, but per-period energy savings outweigh the per-period utility cost ($b^E < b^I$, $p^E > p^I$ and $|b^E - b^I| < |e^E - e^I|$).

3. The energy efficient characteristic is more desirable, and less expensive, such that I is only chosen with a large negative ϵ ($b^E > b^I$, and $p^E < p^I$).

4. The energy efficient characteristic is less desirable, but also less expensive, and the energy savings outweigh the pre-period utility cost. Again I is only chosen with a large negative ϵ ($b^E < b^I$, $p^E > p^I$ and $|b^E - b^I| < |e^E - e^I|$).

Reducing the duration of ownership will increase purchases of the energy efficient good in two cases:

5. The energy efficient characteristic is less desirable, but also less expensive, and the per-period energy savings are less than the per-period utility costs ($b^E < b^I$, $p^E < p^I$ and $|b^E - b^I| > |e^E - e^I|$).

6. The energy efficient characteristic is less desirable, more expensive, and moreover the per-period energy savings are less than the per-period utility costs. E is only chosen with a large positive ϵ ($b^E < b^I$, $p^E > p^I$ and $|b^E - b^I| > |e^E - e^I|$).

Cases 3, 4, and 6 are trivial—these are situations where barring idiosyncratic preferences, one model is clearly dominant. For the non-trivial cases, reducing the duration of ownership shifts the consumer toward the model with the lower price.

4 Data

My data on consumer appliance choices comes from TraQline, a large consumer survey published and syndicated by the Stevenson Company. TraQline is a retrospective survey of consumers who have recently purchased durable goods. Stevenson Company contracts with a variety of internet research panel companies to conduct the surveys. The panel maintains a pool of around 9 million potential respondents, who are recruited online to offer their opinions in a variety of surveys, generally in exchange for small monetary rewards, entrance into a sweepstakes, or points toward larger prizes. While participation in the TraQline survey is voluntary, potential survey takers are sent a generic invitation e-mail which does not mention the subject of the particular survey. TraQline surveys 150,000 consumers each quarter about purchases of new durable goods in the previous quarter. TraQline is widely used by appliance manufacturers and retailers to track market shares and purchasing decisions.

The data cover purchases of refrigerators, clothes washers, dishwashers and water heaters, made from the third quarter of 2008 through the second quarter of 2013.[9] Each observation is a single appliance purchase by a particular household in a quarter. A small number of households purchase more than one of the four appliances in a given quarter, and in these cases each purchase has a separate observation.[10] Although TraQline uses repeat respondents, they are not tracked across multiple survey periods.

The TraQline survey contains a rich set of variables on consumers' purchase demographics. The data identify the consumer's geographic location down to the MSA, age, race, gender education, income, household size, homeownership status, home tenure, and whether the consumer is a first time homeowner. To focus on appliance decisions where the local default is likely to determine whether the appliance conveys, I exclude renters and consumers who purchased the smallest size of refrigerator (i.e. mini fridges, which are universally treated as personal property). I also exclude consumers residing in Alaska and Hawaii due to small cell size. Table 1 shows the demographics of the TraQline sample.[11] Given that by construction TraQline respondants are recent purchasers of a major home appliance, it is no surprise that respondants are higher income, better educated and more

[9] Stevenson company sells extracts of the TraQline data in 5-year increments; this was the most recent available sample when the Federal Trade Commission purchased the data in September 2013.

[10] The TraQline survey begins by asking each consumer whether they purchased one of 10 randomly selected appliances in the previous quarter, and then asks more detailed questions regarding up to 6 of those appliances.

[11] The TraQline data contains demographic weights intended to make the sample match the demographics of the U.S. population. In practice, the weights make no substantive difference to any of my calculations, and so for simplicity I omit them.

likely to be married than the U.S. population as a whole.

In addition to demographics, TraQline has a wealth of information about the purchase decision. Importantly, consumers report the actual price paid for the appliance in question. A common challenge in studies of durable goods is that these products frequently have variable discounts, and rarely sell for list prices. Consumers report the brand of the product, and are allowed to select the brand freely, such that the survey identifies smaller brands that might otherwise be lumped into an "other" category. An important drawback of these data is that although they contain several product characteristics for each appliance type, such as size and configuration, consumers are not asked for model numbers, complicating the task of linking in additional features such as energy usage from other datasets.

TraQline does not contain any direct information on the energy efficiency of the appliances purchased.[12] In order to test how an appliance conveying by default affects choices of energy efficiency, I link the TraQline data with publicly available energy usage data from the Federal Trade Commission, the U.S. Department of Energy and the California Energy Commission. Because TraQline respondents do not report model numbers, I link the energy usage data by brand, year and product characteristics, assigning the average energy usage of all matching models. I generate a probability of EnergyStar status in the same manner, determining the proportion of matching models which meet EnergyStar standards. Appendix A gives more details on how the energy variables are matched to the TraQline data.

4.1 Determining Which Appliances Convey

Refrigerators and clothes washers are considered fixtures in some states but not in others. To determine how likely it is that these appliances will convey in each state, I gather data from Multiple Listings Service (MLS) listings on Realtor.com, the official website of the National Association of Realtors (NAR). Many MLS listings enumerate appliances that are included with the real estate. Including an appliance in a public MLS listing is sufficient to show that the seller intends to have that appliance convey. As noted in section 2, the seller's intent is one of the key factors determining whether an appliance is legally

[12] TraQline does ask consumers weather the appliance was EnergyStar certified. However, this information appears to be unreliable, as far more consumers say their appliances are EnergyStar certified than the actual market share of EnergyStar appliances. Some claims of EnergyStar status are inconsistent with the characteristics of the product. For instance, a substantial percentage of standard electric water heaters are reported as being EnergyStar, even though standard electric water heaters are not and never have been eligible for EnergyStar. Despite this issue, the TraQline data is generally reliable. In particular, market shares of major brands are consistent with those reported by Ashenfelter et al. (2013) using retail sales data from NPD Group.

considered a fixture and required to convey with the real estate. Likewise, including some appliances in a listing but not others indicates that the unmentioned appliances are not attended to convey. Discussions with Move Inc., the company that runs Realtor.com for the NAR, confirm that any listing of appliances is informative as to which appliances the seller intends to convey.

MLS listings on Realtor.com have a unique listing number as part of the URL, and I use this to randomly sample listings. I first produce a list of potential listing numbers by searching Realtor.com for listings in each of the 100 most populous U.S. cities. I then randomly select listing numbers in proportion to the relative populations of each city. I exclude listings which are short sales, foreclosures, condominiums or new construction, as these seemed likely to disregard the local default relating to fixtures. For any listing that includes mention of appliances, I record whether the words "washer" or "refrigerator" are included. I continue sampling until there are at least 100 listings with appliances in each state, to ensure a sufficiently large sample.

Figure 1 maps the likelihood that appliances convey, with states shaded to indicate the proportion of MLS listings that include refrigerators or clothes washers. The top panel shows the frequency that refrigerators convey, the middle panel shows the frequency that clothes washers convey, and the bottom panel shows the distribution of observations in the TraQline data. The average proportion of listings with clothes washers included is lower than for refrigerators, likely because some homes simply do not have a clothes washer, whereas refrigerator ownership is almost universal in the U.S. In general, refrigerators and clothes washers are less likely to convey on the west coast and in the south, while states in the midwest, northeast and mid-Atlantic regions typically have appliances conveying. Still there are exceptions in every region, and not every state with a high occurance of refrigerators conveying also has a high occurance of clothes washers conveying. I link the proportions of appliances conveying to the TraQline data by consumers' state of residence.

Table 2 shows the average price, average probability EnergyStar, and average proportion conveying for my whole TraQline sample and for each appliance type.

5 Effect of Conveying on Appliance Choices

When an appliance conveys by default, this changes the expected length of ownership for the appliance. Where otherwise an appliance would be kept until the consumer actively chooses to replace it, if the appliance conveys it will be sold when the consumer moves. The median U.S. homeowner moves within 7 years of purchase,[13] while major home appliances typically last 10 years or more. Thus, if an appliance conveys the true discounted present value of the investment can be substantially lower than what would be calculated assuming the full useful life of the appliance. In this section I estimate how the state-level defaults governing which appliances convey affect consumers' choices of appliances.

I employ a continuous difference-in-differences approach to identify the effect of an appliance conveying, using the proportion of MLS listings indicating that an appliance conveys as the continuous treatment variable. This approach leverages the fact that dishwashers and water heaters always convey in every state, while refrigerators and clothes washers sometimes convey and sometimes do not. The comparison is then essentially between appliance types and across states with different defaults. Any unobservable differences between states, whether fixed or over time, can be controlled for using fixed effects. Thus, for instance, I do not need to be concerned with the fact that California has extensive energy efficiency regulation and Texas does not, so long as any such differences are consistent across appliance types. For any state-specific factor to be a threat to identification, it would have to create a state-specific differential between (e.g.) refrigerators and dishwashers. It seems unlikely that such a confounding factor exists, especially after controlling for individual consumer demographics such as education and income.

I estimate the following regression to explain the choice of product characteristic y in the purchase of an appliance i, of type a, in state s and calendar quarter t:

$$y_{iast} = \phi c_{as} + \gamma_a + \alpha_s + \delta_t + \theta_{st} + \beta X_i + \varepsilon_{iast},$$

where c_{as} is the proportion of listings showing appliance type a conveys in state s, and X_i is a vector of demographic characteristics of the purchaser. I control for appliance, state, calendar quarter and state-by-calendar quarter fixed effects, denoted by γ_a, α_s, δ_t and θ_{st}, respectively. In all regressions, X_i contains indicators for categories of education, employment status, household size, race/ethnicity, income, time at address, marital status, and whether the consumer had remodeled their home recently. Because my specification includes both state and appliance type fixed effects, ϕ gives the continuous differences-in-differences estimator for the effect of conveying. I estimate the effect of an appliance type conveying on the log price of the appliance chosen, estimated energy use, and the probability the appliance chosen was EnergyStar certified. Energy usage is measured differently for each of the four appliance types I study, so for purposes of my regression analysis, I normalize each measure to be mean zero and standard deviation one, reversing the sign

[13]Calculated from the Panel Study of Income Dynamics (PSID) for home owners during the period 2000–2007.

as needed so that higher numbers indicate greater energy usage.[14] Based on the simple model in section 3, I expect that the more likely an appliance is to convey, the lower the price of the model chosen, while the impact on energy efficiency and EnergyStar status is theoretically ambiguous.

Table 3 presents the results of my differences-in-differences regressions. The first two columns of each panel show results using dishwashers as the control appliance type, and one of the two treated appliances, while the second two columns show results using water heaters as the control type. The final column uses all four appliance types, with separate effects of conveying for refrigerators and clothes washers.

The regressions shown in panel A use log purchase price as the outcome variable. As expected the more an appliance conveys, the lower the average purchase price, although the magnitude and statistical significance depends on the control appliance. When using dishwashers as the baseline, moving from a state where no appliance conveys to one where all appliances convey causes consumers to purchase refrigerators that are about 9% less expensive, and clothes washers that are about 4% less expensive. The estimates are larger when using water heaters as the control group, at 14% and 16%, respectively, although these estimates are much less precise. When using both control appliances and both treated appliances, I find that an appliance conveying causes consumers to purchase refrigerators that are 12% less expensive, and clothes washers that are 7% less expensive, with both results statistically significant at 5%.

Panel B of table 3 uses normalized energy efficiency as the dependent variable. Refrigerators conveying seems to lead to consumers choosing models with about 0.3 standard deviatons lower energy usage regardless of the control, although this is not statistically significant when using water heaters as the control group. The picture for clothes washers is less clear. When using dishwashers as the control and when using both control appliances, the effect of clothes washers conveying on the choice of energy efficiency is essentially zero, with point estimates of less than 0.1 standard deviations in absolute value and opposite signs depending on the control appliance type. In contrast, with water heaters as the control, the effect on clothes washers is similar to that of refrigerators, but with a standard error as large as the point estimate.

Panel C shows results for the probability EnergyStar. Here, whether or not an appliance conveys has little effect on consumers' choices of either refrigerators or clothes

[14]Clothes washers and water heaters are rated based on an "energy factor," with larger numbers indicating a more efficient appliance, although the two appliances have very different normal ranges. Water heaters largely have energy factors between 0.7 and 1.0, while the average energy factor for clothes washers is about 2.2. The data on dishwashers is given as an estimated electricity consumption in kilowatt-hours per year, while refrigerators give an annual electricity cost in dollars per year.

washers, regardless of the control used. None of the coefficients are statistically different from zero, all are small in magnitude, and the standard errors are small enough to reject even a modest change. However, I note that my EnergyStar variable is measured with substantial error, capturing only the proportion of potentially matching appliance models which are EnergyStar certified, and as such my coefficients will be biased toward zero.

In section 3, I showed that reducing the length of ownership can lead to increased demand for the energy efficient product if the energy efficient product has a lower utility of usage. This might occur if, when an appliance conveys, consumers are more likely to choose basic models without premium features. If premium features are associated with higher energy usage, we would expect to observe consumers choosing models that are coincidentally more energy efficient, such as smaller refrigerators. I cannot test this hypothesis explicitly with my difference-in-differences model, because the product features recorded in the TraQline data are not readily comparable between appliance types. However, I provide suggestive evidence through a simple difference model that compares, for instance, refrigerator purchases in states where refrigerators convey to refrigerators in states where they do not convey.

Table 4 shows the results of these simple difference regressions, with each cell showing the coefficient of a separate regression. The first column shows the average marginal effect of the appliance type conveying on the choice of each appliance feature, calculated using a probit regression. The second and third columns use OLS, and show the average change in normalized energy usage and log purchase price associated with each appliance feature. All regressions include state and calendar quarter fixed effects. I emphasize that this analysis is intended merely to be suggestive—without a control I cannot say that any results are caused by the appliances conveying.

I first consider two features of refrigerators: capacity, and through-the-door ice dispensers. Both of these features likely enhance utility, and are associated with higher average energy usage and higher average prices. If consumers consider whether their refrigerator will convey when choosing a model, we would expect these features to be purchased less often in states where refrigerators convey. Indeed, as the first two rows of table 4 show, the more refrigerators convey in a state, the less consumers in that state purchase large refrigerators and refrigerators with through-the-door ice dispensers. As such, my differences-in-differences results showing that consumers choose refrigerators with both lower purchase prices and lower energy usage when they expect the refrigerator to convey could be explained in part by consumers substituting away from premium features. It may be that consumers also substitute away from energy efficient models *ceteris paribus*, but the countervailing effect of choosing more basic models dominates.

The case of clothes washers is less clear. The main premium feature in the TraQline data for clothes washers is loading direction. Front-loading clothes washers are generally seen as more desirable, and are also more energy efficient. However, the third row of table 4 shows that on average consumers are more likely to purchase front-loading models in states where clothes washers convey more often, even though front loaders use less energy and are more expensive. On the other hand, my difference-in-differences analysis shows that clothes washers conveying causes zero effect on energy efficiency, rather than increasing energy efficiency as with refrigerators. In any event, the effect of the clothes washers conveying by default on upfront expenditures on new clothes washers does not seem to be readily explained by consumers substituting away from front-loading models when clothes washers convey.

Finally, as a form of null test, I examine whether consumers purchase premium water heaters in states where refrigerators convey by default. Water heaters always convey and should not be affected by the default governing refrigerators. The final row of table 4 shows results for heat pump electric water heaters, a relatively new type of heater that is highly energy efficient. There is no statistically or economically significant difference between the rate of purchasing heat pump water heaters across states where refrigerators convey more or less.

6 Length of Ownership and the Energy Efficiency Gap

In section 5, I show that the consumers' choice of appliances are affected by whether the appliance type conveys, leading consumers to purchase less expensive appliances. I now consider the implications of this result for attempts to calculate whether consumers undervalue future net benefits of an investment. This type of undervaluation can be thought of as an "energy efficiency gap", but applies generally to the valuation of any stream of benefits from a durable good.

Following Allcott and Greenstone (2012), I modify the decision rule from section 3 to allow consumers to under or overvalue the stream of net benefits from energy efficiencty. Consumers choosing between energy efficient model E and inefficient model I will choose E if and only if:

$$\lambda \sum_{t=0}^{T} \left((b^E - b^I) - (e^E - e^I) \right) \delta^t > (p^E - p^I) - \epsilon,$$

where again b^j and e^j denote the per-period benefits and energy costs of model j, and the parameter λ captures any undervaluation of future net benefits.[15] If consumers fully value future energy costs and product benefits, $\lambda = 1$, while $\lambda < 1$ implies some degree of undervaluation.

In general, λ could be calculated by finding the weighting of future costs and benefits that rationalizes an observed maximum price differential, given a value for the discount factor δ. For instance, one might observe that on average consumers will not pay more than \$200 for an investment that saves \$40 in energy costs per year over 12 years, with no change in non-energy benefits.[16] This observation implies an internal rate of return (IRR) of 19%, much higher than most consumer interest rates. If the actual discount rate is 10%, consumers must be undervaluing future energy savings in some way, implying a $\lambda < 1$ (in this case, 0.725).

However, the calculation of λ depends on the expected length of ownership T. If the expected length of ownership is overestimated, the discounted present value of the stream of benefits will also be overestimated, leading to an inflated implied IRR and a smaller value of λ. Data from NAHB (1998) indicates that refrigerators have a life expectancy of 14–17 years, and clothes washers have a life expectancy of 13 years, while the median home ownership spell is around 7 years. As a result, the bias in calculating the undervaluation of future net benefits for these appliances could be substantial. In the example above, if the expected life of the investment were 7 years rather than 12, λ would be 0.99, implying essentially full valuation.

To calculate the bias in the multiplier λ from failing to account for the appliance conveying if the consumer moves, I fix values for the true discount factor δ and the observed price differential. I then calculate the naïve λ for a range of values for per-period net benefits, assuming the stream of benefits will continue for 16 years for refrigerators and 13 years for clothes washers.[17]

Next, I use the coefficients on log price from the fifth column of table 3 to calculate the change in life expectancy implied by the appliance conveying. The average effect of

[15] For purposes of this section, I assume that the scrap value of both products is zero.

[16] Throughout this analysis I assume that either per-period benefits b^i are identical between the efficient and inefficient products, or else the difference in per-period benefits is known and included in the calculation of λ. Obviously, if a difference in per-period benefits exists and is not accounted for, this will also bias estimates of λ. Even with full valuation of future benefits, consumers may choose not to make an investment in energy efficiency if the energy efficient product is substantially inferior to the inefficient product. This has been offered as one explanation for the apparent energy efficiency gap in the adoption of energy efficient light bulbs (see e.g. Gillingham and Palmer (2014)).

[17] Note that although I present my results in terms of annual energy savings and annual discount rates, in order to allow the effective life expectancy to vary smoothly, I perform my calculations on a monthly basis

the appliance conveying on the upfront cost implies a corresponding decrease in the net present value of investing in the energy efficient good. For each value of per-period net benefits, I calculate the reduction in the life expectancy of the appliance necessary to produce the implied reduction in net present value. I assume that the energy efficient good costs the average price for each appliance in my sample. For instance, the average price for a refrigerator in my sample is \$1,015. If a refrigerator conveying lowers average willingness to pay by 12%, as in table 3, this means it must lower the DPV by \$121. Thus, if the energy efficient good saves \$40 per year in energy costs, a refrigerator conveying must lower the expected length of ownership from 16 years to 9.6 years. Finally, I re-compute the value of λ that rationalizes the maximum price differential, given the "true" life expectancy.

Figure 2 shows the results of these calculations, plotting annual net benefits on the horizontal axis and the resulting naïve and adjusted λ on the vertical axis. In each plot I assume a price differential of \$200, and a discount factor of either 0.9 or 0.85.

For low to moderate levels of per-period net benefits, accounting for refrigerators conveying substantially reduces the apparent undervaluation of future benefits. For per-period benefits leading to a naïve λ of about 0.6 or higher, accounting for the effect of the refrigerator conveying by default produces a λ consistent with full valuation. However, the importance of conveying shrinks as the naïve calculation of undervaluation grows larger. As the per period benefits of energy efficiency increase, the DPV of the energy efficient investment grows, while the effect of the appliance conveying on the DPV stays constant. This means that the implied change in life expectancy is smaller in the scenarios with larger per-period benefits, decreasing the relative importance of conveying by default. For λ around 0.4, accounting for refrigerators conveying reduces the undervaluation by about a third. For very large undervaluations, where consumers appear to be unwilling to pay \$200 for an investment that saves \$100 or more per year, the effect of conveying on the expected length of ownership accounts for only a small portion of the apparent undervaluation.

Accounting for clothes washers conveying has less effect on calculations of the energy efficiency gap for those appliances. Between the smaller effect on upfront expenditure from clothes washers conveying and the shorter "naïve" life expectancy, the smaller bias is to be expected. Still, for low to moderate levels of per-period net benefits, accounting for clothes washers conveying raises the value of λ by 0.1-0.2, depending on the true discount rate, equivalent to reducing the rate of undervaluation of future benefits by 10 to 20 percentage points.

7 Conclusion

Determining whether consumers undervalue energy efficient goods requires, among other things, correctly determining how long consumers expect to benefit from energy efficiency investments. One contribution of this paper is simply demonstrating that in many U.S. states, engineering estimates of the useful life of an appliance will overestimate the true life of an investment, because consumers will necessarily transfer it when they move houses. More broadly, this paper adds to a recent literature finding that engineering estimates may overstate the benefits of investing in energy efficiency appliances and home improvements. Previous works have shown that the per-period savings from energy efficiency investments can be overstated. I show that changes in the expected length of ownership can also affect consumer choices, and failing to correctly account for the length of ownership can lead to overestimating the size of an energy efficiency gap.

My results focus on the effect of the local regime for which appliances stay with a house when the house is sold. However, there are other ways that the effective life of an energy efficiency investment could be overstated. If consumers simply replace their appliances before the product completely breaks down, this will also reduce the length of ownership if there is no practical market for secondhand appliances. Likewise, engineering estimates of the life of an appliance generally assume proper and regular maintenance. If consumers do not maintain their appliances, this will reduce the effective life of the investment.

It is also worth noting that besides the major appliances used in this study, most energy efficiency investments by homeowners necessarily convey. Insulation, high-efficiency windows and most HVAC improvements will always convey with the sale of the house. As such, failure to account for the length of ownership will bias estimates of consumers' valuation of future energy savings.

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Table 1: Demographics of TraQline Sample

	Percent	Count
High School Dropout	0.028	6,931
High School Diploma	0.521	130,823
BA or More	0.451	113,375
Single	0.304	76,319
Married	0.696	174,869
Less than $50K	0.372	88,487
$50K-$100K	0.402	95,858
$100K-$200K	0.193	46,030
More than $200K	0.033	7,796
Employed	0.607	152,560
Retired	0.193	48,472
Other Not-Employed	0.200	50,152
Less than 1 Year at Address	0.188	43,626
1-5 Years at Address	0.201	46,733
5+ Years At Address	0.612	142,269

Table 2: TraQline Price, Conveyance and Energy Characteristics

	All	Refrigerators	Dishwashers	Clothes Washers	Water Heaters
Price Paid	708.4	1015.9	506.9	583.3	572.7
	(496.5)	(640.3)	(232.0)	(272.3)	(468.6)
Proportion Convey	0.580	0.481	1	0.260	1
	(0.362)	(0.262)	(0)	(0.187)	(0)
P(EnergyStar)	0.628	0.590	0.796	0.754	0.131
	(0.365)	(0.327)	(0.202)	(0.321)	(0.289)
Observations	260817	85181	50938	88615	36083

mean coefficients; sd in parentheses

Table 3: Conveyance Customs and Appliance Choices

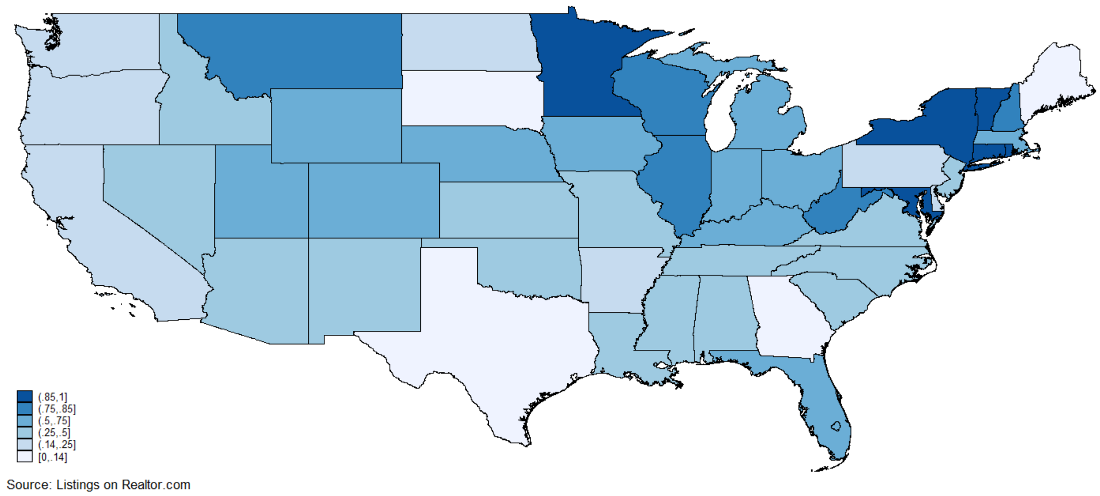
	Panel A: Price				
	Dishwasher Control		W. Heater Control		Both
Refrigerator · Convey	-0.0892*		-0.140		-0.122*
	(0.0371)		(0.0868)		(0.0500)
Clothes Washer · Convey		-0.0381		-0.155*	-0.0708*
		(0.0240)		(0.0729)	(0.0285)
Refrigerator	0.722**		0.700**		0.735**
	(0.0203)		(0.0446)		(0.0254)
Clothes Washer		0.193**		0.189**	0.209**
		(0.00946)		(0.0260)	(0.0110)
Water Heater					0.0422*
					(0.0163)
	Panel B: Normalized Energy Use				
	Dishwasher Control		W. Heater Control		Both
Refrigerator · Convey	-0.239*		-0.325		-0.286*
	(0.0976)		(0.272)		(0.138)
Clothes Washer · Convey		0.0312		-0.326	-0.0704
		(0.0396)		(0.329)	(0.111)
Refrigerator	0.157*		0.176		0.178*
	(0.0591)		(0.115)		(0.0683)
Clothes Washer		-0.0780**		0.0705	-0.0262
		(0.0151)		(0.0858)	(0.0316)
Water Heater					-0.00367
					(0.0695)
	Panel C: P(EnergyStar)				
	Dishwasher Control		W. Heater Control		Both
Refrigerator · Convey	-0.0100		-0.0257		-0.0103
	(0.0136)		(0.0378)		(0.0249)
Clothes Washer · Convey		0.00826		-0.0378	0.00641
		(0.0195)		(0.0339)	(0.0221)
Refrigerator	-0.174**		0.469**		-0.174**
	(0.00631)		(0.0214)		(0.0123)
Clothes Washer		-0.0161*		0.631**	-0.0116
		(0.00775)		(0.00914)	(0.00774)
Water Heater					-0.634**
					(0.00696)
N	87124	88039	76731	77646	164770

Standard errors in parentheses

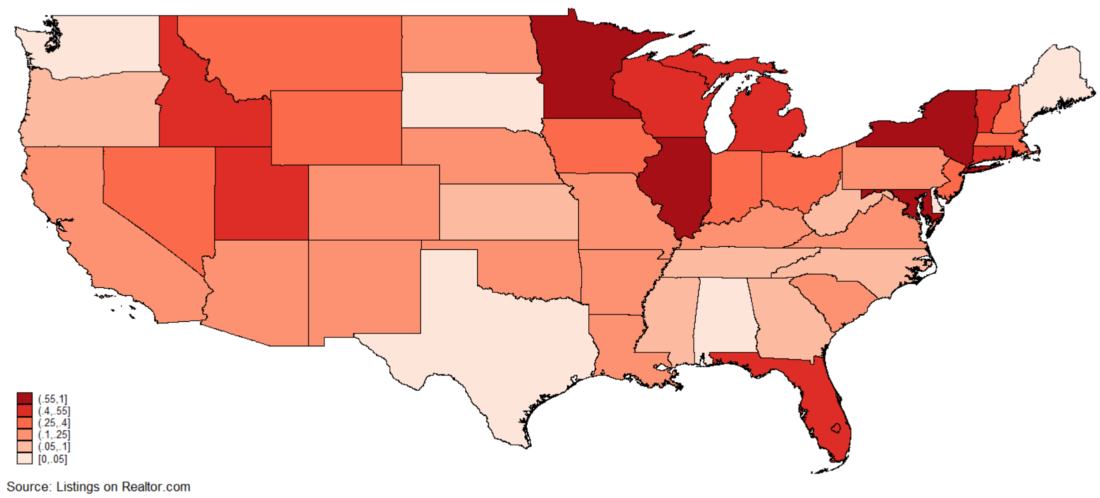
* $p < .05$, ** $p < .01$

Table 4: Effect of Conveyance on Choice of Appliance Features

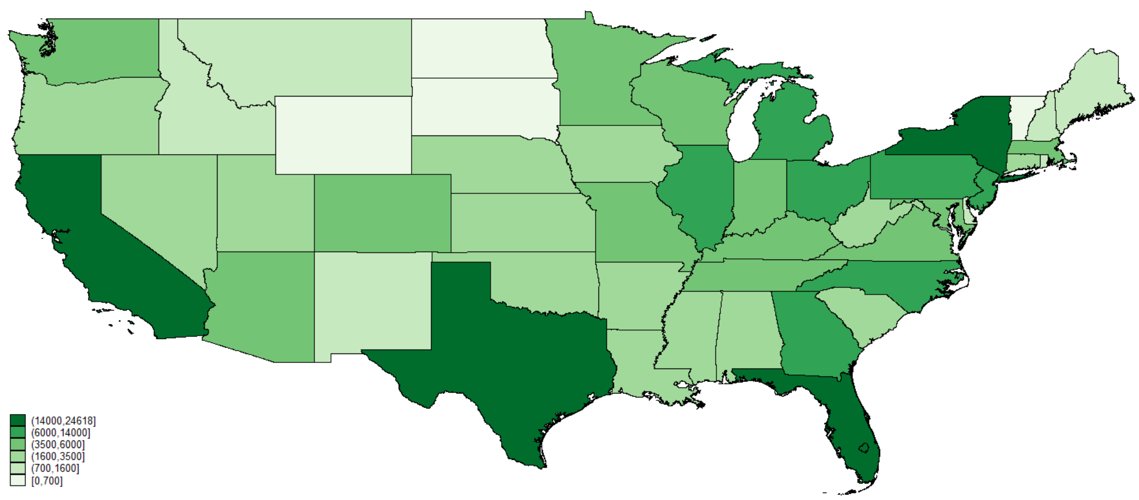
	Effect of...		
Feature	Convey on Feature	Feature on Energy	Feature on Price
Refrigerator; Capacity $\geq$ 23.5 ft^3	-0.433***	0.814***	0.460***
	(0.0124)	(0.0159)	(0.00581)
Refrigerator; Through the Door Ice	-0.487***	1.397***	0.443***
	(0.00780)	(0.0215)	(0.0103)
Clothes Washer; Front Loading	0.730***	-0.645***	0.404***
	(0.00716)	(0.00734)	(0.00726)
Water Heater; Electric Heat Pump	0.00908	-6.586***	0.447***
	(0.00780)	(0.0824)	(0.0442)



(a) Proportion of Listings Where Refrigerators Convey

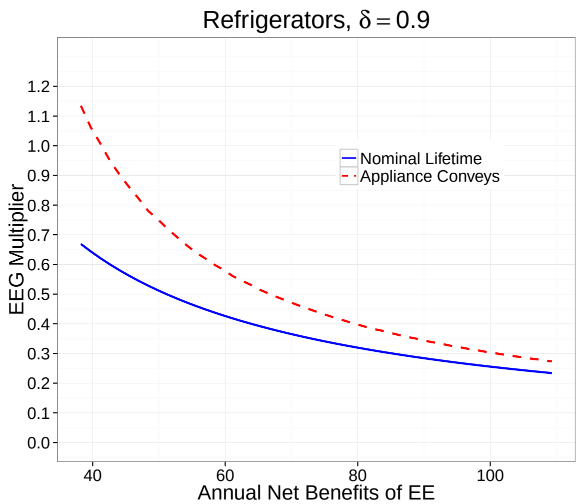


(b) Proportion of Listings Where Clothes Washers Convey

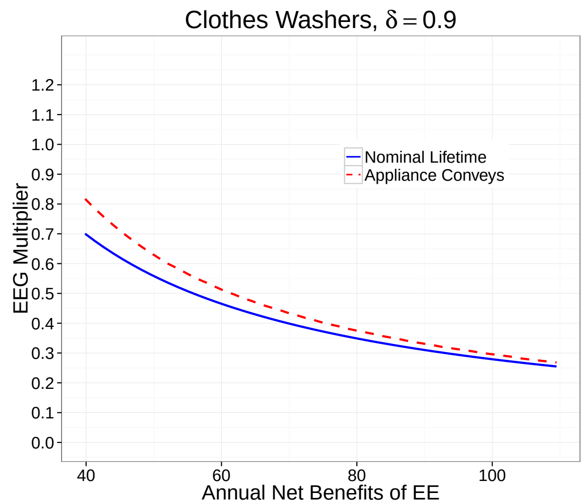


(c) Count of Traqline Respondents 2008–2013

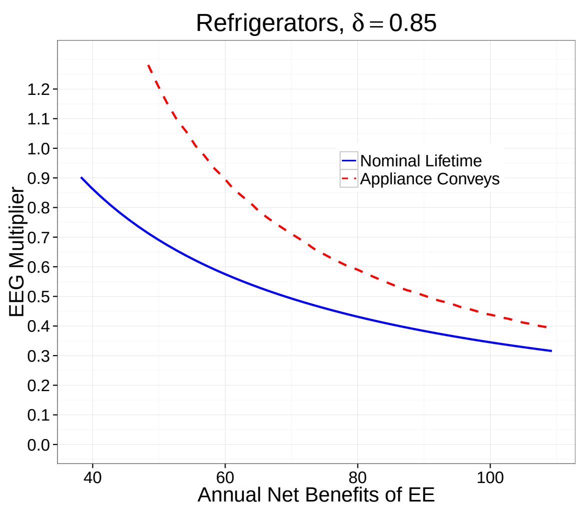
Figure 1: Proportion of Appliances Conveying and TraQline Respondents by State



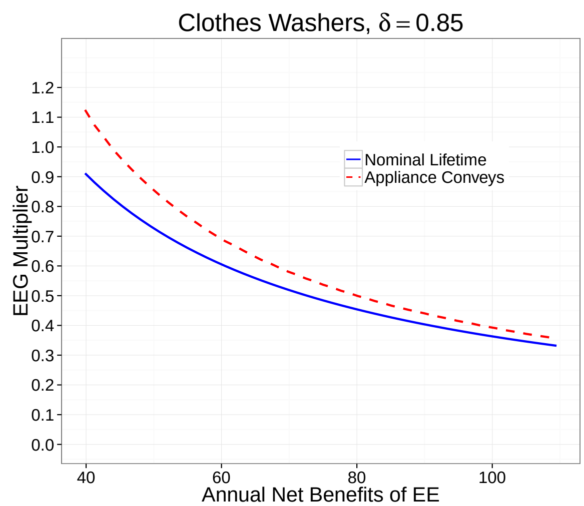
(a)



(b)



(c)



(d)

Figure 2: Implications of Appliances Conveying for an Estimated Energy Efficiency Gap

Appendix

A Energy Usage Matching

This appendix describes the process used to match energy usage and EnergyStar information to the TraQline survey data.

A.1 Refrigerators

All data for refrigerators comes appliance energy usage data that appliance manufacturer's submitted to the U.S. Federal Trade Commission.[18]. The energy usage data is given at the model level, and in addition to average annual electricity cost in dollars, the data indicate the refrigerator's configuration, capacity in cubic feet, whether it has manual or automatic defrost, and whether it has a through-the-door icemaker. The data contain an observation for each year between 2008 and 2012, and I match energy usage information from a given year to TraQline observations taken in the same year, using 2012 information for TraQline observations from the first two quarters of 2013. I join the energy usage data to the TraQline survey data in three stages, aggregating at a higher level each time. First I match refrigerators in TraQline to the average energy usage by models with the same brand, year, configuration, manual defrost, icemaker and capacity bin. I then link TraQline observations with no match to the average by brand, year, configuration, manual defrost and icemaker. Remaining observations with no match are linked to the average by brand, configuration, and manual defrost.

Using the standard that applied during the study period, a refrigerator must have annual energy usage of 80% or less of the minimum efficiency standard. The minimum efficiency standard is a function of the configuration of the refrigerator, whether the model has a through the door icemaker, and a measure of adjusted capacity. Adjusted capacity is equal to 1.63 times freezer volume, plus total fresh volume. I assume that freezer capacity is 34.5% of total capacity for top and bottom refrigerators, and 42.5% of total capacity for side-by-side refrigerators.[19]

[18] These data are now maintained by the Department of Energy, since 2013

[19] These fractions were determined using data scraped from the websites of appliance retailers such as Best Buy. 34.5% and 42.5% represent the average ratio of freezer volume to total capacity. I am grateful to Sebastien Houde for providing these data.

A.2 Dishwashers

Data for dishwashers comes from submissions to the Federal Trade Commission, and proceeds in the same manner as refrigerators. First, the data only indicate brand and whether the model is compact, and so the matching is done in one stage, by brand, year and compact status.

For EnergyStar status, a model is considered EnergyStar if it's annual energy usage in KwH is less than 335 (for models before 2010), 324 (for 2010 and 2011 models) or 295 (for 2012 and 2013).

A.3 Clothes Washers

Data from Clothes Washers comes from the California Energy Commission. These data indicate the modified energy factor and water factor for each model, as well as the brand, manufacturer, and loading direction. I link energy usage to TraQline in three steps. In the first step I link to the average energy factor by brand, manufacturer, year and loading direction. For non-matching observations I then link to the average by brand, manufacturer and loading direction. Remaining observations are matched to the average by brand and loading direction.

EnergyStar status is determined by the modified energy factor and the water factor, with the standard becoming tighter with each year.

A.4 Water Heaters

The publicly available water heater data is much less clean than for the other three appliance types. I combine data from the California Energy Commission, the Federal Trade Commission, and the Department of Energy. Each dataset has a somewhat different list of models, and slightly different variables. Where the same model is present in multiple datasets, I take the every energy usage across the datasets. The data indicate for each model the energy factor, as well as brand, manufacturer, fuel type (electric or gas), capacity and electric type (for heat pump water heaters). I link the average energy usage in several stages, starting with all characteristics, and then aggregating more and more.

EnergyStar status is only available for heat pump electric water heaters, instantaneous gas water heaters, and conventional gas water heaters with energy factors of 0.67 and higher.