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Confronting Regulatory Cost and Quality Expectations: An Exploration of Technical Change in Minimum Efficiency Performance Standards

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ABSTRACT

The dual purpose of this project was to contribute to basic knowledge about the interaction between regulation and innovation and to inform the cost and benefit expectations related to technical change which are embedded in the rulemaking process of an important area of national regulation. The area of regulation focused on here is minimum efficiency performance standards (MEPS) for appliances and other energy-using products. Relevant both to U.S. climate policy and energy policy for buildings, MEPS remove certain product models from the market that do not meet specified efficiency thresholds.

This project took the form of a retrospective review of regulation, which is a type of detailed case study that compares data on *ex ante* (i.e., before regulation) expectations about regulation to *ex post* (i.e., after regulation) observations of regulatory performance so that empirical evidence can guide future rulemaking decisions. This project differs from other retrospective reviews, however, in its focus on regulatory expectations and post-regulatory outcomes of technical change, which is a particularly important factor in the performance of MEPS, as it is in other areas of regulation. It also differs from other retrospective reviews in its focus on five products with different regulatory histories, namely room air conditioners, refrigerator-freezers, dishwashers, clothes washers, and clothes dryers. These five products, which heavily saturate U.S. households and are manufactured in a highly concentrated industry sector, are the full set of large household appliances which were subject to federal MEPS informed by rulemaking analyses conducted by the Department of Energy (DOE) from 1990 to 2012. The research advantages of focusing on these appliances in this time period include limiting selection bias, ensuring the likelihood of sufficient data for retrospective review, and limiting variation in product markets. Finally, this project differs from other retrospective reviews in the scope of data employed. *Ex ante* data included rulemaking analyses and other documents in the regulatory docket. *Ex post* data included rich, often high resolution data covering several aspects of product price, quality, and design: (1) extensive 2003-2011 U.S. point-of-sale data on appliance models matched to model energy use data (for all but clothes dryers) which facilitated construction of a monthly panel of model-specific prices, quality characteristics, and market shares; (2) author-constructed datasets from independent third party appliance testing and product reliability surveys; and (3) an author-constructed dataset of the features identified in the product manuals of 1,109 clothes washer models sold in the U.S. in 2003-11 (these models represented 95% of the identifiable models in the point-of-sale data, which account for 29% of U.S. units sold over that period).

At least seven questions were addressed in this project, which cluster around considerations of whether and how product price, quality, and design changed after regulation. Six of these questions were informed by hypotheses drawn from various literatures; the seventh was fully exploratory, with respect to how well the MEPS rulemaking analysis process treats product design. Key findings, which were generally consistent with hypotheses, included: (1) MEPS rulemaking analyses significantly overestimated observed product prices; (2) the energy efficiency of products purchased after regulation generally exceeded the regulated standards (as well as rulemaking expectations of market share for the one case appliance for which these expectations existed); (3) unregulated aspects of product quality at the time of sale often improved in conjunction with MEPS events, at least according to available models reported on in third-party testing; (4) product reliability generally improved over the period of time the products have been regulated; (5) within-model price declines (i.e., product-level price declines without

consideration of model entry or exit) occurred across products, and these declines were better differentiated by product architecture than by energy efficiency levels for the two products we analyzed; (6) the dominant design of one product, clothes washers, adapted in only a few years to MEPS that were originally expected to be so "technology-forcing" that they were deemed likely to eliminate that design from the U.S. market; and (7) for one product, clothes washers, highly correlated product features contributed both to regulatory performance and to unregulated aspects of product quality.

These findings had several potential implications for the MEPS rulemaking process; these revolve around statutory language that the targets of efficiency standards should be "the maximum percentage improvement" that is "technologically feasible and economically justified." Our results indicate several possible implications of relevance to the economic justification of MEPS, including: that the positive economic impacts of MEPS on consumers may have been underestimated; that the initial price of efficient products may not be of as great a concern as its analytical priority in the rulemaking process suggests, given the existence of lower-than-expected product prices that decline as regulated models remain on the market; that the projected energy savings of MEPS may have been underestimated; that the MEPS process may have generally succeeded in ensuring the retention of product utility and performance under regulation; that the part of regulated product maintenance costs that is tied to significant repair events may have declined over time across products; and that the concept of product architecture may be more useful to technical elements of MEPS cost analyses than a disaggregated approach to product design at the level of product features (i.e., design options, product components, etc.). Our results also raise questions of: what makes a product architecture more or less adaptable to a stringent standard; how can the MEPS technical feasibility criteria better avoid a present-day bias in identifying efficiency-enabling design options and overly pessimistic expectations about future commercial viability; and what are the most appropriate combinations of design options for developing cost-efficiency relationships.

Finally, our results point to several areas for new research on the relationship between regulation and innovation. These include: the connection between the details of regulation and our observed post-regulatory price, efficiency, quality, and reliability outcomes; a mechanism that could underlie the Porter Hypothesis; issues related to the political economy of "technology-forcing," "performance-based," and "technology-based" regulation in the MEPS context; unpacking information asymmetry in the MEPS rulemaking process; and the role of human behavior in regulatory cost and benefit errors.

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1 INTRODUCTION

1.1 Motivation

Expectations about technical change are central to the way policy details are manifested in U.S. regulation in a variety of complex public problem areas, including health, welfare, safety, and environmental protection.[1] This is because the regulatory impact analyses that inform the specifics of U.S. rules often revolve around the details – costs, benefits, etc. – of particular technologies, both at the current time and as they are projected into the future. Best practice in the conduct of rulemaking analyses includes employing techniques that identify "changing future compliance costs that might result from technological innovation or anticipated behavioral changes," according to guidance to federal agencies given by the White House regulatory oversight organization, the Office of Information and Regulatory Affairs (OMB 2011).

Evidence on the accuracy of regulatory cost estimates, however, points to the possibility that agencies have an insufficient understanding of what to expect over time about technologies that are relevant to regulation, and this inadequate understanding may be having a significant impact on the attainment of U.S. policy goals. Over the past forty years, about three-quarters of the 60+ U.S. regulatory cost estimates that have been retrospectively reviewed have proven to be significantly inaccurate, where accuracy is defined as *ex post* costs falling outside the range of +/- 25% of *ex ante* estimates, in keeping with a benchmark established in Harrington, Morgenstern et al. (2000). As discussed in Simpson (2011), the majority of these inaccurate regulatory cost projections are over-estimates of the costs of regulation, and the author was unable to reject the null hypothesis that this robust finding is evidence of systematic bias. A leading conjecture offered to explain this high level of cost-overestimation – and its implicit corollary with respect to leaving significant societal benefits "on the table" in the rulemaking process – is that regulatory analyses are not currently able to accurately project future technical change in industries subject to regulation (Harrington, Heinzerling et al. 2009).

The appropriate modeling of technological change in rulemaking analyses has been placed "at the frontier of economic research" by leading experts in regulation (Harrington, Heinzerling et al. 2009). In part, this is because the economic and legal literatures that inform regulatory analyses are not themselves resolved regarding the expected influence of regulation on the rate and direction of technical change. Two opposing contentions dominate the debate (see Sachs 2012 for a discussion). The first contention is that innovation can be induced to both public and private benefit by well-designed regulation (see, e.g., the "Porter Hypothesis," as articulated in Porter and Van der Linde 1995). The empirical literature has demonstrated that several aspects of regulatory design can influence innovative activities; these include how stringent a regulation is over time, how neutral a regulation is to the various alternative technologies that can potentially achieve any given target, and how responsive a regulation is to new developments in science and

[1] In these policy areas, executive agencies "implement, interpret, or prescribe law or policy" in "rules" which have the substantive effect of law (see the Administrative Procedure Act, Pub. L. 79–404, 60 Stat. 237). The "rulemaking" process is designed to incorporate scientific, technical, economic, and other expertise while following principles of good governance such as transparency and public accountability. Administrative law and presidential Executive Orders require the agency rule-making process to consider a number of issues (e.g., the interests of small entities, the potential burden of regulatory information-gathering, regulatory costs and benefits, etc.) and meet analytical quality standards (e.g., the incorporation of appropriate baselines, the adoption of rigorous analytical techniques, the appropriate treatment of uncertainty, etc.).

technology (see, e.g., Taylor, Rubin et al. 2005, del Rio Gonzalez 2009, Kemp and Pontoglio 2011, Taylor 2012). The second contention is that information asymmetry between regulators and the regulated regarding private sector business operations, including innovation management, implies that regulation should be expected to hinder innovative activities (see, e.g., Stewart 1981).

According to a prominent review of the innovation effects of environmental policy instruments, case studies of regulation and innovation are "a necessary source of empirical evidence about policy impacts and the factors responsible for these impacts" (Kemp and Pontoglio 2011). It seems logical that case studies should also be a useful source of knowledge to help inform the appropriate treatment of technical change in rulemaking cost-benefit analyses. As a practical matter, regulated industries often have different product cycles and approaches to innovation that can affect regulatory analysis assumptions and formulations. For example, the pharmaceutical and automotive industries are both subject to regulation, but their very different product development timelines, supplier R&D relationships, and concepts of product quality suggest ways in which regulatory analyses should probably differ in order to model costs and benefits appropriately (e.g., incorporate different product time horizons, cost trajectories, benefits assessments, etc.). Past regulatory analyses, however, have often not been transparent enough to easily identify their sensitivities to the factors that can underlie different rates and directions of technical change over time in regulated industries.

This may change in the future, however, due in part to recent presidential Executive Orders (EOs) which have called on agencies to periodically conduct "retrospective reviews" of regulation.[2] A retrospective review is a detailed case study that compares data on *ex ante* (i.e., before regulation) expectations about regulation to *ex post* (i.e., after regulation) observations of regulatory performance so that empirical evidence can guide future rulemaking decisions. A useful by-product of requiring federal agencies to implement retrospective reviews regularly is likely to be an increase in the transparency of rulemaking analyses so that it becomes easier to conduct future *ex ante*/*ex post* comparisons.

The creation of a systematically constructed knowledge base not only of regulatory performance, but also of the factors, such as technology, that affect that performance over time would appear to be another potentially valuable by-product of the call for periodic retrospective reviews. But this can only be accomplished with retrospective review research designs that explicitly incorporate these factors in their *ex ante*/*ex post* comparisons. This goes beyond the traditional retrospective analyses called for in current EOs, although it is consistent with the objectives of these EOs, such as "moderniz[ing] our regulatory system" and identifying "appropriate modifications" to make regulatory programs "more effective… in achieving the regulatory objectives" (EO 13610).

1.2 Purpose and Research Questions

This working paper is a retrospective review of regulation with a two-fold purpose. First, we seek to contribute to basic knowledge about the interaction between regulation and innovation, as discussed above, through an in-depth case study analysis. Second, we aim to inform the cost and benefit expectations related to technical change which are embedded in the rulemaking process

[2] These were: EO 13563 (2011) "Improving Regulation and Regulatory Review"; EO 13579 (2011) "Regulation and Independent Regulatory Agencies"; and EO 13610 (2012) "Identifying and Reducing Regulatory Burdens."

of an important area of national regulation. The area of regulation focused on in this project has been particularly prominent in recent years due to its relevance to climate policy: minimum efficiency performance standards (MEPS) for appliances and other energy-using equipment (see, e.g., *The Economist*, September 2014). The basic concept underlying MEPS is that they remove certain product models from the market that do not meet specified energy efficiency thresholds. As will be discussed later, MEPS are best understood in the broader context of U.S. energy efficiency policy, particularly as it relates to the energy used by residential buildings (currently estimated at 22% of U.S. energy use). Today, the Building Technologies Office of the U.S. Department of Energy (DOE) now implements MEPS for more than 60 categories of appliances and equipment (EERE 2015).[3]

To advance our dual purpose, we addressed at least seven research questions in this study. The first four were well-aligned with issues of regulatory burden and benefit that drive many traditional retrospective reviews of regulation. First, we asked how accurate MEPS rulemaking cost projections were when compared to the price of products sold in the U.S. market after regulation. Second, we asked about the energy efficiency of purchased products after regulation, when compared to the minimum levels required by the various MEPS; this is relevant to assessing the effectiveness of regulation and the accuracy of the benefits projections of the MEPS rulemaking analyses (note that the main benefit of MEPS that is assessed in rulemaking analyses is national energy savings and related monetary savings). Third, we asked whether and how the unregulated quality dimensions (e.g., performance, capacity, etc.) of products offered for sale changed with MEPS events. Fourth, we asked whether and how product reliability (i.e., during-use quality) has changed since products have been regulated by federal MEPS. Evidence regarding these latter two questions is of importance not only to questions of regulatory burden but also to the debate referred to above about whether regulation should be expected to induce co-benefits (i.e., "win-wins") or necessitate tradeoffs. It is also of practical relevance to the political and economic context of MEPS, given the prominence of product quality claims before, during, and after the rulemaking process, as incorporated in such things as the rulemaking analysis methodology, stakeholder comments on agency actions, legal proceedings after regulation, etc.

Our three remaining research questions dealt with issues related to the interplay between regulation and product design which are not often called out in traditional retrospective reviews, despite their relevance to policy-relevant topics like rulemaking accuracy and regulatory-induced innovation. In our fifth question, we asked about the effectiveness of two ways to differentiate appliance price trends. This question, which focused on the relative merits of product efficiency levels and product design architectures, was relevant to two technical elements of the MEPS rulemaking analysis process that can affect the accuracy of regulatory cost estimates: the construction of cost-efficiency curves used in economic impact assessments;[4] and the approach

[3] The laws mentioned in this working paper are codified in the United States Code, Title 42, Chapter 77, Subchapter III, Part A—Energy Conservation Program for Consumer Products Other Than Automobiles and Part A-1—Certain Industrial Equipment. For regulations pertaining to appliance standards and test procedures, see CFR Title 10, Chapter II, Part 430; for commercial and industrial equipment standards and test procedures, see Title 10, Chapter II, Part 431; for certification, compliance, and enforcement standards, see Title 10, Chapter II, Part 429.

[4] Depending on the rulemaking, this is based on calculating: the incremental costs of adding specific design options to a baseline model; the relative costs of achieving increases in energy efficiency levels without regard to design; or the costs of a bill of materials derived from product teardowns

adopted since 2011 to deflate certain regulatory cost predictions based on a factor derived from fitting the traditional functional form of an organizational learning curve to price index and quantity data for a covered product (see Taylor and Fujita 2013).

In our sixth question, we considered how the concept of "technology-forcing," or the setting of a standard beyond what currently available "off-the-shelf" technologies can accomplish, pertains to MEPS rulemakings (see definition in Nentjes, de Vries et al. 2007). At several points in the process of setting the stringency of a new product MEPS, energy efficiency-enabling design options are eliminated from consideration on the basis that they are not expected to meet various criteria associated with present or future commercial viability. In one instance, petitioners to overturn a newly implemented, stringent MEPS based their argument on expectations that some of those criteria would be violated through the likely elimination of the dominant design of a product from the U.S. market when the MEPS fully came into effect.[5] Our sixth question asked how accurate these expectations were; this question was particularly relevant to the environmental innovation literature on technology-forcing as well as on the importance of technological neutrality in policy design. For the economics of innovation literature, this question has implications for the resilience of dominant designs and for the "steamship/sailboat" debate.[6]

Finally, our seventh question explored how informed the technology considerations in the MEPS rulemaking cost analyses appear to be regarding concepts of product design. The main design element in the MEPS analyses is the "design option," which lacks a strict definition but in practice includes a loose range of technical characteristics of products, sub-systems, and components. Not only are individual design options eliminated from regulatory assessments for various reasons, as mentioned above, but specific options and limited combinations of options inform the cost-efficiency curves described above. Our seventh question asked what could be learned for the rulemaking consideration of design options from a systematic exploration of the features incorporated in commercial products over a period of regulatory change.

Although the research we present in this working paper is primarily descriptive, a number of hypotheses drove our analyses. Table 1 summarizes these hypotheses, which we discuss in more detail below.

Table 1: Major research questions and hypotheses considered

	Research Question	**Hypothesis**
1	How accurate were MEPS cost projections when compared with post-regulatory prices?	MEPS projections will over-estimate observed prices.

[5] A dominant design is the design that the market resolves is the strongest of the competing alternatives because of its particular combination of performance attributes and technical characteristics. A dominant design can arise at any level of product design (e.g., product architecture, core subsystem, next-order subsystems, peripheral components, etc.). Dominant designs have a number of implications for industry structure and firm survival (see Henderson and Clark 1990; Suarez and Utterback 1995). These include a heightened opportunity for industry concentration and the accumulation by market leaders of "collateral assets" (e.g., market channels, brand image, customer switching costs, etc. – see Teece (1986)) and increased opportunity for "strategic maneuvering" (see Cusumano, Mylonadis, et al. (1992). For more information on dominant design and the related concept of "technology cycles," see Murmann and Frenken (2006), Abernathy and Utterback (1978), Clark (1985), Anderson and Tushman (1990), Baldwin and Clark (2000), Utterback and Suarez (1993), and Tushman and Murmann (1998).

[6] This debate focuses on whether it is correct to consider that a mature product has less room for continued technical change when confronted with a less developed, competing technology.

2	How efficient were purchased products when compared with regulated standards?	Efficiency will at least match the standards.
3	Whether and how did MEPS changes affect unregulated product quality at the time of sale?	Unregulated product quality will either stay the same or improve, overall.
4	Whether and how has product reliability changed since products became regulated?	Product reliability will either stay the same or improve
5	How effective were efficiency levels and product design at differentiating the declining trends in appliance prices over time?	Product efficiency will be inferior to product design in this differentiation
6	Were expectations accurate that one of the product MEPS would be so stringent that it would eliminate the dominant design of that product in the U.S.?	The stringency of the MEPS would not be enough to eliminate the dominant design
7	How well does the MEPS rulemaking analysis treat product design?	No clear hypothesis. We treated this question in a more exploratory manner.

For our first question, we hypothesized that MEPS rulemaking projections would over-estimate observed prices, consistent with well-established findings in the general retrospective review literature (see, e.g., Harrington 2006, Simpson 2011). For our second question, we hypothesized that the energy efficiency of products purchased after regulation would at least match the minimum standards, consistent with previous retrospective reviews of the effectiveness of MEPS (see Dale, Antinori et al. 2009, Nadel and deLaski 2013, as will be discussed further below). For our third and fourth questions, we hypothesized that, in general, we would not see significant tradeoffs regarding the unregulated dimensions of product quality, including reliability, with the advent of federal MEPS regulation for appliances in the late 1980s or with most MEPS events since then. We felt that this was consistent with extant innovation and manufacturing trends over this period, as well as with previous retrospective reviews of the effectiveness of MEPS. There also seemed to be precedent for this in the large case study literature supporting the “win-win” phenomena popularized in the Porter Hypothesis and “triumphs” in the sustainable design literature.

For our fifth question, we hypothesized that observed price trends would be better differentiated by product design than by product efficiency level. We do not feel that product design and product efficiency level are functional equivalents with respect to product price, nor that efficiency level is somehow a better proxy across a period of efficiency regulation.[7] For our sixth question, we hypothesized that the stringency of MEPS would not be enough to eliminate a dominant product architecture from sale in the U.S. We felt that the rulemaking process tends to work against MEPS being a technology-forcing regulation, as separate product architectures (i.e., product categories, per the regulation) are often given separate standards. We also felt that this hypothesis was consistent with the environmental innovation literature in which regulatory stringency has been shown to help drive innovative activities (e.g., Taylor, Rubin et al. 2005). In addition, the level of market concentration in the clothes washer industry (as in other appliances) implies that the dominant product design will be particularly resilient in the face of external

[7] Our hypothesis primarily drew from the literature on “product architecture,” which has been defined as “(1) the arrangement of [a product’s] functional elements; (2) the mapping from functional elements to physical components; [and] (3) the specification of the interfaces among interacting physical components” (Ulrich 1995). The efficiency of a product is only one of its functional elements (i.e., its performance attributes, following Murmann and Frenken 2006), although it is likely to be a core functional element that is contributed to by many of the components and interfaces of a product (i.e., its technical characteristics, following Murmann and Frenken (2006). A product’s design, however, is the expression of its full architecture, and should be closer to product price.

pressures like regulation. Finally, we approached our seventh question in an exploratory manner that was informed by the product architecture literature rather than by specific hypotheses.

The seven research questions we address in this working paper cluster around three aspects of regulated products – price, quality (in its regulated and unregulated dimensions), and design. These are all attributes of products that can be observed in the marketplace, using a variety of data sources. These product attributes are the result of an innovation process that takes time; as a result, any given observed product attribute is the outcome of a prior product development cycle that encompasses formal R&D as well as other inputs to the innovation process (e.g., learning-by-doing, knowledge external to the firm, etc.).

1.3 Research Design and Previous Retrospective Reviews

Our retrospective review research design harnessed post-regulatory market data on the price, quality, and design of several long-regulated appliances that highly saturate U.S. households, and contrasted these data with expectations regarding the rulemaking process. The five products studied here provide particularly useful consumer services, namely: residential cooling in the case of room air conditioners ("room ACs"); kitchen work in the cases of refrigerators-with-freezers ("refrigerators," for short) and dishwashers; and laundry work in the cases of clothes washers and dryers. These five products are the full set of large household appliances which were subject to federal MEPS informed by DOE rulemaking analysis over the 1990 to 2012 period. This condition limits any potential bias that might arise from selecting outlier products or MEPS for study, constrains variation in the analytical processes employed to inform MEPS and the product markets in which the effects of MEPS can be observed, and ensures that even the most recent MEPS of the studied products has an adequate timeframe for post-regulatory observation.

The specific datasets of product price, quality, and design which we analyzed for this retrospective review were informed by past research on the effectiveness of MEPS, as well as by previous retrospective reviews. Note that retrospective review is a relatively new type of analysis in the body of work on the effectiveness of MEPS. According to a review of the most prominent MEPS cost-effectiveness research, "most studies are *ex ante*," "most of the critiques present theoretical arguments rather than empirical evidence," and "most empirical studies provide evidence at the state or program level, supporting the cost-effectiveness of appliance standards" Gillingham, Newell et al. (2006).

There have been four prominent retrospective reviews of MEPS before this project. The first of these is Nadel (2002), in which the author generally considered regulatory expectations from an *ex post* perspective, observing that efficiency improvements slowed in the period between the introduction of new standards, and suggesting that regulatory cost overestimates might be due to neglect of the potential economies of scale involved in manufacturing MEPS-compliant products. Two more recent retrospective reviews, Dale, Antinori et al. (2009) and Nadel and deLaski (2013), published direct comparisons between *ex ante* rulemaking cost estimates and *ex post* observed product prices (for the 1982-95 period and the 1996-2004 period, respectively).[8] For *ex post* observations, Dale, Antinori et al. (2009) used retail data provided by Sears, while

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[8] Dale, Antinori et al. (2009) is based on an earlier paper presented at the 2002 ACEEE Summer Study. The analysis dates back to 1982 because regulatory impact analyses were published at that time, although the first federal standards did not come into effect until 1987.

Nadel and deLaski (2013) used data from the Current Industrial Reports published by the U.S. Census Bureau (specifically, total domestic manufacturer shipments and total value of those shipments). Both studies found a tendency for regulatory analyses to over-estimate the costs associated with new MEPS, sometimes substantially, and both pointed to unexpected technical change as a likely contributory factor to the cost over-estimation. Finally, Taylor and Fujita (2013) reassessed the accuracy of the 1982-95 *ex ante* expectations documented in Dale, Antinori et al. (2009) under a hypothetical scenario in which those expectations were adjusted using the learning curve-based deflator approach mentioned above, which was adopted by the DOE in its MEPS rulemaking analysis methodology in 2011.[9] The authors showed that retroactive application of the new approach, which was designed to make the rulemaking process more sensitive to broad innovation trends, would have indeed generated more accurate results than the DOE's original methodology.

What sets our project apart from these previous efforts is our focus on the role of technical change in the formation of *ex ante* estimates and *ex post* outcomes. Our *ex ante* data shares with previous studies a sourcing in the relevant regulatory impact analyses in the public rulemaking record, but more uniquely, it also includes documents that reveal stakeholder expectations of regulatory-induced technical change (e.g., the detailed blueprint for MEPS rulemaking analysis known as the 1996 Process Rule,[10] a petition for reconsideration of a 2001 clothes washer rule, etc.).

Meanwhile, our selection of several high resolution *ex post* data sources drew from our understanding that product price, quality, and design are reflections in the market of factors like firm strategic decisions regarding pricing, product offerings, etc., as well as broader economic and technological trends. Our data includes: (1) extensive 2003-2011 U.S. point-of-sale data on appliance models which we helped match to model energy use data (for all but clothes dryers) in order to allow us to construct a monthly panel of model-specific prices, quality characteristics, and market shares; (2) datasets we constructed from third-party appliance testing and surveys that speak to product quality;[11] and (3) a unique dataset we constructed and coded that consists of the features identified in the product manuals of 1,109 clothes washer models sold in the U.S. in 2003-11.[12] We rounded out our understanding of product price, quality, and design by consulting many industry, government, and academic publications. Note that although we were unable to conduct interviews to complement our data analysis, wherever appropriate we integrated the expert insights made public in Mauer, deLaski et al. (2013), which is a sister publication to Nadel and deLaski (2013).

Section 3 provides more detail on how we addressed our research questions using these data. We note here that we tried to ensure analytical replicability, particularly in the interest of fostering

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[9] For more details on this refinement, see the sub-section below on MEPS and Regulatory Analysis Methodology.

[10] See "Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products," 61 FR 36974 (July 15, 1996) 10 CFR 430 Appendix A to Subpart C.

[11] Mauer, deLaski et al. (2013) also used the third-party appliance testing data source we employed.

[12] This set of manuals represented 95% of the 1,165 clothes washer models in our point-of-sale data for which model numbers are identifiable (i.e., "unmasked"). Unmasked clothes washer models account for 29% of units sold in the U.S. over the 2003-11 period.

the systematic construction of a knowledge base for future insight into regulation and technical change.

1.4 Paper Structure and Key Results

This working paper has several sections. The second section grounds our retrospective review in the policy setting of energy efficiency, the market context of our five products, and the regulatory background of the MEPS we assess, including detail on the MEPS rulemaking process. As mentioned above, the third section provides more detail on our research design and the data and analysis techniques we employ. The fourth section presents the results of our analyses, which are organized by comparisons of expected and observed product price, efficiency, quality, and reliability after regulation; the fourth section also presents our exploration of product design, which includes consideration of how product features relate to observed product attributes. The final section discusses how our results relate to our dual purpose of informing future MEPS rulemaking analyses as well as scholarship on regulation and innovation.

In general, our results were consistent with our hypotheses. Regarding product price and quality, we found that purchased products in the U.S. generally surpassed regulatory expectations. *Ex ante* regulatory cost projections significantly over-estimated the majority of model price observations across all efficiency levels. By product, significantly over-estimated observations accounted for: > 95% of room AC observations; 54-66% of refrigerator observations (depending on product type); 42-72% of dishwasher observations; and 50-81% of clothes washer observations.[13] In addition, we found that within-model (i.e., with fixed effects) average prices declined for the refrigerators and clothes washers that U.S. consumers bought over the 2003-11 period. Meanwhile, we found that the monthly sales-weighted average energy use of these products was better than the standard for almost all the data points in our study period, and in the one case for which we had relevant data (clothes washers), we saw that regulatory analyses underestimated how enthusiastically U.S. consumers would buy highly efficient products. These better-than-expected price and efficiency outcomes did not occur to the general detriment of the availability of products with high quality performance attributes other than energy use, despite stakeholder concerns and the revealed concerns of the designers of the MEPS rulemaking process in 1996. Instead, in most cases the statistically significant changes that occurred in third-party quality variables across MEPS events represented improvements in product quality. Similarly, the rate of significant repairs over five years of product ownership declined across our study period, according to third-party surveys.

Although our analyses do not provide causal evidence that MEPS induced innovation to both public and private benefit, as realized in these positive indicators of post-regulatory product price, efficiency, and quality, our results align more with this contention than they do with the contention that regulation hinders innovation. They also suggest that the mechanism by which MEPS could induce innovation relates to product design. The significance of product design – at the level of product architecture – is apparent in our results that show a stronger effect of product design versus product efficiency levels in differentiating the within-model product price declines mentioned above, at least for refrigerators and clothes washers. It is also evident in the rapid evolution of the dominant design of clothes washers in the face of regulation that was initially

[13] Clothes dryers had to be modeled in a different way, but the results were similar.

perceived to be technology-forcing. While this evolution may, in part, reflect the benefits of industry concentration with respect to the resources needed to effectively support innovation, it highlights the importance to rulemaking analysis of improving how expectations are formed regarding the technical possibilities under regulation.

A few insights about product design under regulatory conditions present particularly intriguing avenues for future research. First, there is a high degree of feature correlation in clothes washers that may occur in other appliances as well, either for technical and/or strategic reasons. If this holds true, it hints at a need to refine the rulemaking analysis approach to assessing design options that could potentially facilitate compliance with future MEPS, which tends to focus on individual options or a small set of option combinations. Future research on the engineering and business rationales for various feature combinations may be useful in supporting any potential analytical refinement. Second, many technical features of clothes washers appear to contribute both to product energy use and to unregulated aspects of product quality; this may also hold true for other appliances. One implication of this is that it may be quite difficult for the rulemaking process to identify, *ex ante*, the technical features that can enhance energy efficiency. When this result is combined with the result that unregulated dimensions of product quality often improved for clothes washers across MEPS events, according to third-party testing, it implies that it may also be difficult to predict, ex ante, whether features that are expected to enhance energy efficiency in future products will be commercially viable, as called for in the current rulemaking process. It also helps to posit a mechanism by which regulatory-induced innovation might be expected to occur more frequently in certain products or areas of regulation than others. Perhaps regulatory constraints on product energy use – a product attribute that many technical features contribute to – could not only reduce the search costs involved in designing low-energy products, but also stimulate cascading problem-solving across technical features that can potentially enhance product quality. This may not hold in other regulatory areas in which the regulatory constraint primarily addresses an isolated technical feature of a product. This insight merits further investigation as a potentially important contribution to the scholarship on regulation and innovation with practical application to future rulemaking analyses. Third, clothes washer features have relatively stronger correlations with product efficiency, rather than product price. When combined with the finding that product architecture better differentiates within-model product price trends than product efficiency, it implies that price projections based on technical features may have more error than price projections based at the level of product architecture. In future work, it would be helpful to know if this is consistent for products other than clothes washers.

2 Policy, Market, and Regulatory Context

2.1 Energy Policy Context

Reducing the energy intensity of the U.S. economy has been both a policy objective and a trend for many years, and it is likely to be the subject of ongoing regulatory attention due to economic, environmental, and national security policy goals (for more on U.S. energy intensity trends, see, e.g., Wing 2008). Energy is a secondary factor of production; more efficient energy use can contribute to productivity and economic growth (Warr and Ayres 2010), support electricity system reliability, and reduce the need for new energy supplies with their concomitant environmental impacts, including greenhouse gas emissions. For consumers, reducing the energy required to enjoy everyday goods and services is beneficial for all income groups, although the

poor particularly benefit, given the inelasticity of their demand. The most recent U.S. residential survey data show that those at 100% below the poverty line spend, on average, 84% as much on residential energy as the average U.S. household (author calculations from U.S. EIA (2013)).

The various energy-using sectors of the economy are the target of a suite of federal policy instruments. In the U.S., the traditional breakdown of these sectors, with their respective share of energy consumption (according to 2012 data), is as follows: residential buildings (22%), commercial buildings (19%), industry (31%), and transportation (28%) (Kelso 2012). Relevant U.S. federal policies include: energy building codes; energy use information programs; minimum efficiency performance standards for appliances and other equipment; a voluntary labeling program for appliances and other equipment that excel in their energy efficiency; public sector procurement of efficient appliances and other equipment; vehicle fuel economy standards; gasoline taxes; efficiency-promoting financial and technical assistance; and R&D support of improved efficiency.

Within this policy context, the regulatory area we study is minimum efficiency performance standards (MEPS) for appliances and other energy-using products. The basic concept underlying MEPS is grounded in the observation that for any energy-using product offered for sale in the U.S., different product models will consume different amounts of energy in the course of their operations; this can be plotted against market share. When a new MEPS is established, it establishes a threshold level of energy efficiency and requires that after a certain period of time, all new product models must meet that threshold. In essence, MEPS remove from the market those products that do not meet the threshold. Note that conventional engineering forecasts in the energy efficiency literature assume a connection between more efficient products and more expensive products (Ellis, Jollands et al. 2007); more expensive products also tend to be those with higher-end features (Greening, Sanstad et al. 1997).

Figure 1 presents several trends regarding energy-using products in U.S. households that contextualize the significant energy efficiency improvements observed in the energy use of appliances and other equipment over 30+ years. The numbers under the left-hand panel of Figure 1 show that total household energy use has held almost constant since 1978 despite a growing U.S. population. Meanwhile, the left-hand panel figure shows the increasing share of household energy use attributed to appliances, electronics, and lighting, as opposed to other household uses of energy.[14] The right-hand panel of Figure 1 shows the increasing saturation of U.S. households with specific energy-using products since 1980. Several factors can potentially explain these trends, including: technical changes in the products offered for sale in the U.S.; changing consumer purchases amongst the different product models offered for sale; and the changing use of products once they are installed in households. MEPS are the federal policy instrument that has offered the most long-standing and direct support for the first of these factors.

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[14] Although the reduced role of space heating as a household use of energy over time partially reflects U.S. demographic shifts from colder to warmer areas of the country, this does not fully explain the percentage shift in household energy use displayed in the left-hand panel of the figure.

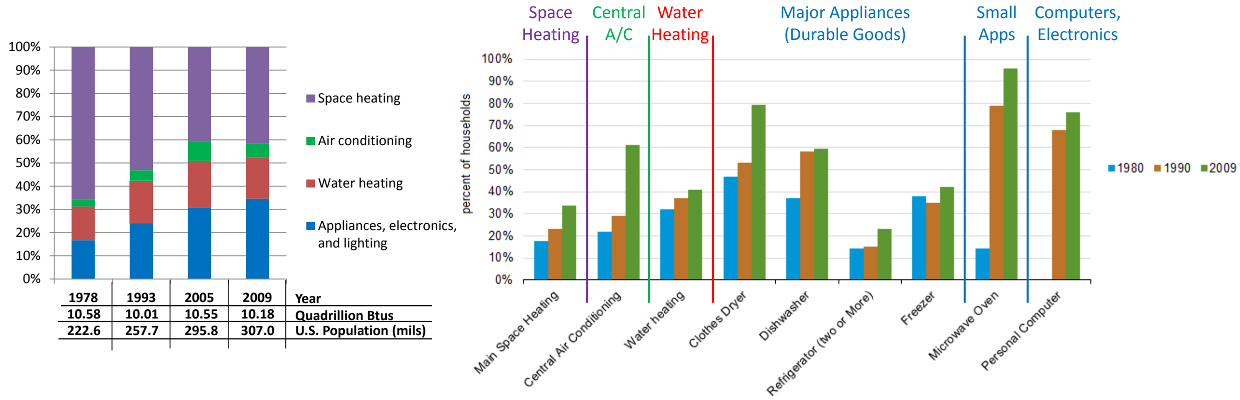
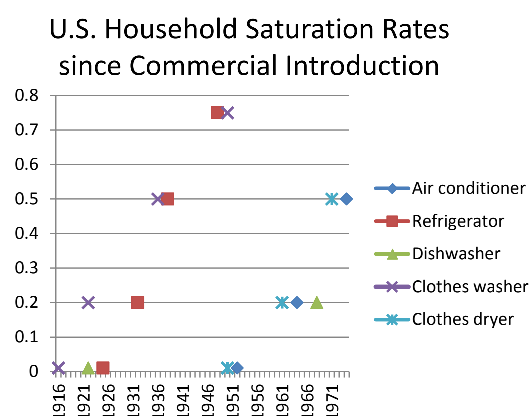


Figure 1: U.S. household energy use over time.
Notes: The first panel shows the changing percentage of U.S. residential energy use by type of use from 1978-2009. The table below the graph provides details on two interesting trends over this period: a growing population and generally flat overall residential energy use. The second panel shows the diffusion throughout U.S. households from 1980-2009 of specific energy-using equipment. This panel provides insight into the relative importance of the regulation of domestic appliances with respect to their energy use. Source: Authors' calculations from U.S. EIA (2015)

2.2 Market Context

Figure 2 characterizes the growth of the U.S. market over the last 100 years for the five products studied in this project (the "case appliances," i.e., room air conditioners, refrigerator/freezers, dishwashers, clothes washers, and clothes dryers). The left-hand panel of Figure 2 highlights the points in time that each appliance reached U.S. household saturation milestones of 20%, 50%, and 75% after their initial commercial introduction, while the accompanying table presents their levels of household saturation in 2005, according to the DOE.[15] The accompanying table presents the 2005 saturation of U.S. households by the five products we study, according to the DOE. Note that almost a fifth of U.S. households had two or more refrigerators by 2005, while one-tenth of households at 100% below the poverty line had two or more refrigerators by 2009 (U.S. EIA 2013).



U.S. Household Saturation in 2005

Appliance	Saturation
Room air conditioners	25.2%
Refrigerator/freezers (1)	99%
Refrigerator/freezers (2 or more)	19.2%
Dishwashers	60.5%
Clothes washers	93%
Clothes dryers	81.1%

Figure 2: Saturation of appliances in U.S. market.

[15] The "air conditioner" series in the left-hand panel of Figure 2 does not distinguish between central and room AC.

Source: Data from Bowden and Offer (1994) and author compilation from Technical Support Documents (TSDs) for the MEPS for room ACs and clothes dryers, refrigerator/freezers, dishwashers, and clothes washers. Note that the "air conditioner" data in the figure includes central air conditioners as well as room ACs.

With the possible exception of room ACs, the case appliances are major appliances which can be characterized with several descriptors. They are "durable goods" which deliver utility over a long period of time at price points that make their purchase significant to most consumers. In the U.S. they are generally considered an inherent part of a unit of real estate offered for either sale or rent, partially because they can require specialized connections to the electrical, natural gas, plumbing, and ventilation systems of a building. For many years, most major household appliances were available in one color – white – due to the nature of the enamel-coated sheet steel they were made with; this led to the frequent reference to major appliances as "white goods."[16] Major household appliances can also be considered "experience goods," in a sense, whose price and/or quality is difficult to observe in advance of consumption. There are, however, aspects of the industry that keep the pressure on appliances to be more of a "search good" whose price and/or quality can be evaluated before purchase. For example, the long-standing presence of third party analysis on appliance quality from sources like *Consumer Reports* magazine, which started in 1936, has been useful in pre-purchase evaluation, and online information has further facilitated substitution and price competition.

Table 2 presents the leading brands of the case appliances, according to U.S. point-of-sale data for 2003-2011, as gathered by the NPD Group. The table is indicative of the high degree of concentration in the U.S. industry today, after more than thirty years of significant mergers and acquisitions. The dominant manufacturers are large, multinational companies "with high fixed and exit costs resulting from their substantial manufacturing and assembly plants" (MarketLine 2014). Despite the concentration in this market,[17] large manufacturers are considered very competitive, with intense rivalry in developed markets in which they compete for smaller demand, and less intense rivalry in other nations where they can grow without interfering as greatly with rivals' market share (ibid.). Large manufacturers often have considerable assets that enable them to "forward integrate, primarily via online channels, and invest heavily in promotion and advertising" that is helping to decrease their reliance on retailers for distribution (ibid.).

Table 2: U.S. market share of the top five manufacturers of each case appliance, 2003-11.

	Room ACs	**Refrigerators**	**Dishwashers**	**Clothes Washers**	**Clothes Dryers**
Whirlpool*	12.5%	24.2%	26.8%	34.0%	34.7%
GE		12.3%	14.8%	16.9%	16.7%
Maytag*			9.6%	12.1%	12.8%
LG				12.1%	10.6%
Frigidaire	34.2%	22.5%	23.3%		
Haier	23.2%	7.3%			

[16] Confusingly, this term can also be used to refer to household linens.

[17] If the market share of Whirlpool is added together with that of its subsidiaries, Maytag and Kitchen-Aid, Whirlpool can be seen to have a particularly large proportion of the market for dishwashers, clothes washers, and clothes dryers.

Samsung	6.7%	7.5%		7.2%	7.9%
KitchenAid*			8.7%		
Friedrich	8.7%				
Total	**85.3%**	**73.8%**	**83.1%**	**82.3%**	**82.7%**

Source: Author calculations from NPD Group data. Notes: Market shares do not include retail-specific brands like Kenmore. * = subsidiaries of Whirlpool (i.e., Maytag and KitchenAid)

Retailers remain the dominant distribution channel in the appliance industry, however, and the larger ones are able to bargain on price across manufacturers for the best positions on their limited floor space.[18] The universe of retailers for new appliances consists of the well-known, such as large chain department stores (e.g., Sears, Kohls), home improvement stores (e.g., Home Depot, Lowe's), discount stores (e.g., Wal-Mart, K-Mart), and consumer electronics stores (e.g., Best Buy), as well as less well-known independent appliance stores. There is also growing online competition (e.g., Amazon) that is not as constrained by the floor space occupied by appliances, which tend to have low stock turnover. Meanwhile, with much of the market driven by appliance replacement, the growth of online platforms like Craigslist, E-Bay, and Freecycle is facilitating a strengthening secondary appliance market (MarketLine 2014).

2.3 Federal Efficiency Policy and Case Appliances

In this section we sketch the federal policy context for the five case appliances. This context includes a suite of federal policy tools, including test procedures, mandatory energy use labeling, minimum efficiency performance standards (MEPS), and voluntary endorsement labeling in the form of ENERGY STAR (EStar) specifications. It also includes the unique and complex U.S. system of government, which is characterized by separation of powers, strong interest groups, and tension between federal powers and states' rights. Although all of these instruments and institutions helped shape appliance efficiency regulation, we do not include a full treatment here of each of them.

This section has two parts. In the first part, we discuss in some detail the chronology of federal regulatory events for the five case appliances, as well as provide important background information on the MEPS rulemaking analysis process. In the second part, we detail some of the developments in the EStar program, particularly those with relevance to the case appliances.

MEPS and Regulatory Analysis Methodology

MEPS Chronology for Five Case Appliances

As detailed in Appendix A, the origins of U.S. federal MEPS trace back to European MEPS in the early 1960s. The first U.S. interest in MEPS is generally considered to date back to state-level reactions to the northeast blackout of 1965. California played a pioneering role in the establishment of MEPS, bringing the State's first mandatory MEPS into effect in 1977. Federal attention to MEPS began in the mid-1970s with a focus on consumer pocketbook issues at a time of high energy prices. The establishment of federal MEPS by 1980 was first called for in the 1975 Energy Policy and Conservation Act (EPCA, Pub. L. No. 94-163).

EPCA, which encompassed many aspects of energy policy, introduced three of the four main features of U.S. federal energy efficiency policies for appliances and other equipment which

[18] Large appliance retailers tend to sell a diverse array of products in addition to appliances, which limits floor space.

continue today: test procedures, energy consumption labeling, and MEPS. EPCA directed the head of the then Federal Energy Administration (now the U.S. Department of Energy, or "DOE") to direct the National Bureau of Standards (now the National Institute of Standards and Technology) to develop test procedures that would determine "estimated annual operating costs of covered products" of specified types, as well as "at least one other useful measure of energy consumption of such products which the Administrator determines is likely to assist consumers in making purchasing decisions." For EPCA covered products, test results were to be disclosed within 90 days or the product could not be marketed in the U.S. In addition, assuming it was "technologically and economically feasible," within 180 days of the test, covered products would be subject to labeling of estimated annual operating costs, according to rules determined by the Federal Trade Commission (in the precursor to today's "Energy Guide" program).[19]

The five case appliances were all "covered products" under the 1975 EPCA (see Section 322(a) paragraphs (1-10)). This meant that they were to be subject not only to test procedures, but also to "any requirement which the Administrator determines is necessary to assure that each covered product … meets the required minimum level of energy efficiency specified." For the covered products we study, EPCA called for the Administrator to, within 180 days of the act's enactment, "by rule":

> "prescribe an energy efficiency improvement target for each type of covered product … designed so that, if met, the aggregate energy efficiency of covered products … which are manufactured in calendar year 1980 will exceed the aggregate energy efficiency achieved by products of all such types manufactured in calendar year 1972 by a percentage which is the maximum percentage improvement which the Administrator determines is economically and technologically feasible, but which in any case is not less than 20 percent."

EPCA made it unlawful for any "manufacturer or private labeler" to "distribute in commerce" any new covered product not in compliance with labeling or with "an applicable energy efficiency standard," as well as to fail to permit access to required records. EPCA was explicitly designed to "supersede" (or preempt) any state regulation that:

> "may now or hereafter provide for…(1) the disclosure of information with respect to any measure of energy consumption of any covered product…or (2) any energy efficiency standard or similar requirement with respect to energy efficiency or energy use of a covered product,"

as long as certain conditions held. These conditions were: if an applicable federal rule existed; and if a state regulation required a different test procedure, different information disclosure, or a different standard. Note that this was particularly expected to apply to such products as room air conditioners, refrigerators, and gas clothes dryers, which were all subject to early California regulation.[20]

Applicable federal rules, however, did not come into existence by 1980, as was first called for in the 1975 EPCA. Federal MEPS took some time to get underway for a variety of reasons, including institutional ones. The requirements in EPCA 1975 were amended in the National Energy Conservation Policy Act (NECPA) of 1978 (Pub. L. No. 95-619), as a result of a variety of developments including delays in establishing test procedures and the reorganization of the

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[19] Although authorized in 1975, the first labeling rule was established in 1979.

[20] The first California appliance standards were established in 1976 for refrigerators and room air conditioners (both effective for certain products by 1977), with gas clothes dryers established in 1977 (effective 1979). Note that clothes washers and dishwashers were not regulated by California MEPS until 2002.

Federal Energy Administration (FEA) into the Department of Energy (DOE). NECPA also provided new details on the rulemaking process, altered the rules regarding state preemption and introduced a prioritization of the major covered products (e.g., room air conditioners, refrigerators, and gas clothes dryers were higher priorities than clothes washers or dishwashers). According to Nadel (2002), the DOE proposed the first MEPS rules for a variety of products just before the Carter Administration left office. The first MEPS were not finalized until 1987, however, with the passage of the National Appliance Energy Conservation Act (Pub. L. No. 100-12). Some of the reasons for the delay are detailed in Appendix A.

When the first federal MEPS were finally established in 1987 as part of the NAECA legislation, all five case appliances were included. The regulatory approach for each product differed slightly, however, based on: (1) whether a measure of energy efficiency performance was used or whether a technical option was proscribed instead; and (2) how "product classes" of a given covered appliance type were established (note that provisions on this latter topic date back to EPCA and NECPA).[21] In NAECA, room air conditioner standards were to come into effect on January 1, 1990, and were to be based on different "energy efficiency ratios" depending on whether the air conditioner model had reverse cycles and/or louvered sides.[22] Similarly, refrigerator-freezers were regulated in NAECA with a January 1, 1990 effective date, based on different allowable "maximum energy use" rates (calculated in kWh/year) depending on adjusted volume (as detailed in relevant test procedures), freezer location (e.g., top-mount, side-mount, bottom-mount), type of defrost (e.g. manual, partial, or automatic), and incorporation of through-the door (TTD) ice service (note that this feature was only considered for top-mount and side-mount refrigerators). But unlike room ACs and refrigerators, which were regulated in NAECA using an efficiency "performance-based" approach, dishwashers, clothes washers, and clothes dryers were regulated using a "technology-based" approach. In NAECA, effective January 1, 1988, dishwashers "shall be equipped with an option to dry without heat," clothes washer rinse cycles "shall include an unheated water option, but may have a heated water rinse option," and gas clothes dryers "shall not be equipped with a constant burning pilot."

NAECA was implemented with the requirement of two subsequent rulemakings cycles for each product, in order to determine if more stringent standards were justified. After the passage of NAECA in 1987, the five case appliances have had unique regulatory schedules, as detailed briefly below.

Room ACs

For room ACs, the first of the two rulemakings required by NEACA occurred on September 24, 1997 and set a standard effective for products manufactured on or after October 1, 2000. The amended standards consisted of a minimum energy efficiency ratio (EER), expressed as cooling capacity in British thermal units (Btu) per hour divided by electrical input power in watts. The standards varied based on the size of the room AC, whether it had louvered sides and a heating cycle, and whether it was sold for casement installations. The second rulemaking was delayed as a result of the 1995-96 Department of Energy (DOE) review of the process for developing

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[21] Classes in NAECA are separated according to the criteria of the "(1) type of energy used, or (2) capacity or other performance-related features such as those that provide utility to the consumer or others" (Nadel and Goldstein 1996).

[22] Louvered sides extend from a room AC to position it in a window. Models without louvered sides are placed in built-in wall sleeves, giving rise to the characterization as "built-in" models.

appliance MEPS, which suspended several rulemakings indefinitely (see “Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products,” 61 FR 36974 (July 15, 1996) 10 CFR 430 Appendix A to Subpart C, or the “Process Rule”; see below in the clothes dryer discussion and in more detail in the section on Regulatory Impact Analysis Methodology). On October 9, 2007, DOE reinitiated the NAECA second rulemaking activity for room ACs (accompanied by clothes dryers) and finalized it in 2011. It came into effect on June 1, 2014, and was supported by a consensus agreement (see the “Agreement on Minimum Federal Efficiency Standards, Smart Appliances, Federal Incentives and Related Matters for Specified Appliances’’ (the ‘‘Joint Petition’’ or “Consensus Agreement”)).

Refrigerators

For refrigerators, the first of the two rulemakings required by NAECA occurred in 1989 and set a standard effective for products manufactured on or after January 1, 1993.[23] DOE completed the second NAECA rulemaking with a final rule on April 28, 1997 and an effective date of July 1, 2001. In 2004, stakeholders petitioned the DOE requesting a new rulemaking to amend refrigerator MEPS. The petition was granted in 2005 and the DOE published a report containing a limited set of relevant analyses on potential energy-savings and economic-benefits associated with a new refrigerator MEPS, but ultimately the agency prioritized other product MEPS in its fiscal year 2006 regulatory schedule-setting process. In another development, in 2005, DOE’s Office of Hearings and Appeals granted five exceptions to MEPS for refrigerator-freezer products with bottom-mounted freezer and through-the-door (TTD) ice service on the basis that there was no appropriately-defined product category for such refrigerator-freezers (the existing standard covered bottom-mount freezer products that lacked TTD ice-service).[24] With the passage of the Energy Independence and Security Act (EISA) of 2007, the DOE was required to publish a final rule no later than December 31, 2010 to determine whether to amend the standards in effect for refrigerators manufactured on or after January 1, 2014. Today’s MEPS are an amended standard, issued September 15, 2011, for refrigerators manufactured after September 15, 2014. Note that additional sub-product classes of refrigerator with bottom-mounted freezers were added to the 2010 final rule.

Dishwashers

For dishwashers, the first of the two rulemakings required by NAECA occurred in 1991 and came into effect on May 14, 1994. This set of MEPS regulated dishwashers according to a performance metric known as an “energy factor,” which was calculated in cycles/kWh. The second rule-making was delayed by the Process Rule (see above under Room ACs) and finally occurred as a result of EISA 2007. The revised standard, effective January 1, 2010, involved a changed energy efficiency metric of “maximum allowable energy use per year,” as calculated in

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[23] Subsequently, DOE determined that new standards for some of the refrigerator product classes were based on incomplete data and incorrect analysis, and therefore required revision. As a result, DOE published a correction that amended the new standards for three product classes: (1) refrigerators and refrigerator-freezers with manual defrost, (2) refrigerator-freezers—automatic defrost with bottom-mounted freezer but without through-the-door (TTD) ice service, and (3) chest freezers and all other freezers.

[24] The exceptions were received by Maytag Corporation, LG Electronics, Inc., Samsung Electronics, Electrolux Home Products, and BSH Home Appliances Corporation. The rationale behind these exceptions was that TTD products use more energy for several reasons, including: added heat loss through the door to the fresh-food space, the need for lower temperatures in the space reserved in the fresh food compartment in order to store ice, and the energy consumed by the fan used to cool the space used for ice production and storage.

kWh per year. In 2012, a direct final rule for residential dishwashers was published by DOE, as supported through the Joint Petition consensus agreement (see above under room ACs). It came into effect in 2013.

Clothes Washers

For clothes washers, the first of the two rulemakings required by NAECA occurred in 1991 and came into effect in 1994. It introduced a unit of performance measurement known as an "energy factor" (EF), which was expressed as cubic feet of washer capacity-per-kilowatt-hour-per-cycle of the clothes washer. This factor incorporates both the energy consumed by the machine as well as by the act of heating the water for washing (Mauer, DeLaski et al. 2013). The 1991 standards applied only to top-loading clothes washers; front-loading machines represented less than 2% of the U.S. market, although they were very widely adopted in Europe by that point in time.

DOE completed the second NAECA rulemaking with a final rule in 2001, which came into effect in two stages (or "tiers") in 2004 and 2007. The performance metric for the 2001 standards was the "modified energy factor" (MEF), which incorporated a new equation element tied to clothes dryer energy consumption in addition to the EF's elements associated with machine and water heater energy consumption. This new equation element was the "remaining moisture content" of the clothes at the end of the wash cycle (Mauer, DeLaski et al. 2013). The 2001 standards applied to both top-loading and front-loading clothes washers, which had significantly penetrated the U.S. market by that point in time. It was generally expected in the rulemaking, however, that the second tier of that MEPS, to become effective in 2007, would be technology-forcing, eliminating top-loading clothes washers – the dominant design in the U.S. – from the U. S. market.[25] A petition to override the 2001 clothes washer MEPS illustrates the concern. In its letter to the DOE Secretary in support of the petition, the Competitive Enterprise Institute (CEI) quotes the 2001 Final Rule as saying that "the original manufacturer data assumed that all clothes washers at … [the 2007 standard] would be [front-loading] horizontal-axis machines," and cites specific tables in the rule's Technical Support Document (TSD) in which the "DOE assumes that top loaders will no longer be sold once the 2007 standard takes effect" (Competitive Enterprise Institute 2001). The comment stated that "any market shift from 'tried and true' models [top-loading machines] to unproven ones is very likely to result in increased maintenance costs" (ibid.) The CEI's reliability concern was not limited only to what they considered the standards-favorite substitute of front-loading machines, however. In acknowledging that the Final Rule contains a "change in position" – that "manufacturers have already begun offering top-loading, vertical-axis clothes washers that would meet the 2007 standard" – the CEI comment calls for evidence "that these new ultra-efficient top-loading models provide all the performance characteristics consumers demand," as new information indicated to the CEI that they "are not problem-free."

Under a provision dating back to NECPA, in 2006 California submitted a petition for a waiver to establish water conservation standards for residential clothes washers. The petition was denied by the DOE on December 28, 2006, although the denial was subsequently overturned. Note that EISA 2007 added a water factor performance metric to federal clothes washer MEPS, consistent with the waiver request, which was to come into effect on January 1, 2011. In 2012, the DOE adopted new clothes washer standards, to come into effect in 2015 and in 2018, in a development

[25] See footnote **Error! Bookmark not defined.** for more information on dominant design.

that was supported through the Joint Petition consensus agreement (see above under room ACs). In the 2015 and 2018 clothes washer MEPS, the performance metrics are the "integrated modified energy factor" and the "integrated water factor."

Clothes Dryers

For clothes dryers, the first of the two rulemakings required by NAECA occurred in 1991 and resulted in a rule that came into effect on May 14, 1994. This rule introduced a unit of performance measurement known as an "energy factor" (EF), which was expressed in pounds of clothing-load per kWh. DOE initiated the second NAECA rulemaking by publishing an advance notice of proposed rulemaking on November 14, 1994, but the Process Rule (see above under Room ACs and in more detail below in the section on Regulatory Impact Analysis Methodology) suspended further action. On October 9, 2007, DOE reinitiated the second NAECA rulemaking activity for clothes dryers (accompanying room ACs). A direct final rule, published on April 21, 2011 and supported by the Joint Petition consensus agreement (see above under room ACs), fulfilled the second of the NAECA rulemakings. It came into effect on January 1, 2015.

Regulatory Impact Analysis Methodology

The original 1975 EPCA called for the Federal Energy Agency (which merged into the newly established DOE in 1977) to set efficiency targets that are "the maximum percentage improvement" that is "technologically feasible and economically justified." The need to interpret these criteria for standard-setting has translated into an evolving set of analytical approaches that have shaped MEPS in important ways. Their evolution also provides our project with important information on regulatory expectations regarding technology cost and quality.

Over the first two decades that followed the passage of the original 1975 EPCA (which has so far been amended in 1978, 1987, 1988, 1992, 1998, 2005, 2007, 2011, and 2012), the most significant event in the evolution of rulemaking analysis was the 1996 Process Rule (see "Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products," 61 FR 36974 (July 15, 1996) 10 CFR 430 Appendix A to Subpart C). Besides suspending several rulemakings indefinitely, as mentioned above, the Process Rule stipulated "in considerable detail" the "procedures, interpretations, and policies for the development of new or revised" MEPS. Note that the Process Rule allows some nonconformity with its requirements, providing that the DOE provides interested parties "with notice of the deviation and an explanation." According to the current DOE website, although the Process Rule remains in effect today, some elements have indeed been "superseded or supplemented by more recent practices."

We do not attempt to provide a comprehensive overview here of the fourteen sections that comprise the twelve-page Process Rule. Instead, we focus our description on the parts of the Process Rule that are most relevant to understanding the expectations of regulators and other interested parties regarding the costs, quality, and design of regulated products. We particularly focus here on one section of the Process Rule: Section 4, which describes the procedure for developing efficiency standards and the factors to be considered in that process. For some steps detailed in Section 4 which have particular relevance to expectations of product cost, quality, and design, we exceed the boundaries of the Section 4 language, either incorporating material from other Process Rule sections or from other sources. Appendix A contains additional material on the Process Rule, including its objectives (Section 1) and extra detail on various aspects of the MEPS rulemaking process.

Section 4 of the Process Rule, titled the "Process for Developing Efficiency Standards and Factors to be Considered," establishes six steps to MEPS rulemaking activity. These steps are: (a) "identifying and screening design options;" (b) "engineering analysis of design options and selection of candidate standard levels;" (c) "advance notice of proposed rulemaking" (ANOPR); (d) "analysis of impacts and selection of proposed standard level;" (e) "notice of proposed rulemaking" (NOPR); and (f) "notice of final rulemaking." The expectations regarding the cost, quality, and design of regulated products are interwoven throughout these steps, although some steps have more relevance than others. We focus here on steps (a), (b), and (d), then summarize some of what the other MEPS rulemaking steps reveal about regulatory expectations.

In the first step of the rulemaking process, (a) "identifying and screening design options," the DOE initiates a rulemaking and works with outside experts and other interested parties to identify "product categories" and "design options." The initial list of "candidate design options" is supposed to "encompass all those technologies considered to be technologically feasible." Various candidate design options are then either screened out or allowed to be analyzed further in other steps of the multi-year rulemaking process. According to Section 4 and Section 5 of the Process Rule, design options must: (i) be "technologically feasible," which is defined as "incorporated in commercial products or in working prototypes"; (ii) be practical for mass production in commercial products, with reliable installation and servicing "on the scale necessary to serve the relevant market at the time of the effective date of the standard"; (iii) not have adverse impacts on product utility to significant subgroups of consumers or make unavailable any covered product type "with performance characteristics (including reliability), features, sizes, capacities, and volumes that are substantially the same as products generally available in the U.S."; and (iv) not have adverse impacts on health and safety. The reasons for discarding any design option are to be "fully documented and published as part of the ANOPR."

In the second step in the rulemaking process, (b) "engineering analysis of design options and selection of candidate standard levels," the DOE "performs the engineering analysis and the benefit/cost analysis" on the candidate design options and selects candidate standard levels which will be published in a Technical Support Document (TSD) to accompany the ANOPR. The engineering analysis procedure has several parts which are described in both Section 4 and Section 9 of the Process Rule, while the selection of candidate standard levels is described in both Section 4 and Section 5. The engineering analysis procedure begins with DOE, in consultation with outside experts, identifying one or more relevant analytical methods. The "DOE and its contractor" then perform engineering analysis and life-cycle cost analyses of the design options which are reviewed and then potentially revised; new information developed in this process can be used to screen out additional design options on the basis of the same factors discussed above. The main "purpose of the engineering analysis is to develop the relationship between efficiency and cost" of the product. Although "ranges and uncertainties" of cost and efficiency performance are established in the engineering analysis and "carried forward in subsequent analyses," efforts are made "to minimize uncertainties by using measures such as test data or component or material supplier information where available." Additional information can include product tear-down and laboratory testing. After assessing each design option, engineering models "predict the efficiency impact of any one or combination of design options

on the product." This requires establishing "a base case configuration or starting point," "as well as the order and combination/blending of the design options to be evaluated."[26]

The procedure for selecting candidate standard levels begins by taking the results of the engineering analysis and the life-cycle cost analysis of the candidate design options and then eliminating certain design options. The eliminated design options are discarded either because they "have payback periods that exceed the average life of the product or which cause life-cycle cost increases relative to the base case, using typical fuel costs, usage, and discount rates" or because new information shows that they are subject to screening analysis criteria. Once these design options are eliminated, candidate standard levels are determined from a range of design options that typically includes "the most energy efficient combination of design options; the combination of design options with the lowest life-cycle cost; and a combination of design options with a payback period of not more than three years." Other candidate standard levels may be selected if they "incorporate noteworthy technologies or fill in large gaps between efficiency levels of other candidate standard levels." The candidate standard levels are identified in the ANOPR and put forward for public comment, hearing, revisions, and further impact analysis.

The fourth step of the rulemaking process, (d) "analysis of impacts and selection of proposed standard levels," involves detailed "economic analyses" of the candidate standard levels, the results of which feed into the selection of a proposed standard to be published in the NOPR for final comments, revision, and the selection of the final product standard. The economic analyses begin with identification of issues for analysis and analytical methods, in consultation with interested parties and outside experts. The nine factors to be considered in selecting a proposed standard, which are in many cases the results of the required economic analyses, are: (i) "consensus stakeholder recommendations"; (ii) "impacts on manufacturers"; (iii) "impacts on consumers"; (iv) "impacts on competition"; (v) "impacts on utilities"; (vi) "national energy, economic, and employment impacts"; (vii) "impacts on the environment and energy security"; (viii) "impacts of non-regulatory approaches"; and (ix) "new information related to the factors used for screening design options." Appendix A provides a considerable amount of detail from the Process Rule that state what must be considered in assessing many of these factors. Note that these nine factors are not the sole criteria that inform the selection of the proposed standard; instead, they are considered jointly with several other policies on the selection of standards, as articulated in Section 5 and detailed in Appendix A.

Before concluding this description of the MEPS rulemaking process and then touching on what it reveals about regulatory expectations, we provide a bit more background here on two of the nine factors considered in selecting the proposed standard. We do this because we will refer back to the underlying analyses for these selection factors later in the working paper. The two selection

[26] According to Taylor and Fujita (2013), three approaches are currently used to determine cost-efficiency relationships in the engineering analysis: (1) a design-option approach, which calculates the incremental costs of adding specific design options to a baseline model; (2) an efficiency level approach, which calculates the relative costs of achieving increases in energy efficiency levels without regard to the particular design options involved; and/or (3) a reverse engineering or cost-assessment approach, which involves a "bottom-up" manufacturing cost assessment based on a detailed bill of materials derived from teardowns of the product being analyzed. The ultimate methodology is selected on a product-by-product basis.

factors of interest here are the "impacts on consumers" and the "national energy, economic, and employment impacts."

First, according to Section 4 of the Process Rule, consideration of the consumer impacts of candidate standard levels should include:

> "impacts based on national average energy prices and energy usage; impacts on subgroups of consumers based on major regional differences in usage or energy prices and significant variations in installation costs or performance; sensitivity analyses using high and low discount rates and high and low energy price forecasts; changes to product utility and other impacts of likely concern to all or some consumers…; estimated life-cycle cost with sensitivity analysis; and consideration of the increased first cost to consumers and the time required for energy cost savings to pay back these first costs."

Section 11 of the Process Rule provides additional detail, including establishing that a three year or more "payback period of a potential standard" will set off a requirement for the DOE to assess the likely impacts of the candidate standard level on "low-income households, product sales, and fuel switching." In MEPS rulemakings today, one of the economic impact analyses that contributes to determining the impacts of standards on consumers is known as the life-cycle cost and payback period analysis (LCC). The inputs to the LCC include the engineering analysis outputs of efficiency levels for different product classes, which are tied to manufacturer production costs (as derived with industry cooperation) and then transformed through the "energy use analysis" and the "markup analysis" to generate projected product prices at each efficiency level.[27] In the LCC, which has a five-year time horizon, the DOE determines single-period consumer cost in terms of any increase in the product price and single period consumer benefit in terms of any operating cost savings from reduced product energy use. The LCC does this by adding the initial product price and operating cost data for each efficiency level as assessed over the period of a product's lifetime, starting from the effective year of the standards.

Second, Section 4 of the Process Rule states that consideration of the "national energy, economic, and employment impacts" of candidate standard levels should include: "estimated energy savings by fuel type; estimated net present value of benefits to all consumers; and estimates of the direct and indirect impacts on employment by appliance manufacturers, relevant service industries, energy suppliers, and the economy in general." In MEPS rulemakings today, one of the major economic impact analyses that contributes to this consideration is known as the national impact analysis (NIA). In the NIA, the DOE determines the cumulative costs and cumulative benefits of the various efficiency levels over a thirty-year forecast period. Two of the variables that influence this determination are projected product shipments and the likely market saturation of each product class over the thirty-year period following the likely effective date of the standard.

Two relatively recent refinements to the LCC and NIA are important to highlight here. First, there is a methodological refinement, now known as the "price-learning adjustment," which was introduced into the MEPS rulemaking process in 2011 and retrospectively analyzed in Taylor

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[27] In the "energy use analysis," the DOE estimates the operating costs of products at each efficiency level by leveraging consumer energy use data and unit energy prices. In the "markup analysis," the DOE estimates product purchase price by applying markups and sales tax to the manufacturing production cost, depending on the type of distribution channels through which consumers obtain products.

and Fujita (2013), as mentioned in section 1.3.[28] The price-learning adjustment originated with two insights discussed in Desroches, Garbesi et al. (2013): (a) the pattern of MEPS rulemaking analysis overestimates documented in the Dale, Antinori et al. (2009) retrospective review mentioned in section 1.3; and (b) the realization that by holding product price at its initial level in the LCC and NIA over their respective periods of analysis, the DOE was not being consistent with the downward price trends that have regularly been observed for many covered products over the decades. The LCC and NIA refinement that grew from these two insights fitted the traditional functional form of an organizational learning curve to price and quantity data for a covered product in order to use the resulting parameters to adjust both the baseline and efficiency level product prices employed in the LCC and the NIA. Note that the price data used in calculating the price-learning adjustment is long-standing – the Producer Price Index, which has long been compiled by the U.S. Bureau of Labor Statistics – but can also be highly aggregate (e.g., the "laundry products" series does not distinguish between products such as clothes washers and dryers). These data therefore do not allow for a differentiated adjustment in the LCC and NIA according to product class or efficiency level.

The second refinement to the LCC and NIA we highlight is a recent change to a general assumption that the shipments of products made obsolete by a new MEPS would simply "roll-up" to the point where they just meet the new standard. Starting in 2014, the DOE began to allow analyses to redistribute these shipments across product classes and candidate standard levels, based on models of the impact of up-front purchase costs and operating costs on historic choice probabilities. This refinement is known as the "consumer-choice" analysis.

There are several aspects of the MEPS rulemaking analysis methodology that appear problematic regarding regulatory expectations of technical change. First, the initial criteria for "technologically feasible" design options – that they must be in commercial products or working prototypes at the beginning of the roughly six-year process during which a standard is set and comes into effect – seems outdated.[29] It essentially locks into rulemaking consideration only those technologies that are at least six years old (and the result of prior product development cycles) by the effective date of the standard. This seems quite old given the rapid pace of today's product development cycles, which have been enhanced by new information technologies. Second, on a related note, it seems short-sighted to screen out individual design options in the first step of the rulemaking process (the screening analysis) based on expectations that they will not be "practicable to manufacture, install, and service" at the time a final standard comes into effect. Manufacturers, installers, and repair services have organizational capabilities that allow them to keep current with today's rapid pace of technical change (in the appliance sector, this includes the trend toward the "internet of things," in which information/communication technologies are embedded in the products). This aspect of the screening analysis seems to imply that efficient technologies are potentially so different from non-efficient technologies that they might overrun these capabilities, and that this is worth safeguarding against six years before it might become a problem. Third, the screening analysis also seems to have an inherent concern

[28] The price-learning adjustment was incorporated into the 2011 direct final rules for residential refrigerator-freezers, clothes dryers, and room air conditioners as well as the 2012 direct final rules for residential clothes washers and dishwashers (see Taylor and Fujita 2013).

[29] This is based on the typical length of a rulemaking (3 years) and the low-end of the typical time given for compliance after MEPS adoption (3-5 years).

that energy efficiency regulation might require tradeoffs in product cost and/or performance (as opposed to stimulate "win-wins"). This is evidenced in the call to screen out design options that can be expected to adversely harm product utility to subgroups of consumers[30] or to make any product performance characteristics unavailable by the time the final standard comes into effect in about six years. Fourth, the engineering analysis emphasis on deriving cost-efficiency curves that feed into other analyses indicates an expectation that a predictable relationship will exist between product cost and the regulated performance characteristic of product efficiency. We will revisit this last expectation, in particular, later in this paper.

ENERGY STAR

As mentioned above, three of the four main elements of federal efficiency policy – test procedures, energy consumption labeling, and MEPS – were established in the original 1975 EPCA.[31] The fourth came about much later, but was added to Section 324 of the EPCA in 2005 by amendment under the direction of Section 131 of the 2005 Energy Policy Act (the "2005 EPAct," Pub.L. No. 109-58). This fourth efficiency policy element is the ENERGY STAR ("EStar") program, which the EPA and the DOE jointly administer. The EStar program develops specifications for products that have superior energy efficiency performance and highlights those products for consumers through a special label for which industry partners voluntarily apply. Figure 3 illustrates the concept underlying the EStar program, according to presentations given regularly by EStar appliance program officials (see, e.g., Karney 2004, Karney 2005, Karney 2007).

[30] This would appear to particularly refer to low-income consumers, given articulated concerns in other sections of the Process Rule.

[31] An argument could be made that federal tax credits and federal procurement of energy efficient products comprise a fifth and sixth major element of federal efficiency policy. Regarding tax credits, the 2005 EPAct provided them to manufacturers for their production of several energy-efficient appliances in order to defray the costs of producing appliances that exceeded federal MEPS. The credit program was modified by the Emergency Economic Stabilization Act of 2008 (Division A of Pub.L. No. 110–343) and extended through 2010. Regarding federal procurement, Taylor and Fujita (2012) provide a chronology of the relevant presidential Executive Orders and public laws.

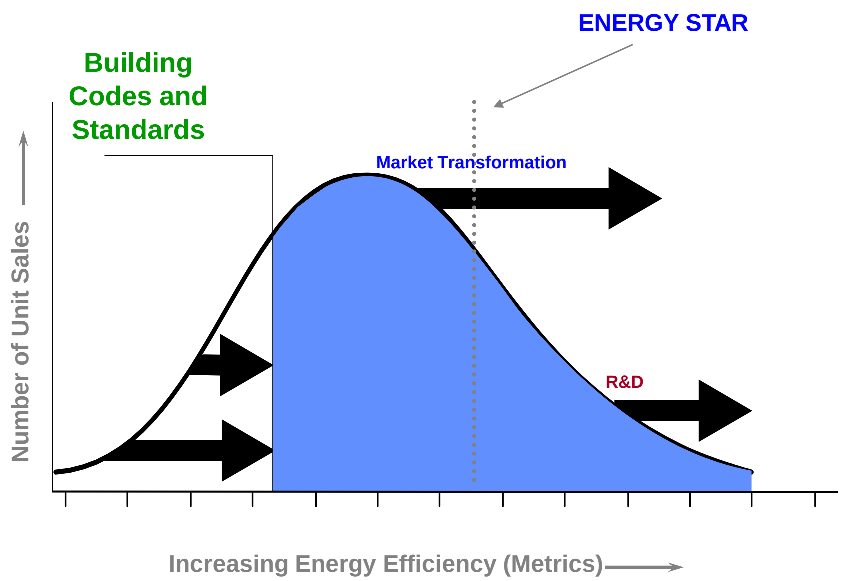

Figure 3: The EStar "Theory of criteria setting."
Source: Karney (2004)

According to EStar officials, the appliance program traces its origins back to two pieces of legislation (see discussion in Karney 2004). First, Section 103(g) of the 1990 Clean Air Act Amendments ("1990 CAA," Pub.L. No. 101-549), which called for the U.S. Environmental Protection Agency (EPA) Administrator to "conduct a basic engineering research and technology program to develop, evaluate, and demonstrate non–regulatory strategies and technologies for reducing air pollution." This lay the groundwork for the EPA's voluntary Green Lights program in 1991, which promoted more efficient lighting through public-private partnership, and the original EStar voluntary labeling program, which focused initially on computers and monitors, both with an eye to reducing greenhouse gas emissions (Interbrand 2007). Second, Section 127 of the 1992 Energy Policy Act ("1992 EPAct", Pub.L. No. 102-486) called for the EPA to submit a report to Congress, within 18 months, "on the potential for the development and commercialization of appliances which are substantially more efficient" than federal or state MEPS. The 1992 EPAct compelled the EPA to consult with utilities and appliance manufacturers in order to identify high efficiency appliances which met five conditions: (1) substantial efficiency improvement potential; (2) significant national or regional energy savings potential; (3) likely cost-effectiveness for consumers; (4) likely commercialization and promotion support from electric, water, or gas utilities; and (5) unlikely commercialization by appliance manufacturers without support.[32] The 1992 EPAct also required the EPA to describe both general actions and specific programs through which the EPA and the DOE might coordinate and assist utilities and appliance manufacturers in commercializing highly efficient appliances, as well as to suggest necessary funding levels for implementing any recommendations.

[32] These conditions informed the "guiding principles" of the EStar program for appliance specification development, which have evolved to some extent over time. In 2004, the guiding principles were: product efficiency; commercial availability (that is non-proprietary); cost-effectiveness; and performance (Karne 2004). By 2007, two additional criteria were added: energy consumption can be quantified; and the label differentiates products and is visible to purchasers (Karney 2007). By 2011, water savings were added to energy savings as an objective of specification and an object of measurement (Stevens 2011).

The EStar appliance program came into effect in 1996, and had several major adjustments in the following two decades. In 1996, the EPA and DOE agreed that the DOE would manage the EStar program for “kitchen appliances, water heaters, and windows” while EPA would manage it for “office equipment, consumer electronics, and heating and cooling products” (Interbrand 2007). Within a year, the first EStar specifications were issued for four of the five case appliances (clothes dryers were the exception, with no EStar specification coming into effect until 2015). These specifications were modified over time, and the effort to routinize these modifications has taken some time to establish. The 2005 EPAct Section 131 required the DOE and EPA to “regularly update product criteria for product categories.” (Karney 2007) More pointedly, a 2009 Memorandum of Understanding (MOU) between the EPA and DOE established that “for appliances and other product categories with longer-lived product models, specifications will be reviewed for a possible revision at a minimum of every three years or once the market share for ENERGY STAR qualifying products reaches about 35%.” The 2009 MOU also shifted the major responsibility for establishing the criteria for the case appliances from the DOE to the EPA. On January 1, 2011, another important adjustment to the EStar appliance program took effect, namely the introduction of third-party certification for the majority of EStar covered products, including the case appliances. This development occurred in response to several reports in 2007-2010 by the U.S. Government Accountability Office and the EPA’s Office of Inspector General.[33] Note that there has been varying degrees of international adoption of elements of the EStar products program over time, although this is less relevant for appliances than for office equipment (see details at Energy Star 2015).

Meanwhile, national awareness of EStar certification as an indicator of energy efficiency has grown over time. It has also varied by product, as can be seen in Figure 4. This figure presents the compiled results for the case appliances of one question asked annually in a nationwide survey conducted since 2000 by the Consortium for Energy Efficiency (CEE) in order to collect data on “consumer recognition, understanding, and purchasing influence” of the EStar label (for the methodology and full set of results, see, e.g., EPA Climate Protection Partnerships Division 2014, as well as the other reports in the "Energy Efficiency Program Library" on the CEE website). The question of interest here asks respondents to point to the products which they associate with the EStar label. As Figure 4 makes clear, national awareness of EStar varies greatly across the four case appliances covered by EStar over this period, with 80-90% of survey respondents recognizing EStar with respect to refrigerators by 2010, as opposed to only 40-50% of respondents recognizing it with respect to room air conditioners by 2005, a situation that has generally held stable since then. Note that for all four case appliances, the 2000-07 period saw fairly steady growth in awareness of the EStar label, with a general flattening of awareness trends since that period.

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[33] Among the findings were: (1) the program qualified some products based on “factors other than total energy consumption” such as when the products were “in standby mode rather than when they were operational”; (2) “problems with EPA’s documentation of the criteria it used to determine when to update product performance specifications, and little oversight of the use of the Energy Star label in retail stores”; (3) at times the “program sought to maximize the number of qualified products at the expense of identifying products and practices focused on maximizing energy efficiency”; and (4) the process for qualifying products had “serious vulnerabilities” as it was “based on self-certification of products by manufacturers.” (GAO 2011)

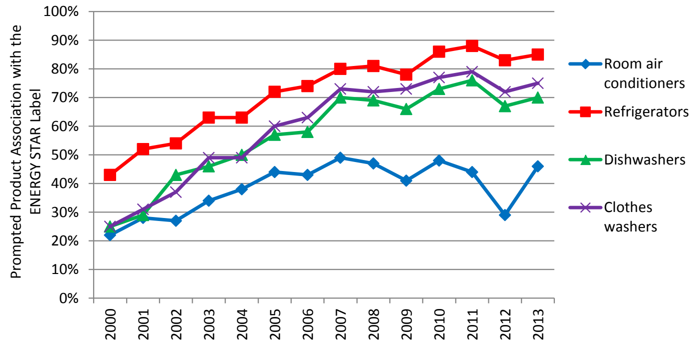

Figure 4: National awareness of an association between the EStar label and the case appliances, 2000-13. Source: Author's calculations from CEE National Awareness survey reports (i.e., EPA Climate Protection Partnerships Division 2014, as found in "Energy Efficiency Programs Library" at CEE)

Although documentation on the evolution of EStar specifications for the case appliances can sometimes be contradictory and incomplete, here we provide as much chronological detail as we have been able to glean from multiple primary sources (e.g., EStar program manager reports to stakeholders, archived web sites, annual EStar program reports, GAO reports, etc.).

Room ACs

The first version of room AC specifications came into effect in 1996. The second major version came into effect in 2001, according to Brown, Webber et al. (2000), with more minor changes occurring in 2003 and 2005 when the set of covered products expanded to include, respectively, products without louvered doors and products with reverse cycle heating. In 2010, a version "2.1" specification was finalized which primarily involved changes that anticipated the start of third-party certification in 2011 (Stevens 2011). The third version of room AC specifications was finalized in June 2012 and took effect on October 1, 2013, with a minor modification, version 3.1, becoming effective on May 30, 2014. Version 3.1 is the current specification, according to the opening EStar webpage for consumers to search for product specifications.

Refrigerators

The first version of refrigerator specifications came into effect in 1996. According to Karney (2007), the initial EStar specifications were set at a level of 20% better than the 1993 MEPS. In the second version of specifications in 2001, this changed to 10% better than the 2001 MEPS, with a more minor modification in 2003 that expanded the program to cover all categories of refrigerators. In the third version of refrigerator specifications in 2004, the specification changed to 15% better than the MEPS (Karney 2007). Version 4.0 became effective on April 28, 2008 and version 5.0 came into effect on September 15, 2014. Version 5.0 is the current specification, according to the opening EStar webpage for consumers to search for product specifications.

Dishwashers

The first version of dishwasher specifications came into effect in 1996. The second version came into effect on January 1, 2001, when the criteria changed from "a minimum EF of 0.52 to a minimum EF of 0.58" (Karney 2005). According to the index of EStar archived specification development material, Version 3.0 came into effect on January 1, 2007. Version 4.0, however, came into effect in two phases, with the first effectiveness date on November 14, 2008 and the second on July 1, 2011. Version 5.0 became effective January 20, 2012; the current specification is a minor modification of this, labeled 5.2, which also became effective on January 20, 2012, according to the opening EStar webpage for consumers to search for product specifications.

Clothes Washers

The first version of clothes washer specifications came into effect in 1997, according to the opening EStar webpage for consumers to search for product specifications and Brown, Webber et al. (2000). The second version came into effect in 2001, and involved changing the clothes washer criteria to use MEF instead of EF (Karney 2004). The third version came into effect on January 1, 2004, and the fourth version came into effect on January 1, 2007. Version 5.0 came into effect in two phases, with Tier 1 effective July 1, 2009 and Tier 2 effective on January 1, 2011. Version 6.0 became effective on February 1, 2013, but did not involve changes to the residential clothes washers we study here; instead, it changed the requirements for commercial clothes washers and all-in-one washer/dryer combinations. Version 7.0 became effective March 7, 2015. This is the current specification, according to the opening EStar webpage for consumers to search for product specifications.

Clothes Dryers

The first version of clothes dryer specifications – which is the current specification – came into effect on January 1, 2015. Stevens (2012) articulates the key drivers for EStar to cover dryers as: (1) “high household penetration (nearly 80% of homes)”; (2)” new, higher efficiency clothes dryer technology” introduced in some markets; and (3) growing collaborations around high efficiency dryers, such as the 2010 “Super Efficient Dryer Initiative” and the 2012 EStar Emerging Technology Award for Advanced Clothes Dryers.

2.4 Summary of Federal Actions regarding Case Appliances

Table 3 summarizes the major federal policy events that shaped the development of the five case appliances, according to the year in which the policy change took effect. All of the major MEPS developments are represented, as well as the EStar specification changes which we judged were most relevant for informing our quantitative analysis. The numbering system in this table is based primarily on the order in which the major developments occurred. When a major MEPS or EStar specification was designed to be implemented in two phases, however, that MEPS is labeled in this table with the chronological number associated with the major event and an indicator (A or B) that represents the effectiveness phase-in date. Similarly, when a lesser EStar change occurred, such as an expansion to an additional product category, it is labeled in this table with the chronological number associated with the major event and an asterisk indicating the modesty of the change. The MEPS that are highlighted in bold are the ones we consider for the majority of our retrospective review analyses. As a reminder, we found that some of the source material on the EStar program was somewhat vague and/or contradictory. We used historic snapshots of the EStar product-specific web pages as captured by Archive.org as our main reference in corroborating the timing of EStar changes.

Table 3: Federal policy timeline for the five case appliances.

Year	RAC	REF	DW	CW	DR
1988			MEPS 1	MEPS 1	MEPS 1
1989					
1990	MEPS 1	MEPS 1			
1991					
1992					
1993		MEPS 2			

1994			**MEPS 2**	MEPS 2	**MEPS 2**
1995					
1996	EStar 1	EStar 1	EStar 1		
1997				EStar 1	
1998					
1999					
2000	**MEPS 2,** EStar 2				
2001		**MEPS 3**, EStar 2	EStar 2	EStar 2	
2002					
2003	EStar2*	EStar2*			
2004		EStar 3		**MEPS 3A**, EStar 3	
2005	Estar2*				
2006					
2007			EStar 3	**MEPS 3B**, EStar 4	
2008		EStar 4			
2009			EStar 4A	EStar 5A	
2010			MEPS 3		
2011				MEPS 4, EStar 5B	
2012			EStar 4B		
2013	EStar 3		MEPS 4	EStar 6	
2014	MEPS 3, Estar 3*	MEPS 4, EStar 5	EStar 5		
2015				MEPS 5A, EStar 7	MEPS 3, EStar 1

Notes: RAC=Room Air Conditioners; REF=Refrigerator/Freezers; DW=Dishwashers; CW=Clothes Washers; DR = Clothes Dryers. MEPS and EStar numbering is chronological, with A or B representing the effectiveness phase-in date if the policy event is implemented in two phases, and * indicating that an Estar change was somewhat modest, such as an expansion to additional product categories.

3 DATA AND METHODOLOGY

As discussed in section 1.1, in the course of meeting the dual purpose of this retrospective review project to inform both scholarship on regulation and innovation as well as regulatory expectations related to technical change in an important area of national regulation, we address at least seven questions. These questions cluster around three aspects of regulated products, namely price, quality (in its regulated and unregulated dimensions), and design. Some of the questions directly compare *ex ante* material on regulatory expectations to *ex post* data on products after regulation. These include questions asking how MEPS cost projections compared to observed appliance prices and how the efficiency standards compared to the efficiency of purchased products. Other questions involve regulatory expectations related to technical change and the outcomes of regulation regarding product quality and design. These include: how relevant were concerns about tradeoffs in unregulated dimensions of product quality with MEPS (these expectations are reflected in the screening analysis process as well as in specific petitioner

comments); how to conceptualize the changes in products that underlie declining price trends with respect to product energy use and design; how accurate were expectations that the stringency of one of the product MEPS would eliminate the dominant design of that product in the U.S.; and how accurately did the rulemaking analysis process reflect the realities of product design.

In this section, we provide more detail about data and analytical approaches we employed to address these research questions.

3.1 Data efforts

Ex Ante

As detailed extensively above and in Appendix A, the DOE conducts a significant amount of analysis in support of any given standards rulemaking. The results of these analyses are published in varying levels of detail in "Technical Support Documents" (TSDs), with "draft" TSDs accompanying the ANOPR and the NOPR, and a "final" TSD accompanying the Notice of Final Rulemaking. For our *ex ante* data, we turned to these TSDs as well as to the relevant underlying models, whenever they were available. As we discuss below, we also incorporated stakeholder expectations of regulated technologies, as evidenced in the MEPS dockets.

The MEPS we assessed are highlighted in bold in Table 3; their relevant product classes and standard levels are summarized in Appendix B. The MEPS considered were: (1) the room AC MEPS that came into effect in 2000; (2) the refrigerator MEPS that came into effect in 2001; (3) the dishwasher MEPS that came into effect in 1994; (4) the clothes washer MEPS that came into effect in two tiers, 2004 and 2007; and (5) the clothes dryer MEPS that came into effect in 1994. These standards were selected for this retrospective review project primarily because they are the most recent for which we have significant available and relevant market data, and secondarily because they are all performance-based standards, rather than the technology-based standards originally set forth for three of the case appliances in the 1987 NAECA.[34]

The focus of our efforts to collect *ex ante* material was on regulatory expectations regarding product price, quality (including product energy use), and design. We were particularly interested in the TSD price projections associated with potential "efficiency levels" for each product class (a design category) for each case appliance, in part because of the importance of these projections to the rulemaking analysis.[35] We were also interested in TSD projections of product market share by efficiency level, which came into play in the case of the clothes washer MEPS we analyzed (which had the most recent rulemaking process of the various case

[34] The early effectiveness date of the dishwasher and clothes dryer MEPS we consider should still pertain to current market data. As detailed in Appendix A, the National Impact Analysis conducted by the DOE in its rulemakings use a forecast period of 30 years. In addition, the average lifetime of dishwashers is currently considered to be 15 years (according to the TSD for the dishwasher MEPS that came into effect in 2013, which included analysis of "residential dishwasher lifetimes in the field" which yielded the 15 year estimate; see Fed Reg. Vol. 77, No. 190 / Monday, October 1, 2012) and the lifetime of clothes dryers is estimated at 12-16 years (according to the 2011 Energy Star Market Analysis and Scoping Report, which itself uses 16 years for analytical purposes).

[35] These projections inform the trial standard levels (TSLs) assessed in the "national impact analysis" (NIA).

appliances).[36] Appendix C provides a detailed listing of the product classes, TSLs, and associated projections of price and energy use that we assembled. Finally, we were interested in regulatory expectations of the consumer impacts of standards, as expressed in material we found in the clothes washer regulatory docket (specifically, a stakeholder petition for reconsideration of the 2001 clothes washer MEPS – see the MEPS chronology for clothes washers in section 2).

We note that we leave for future work a rigorous retrospective review of the impact of standards on manufacturers, despite the prominence of this subject in establishing whether new standards are economically justified. An initial assessment of the quality of the TSD data on expected manufacturer impact for several MEPS led us to conclude that we did not have sufficient resources available to conduct such a review at this time.

Ex Post

As summarized in section 1.3, we employ higher-resolution *ex post* data on post-regulatory product price and quality (including, but not limited to product energy use) than previous studies. As summarized in Table 4, below, for all five case appliances, we employed extensive 2003-2011 U.S. point-of-sale data on model sales and characteristics which we helped match to model energy use data (for all but clothes dryers) in order to allow us to construct a monthly panel of model-specific prices, quality attributes, and market shares. We also gathered and coded third-party appliance testing and reliability survey data in order to consider *ex post* product quality and reliability. We supplemented this quality information with reference to some of the interview-generated insights from Mauer, deLaski et al. (2013), as we were unable to conduct our own interviews for this project.

We also generated original *ex post* data on product design. For clothes washers, we constructed a dataset that consists of the features identified in the product manuals of 1,109 models sold in the U.S. in 2003-11. As recounted in footnote 12, these 1,109 models represented 95% of the 1,165 clothes washer models in our point-of-sale data for which model numbers are identifiable (i.e., "unmasked"). Unmasked clothes washer models account for 29% of units sold in the U.S. over the 2003-11 period.

Table 4: *Ex post* data utilized in this paper

[36] The rulemakings we review took place before the "consumer choice" analysis was introduced into the shipments analysis, as mentioned in section 2, back when the assumption was that after a new standard, the market share of products that were too inefficient would uniformly roll-up to market share at the new minimum standard level.

	Monthly panel of model-specific prices and market shares	Quality and reliability metrics		Energy use data			Detailed product feature data
	NPD	**Consumer Reports – Rating**	**Consumer Reports – Brand Reliability**	**FTC Energy Data**	**CEC**	**ENERGY STAR**	**User Manual Data**
Room AC	2003-2011	1990-2002, 2004-2005, 2010-2012	1991, 1993	2003-2008, 2010-2012			
Refrigerator	2003-2011	1987-1989, 1991-1992, 1994, 1996, 1998-2002, 2004-2012	1987-1989, 1991-1992, 1994, 1996, 1998-2002, 2004-2012	2003-2012			
Dishwasher	2003-2011	1983, 1987, 1990, 1993, 1995, 1997-1998, 2000-2002, 2004-2012	1987, 1990, 1993, 1995, 1997, 1999, 2000-2002, 2004-2012	2003-2012			
Clothes Washer	2003-2011	1989, 1991-1993, 1995-1997, 1999-2002, 2004-2012	1989, 1991-1993, 1995-1997, 1999-2002, 2004-2008, 2011	2003-2012	1993-2013	2001-2013	✓
Clothes Dryer	2003-2011	1989, 1992-1993, 1995, 1998-2002, 2004-2008, 2010-2012	1988, 1992-1993, 1995, 1998-2002, 2005-2008, 2010-2012				

MODEL-SPECIFIC PRICES, MARKET SHARES, ATTRIBUTES, AND ENERGY USE DATA

We used two main data sources to construct a monthly panel of model-specific prices, market shares, features, and energy use.

Data from the NPD Group

The primary data source we employed was point-of-sale market data from the NPD Group. These data consisted of monthly observations of the total revenue and total quantity sold of individual product models in 2001-11, without geographic differentiation across the U.S.

The NPD data have a few idiosyncrasies that are important to mention. First, the NPD Group does not acquire data from a random sample of retailers, but rather relies on data from those retailers with which they have contracts. The list of these retailers is provided in Appendix D. Second, as shown in Table 5, a significant proportion of the models contained in the NPD data are “masked,” with their model numbers unidentified; the NPD Group masks certain models in order to protect the identity of individual retailers that have retailer-specific brands, such as Sears’ Kenmore brand. In order to understand how the masked and unmasked models differ, we conducted a variety of comparisons. We found that for the most part, the masked models tend to be slightly less expensive than their unmasked counterparts, but follow the same general trends and patterns. It is our understanding that the masked products sold by store brands like Kenmore tend to be manufactured primarily by Whirlpool, Maytag and GE, and tend to be similar to their manufacturer-branded counterparts. Our sense is that relying solely on the unmasked data from NPD, while limiting the analysis to a subset of the U.S. appliance market, does not systematically undercut the broader results of our analyses.

Table 5: U.S. Market Coverage of NPD Data

	Total Units Sold in U.S. Market 2003-11	Percent of Units Sold Covered by NPD Data 2003-11	Percent of Units Sold Covered by Unmasked NPD Data 2003-11
Room AC	63,590,809	31%	13%
Refrigerator	90,639,306	39%	20%
Dishwasher	38,814,581	50%	32%
Clothes Washer	67,817,834	47%	29%
Clothes Dryer	56,645,337	37%	27%

Source: Author calculations based on data from NPD Group

For most of our products, the unmasked NPD data covers between a fifth and a third of the units sold in the U.S. market, with a lower proportion of unmasked room ACs (13%). These proportions indicate the pool of models we were able to match to energy use. Note that the 2001 NPD data contain significantly more masked observations than any other year. This is one reason why we only use the NPD data from 2003-11, rather than from the entire time period; the other reason is that the energy use data series which we match to the NPD data only begins in 2003, as mentioned below.

Depending on the appliance, the NPD data include certain product design attributes. For each product, we observe the following NPD "product type" attributes.[37] For room ACs: window and built-in. For refrigerators: top-mount freezer; top-mount with through-the-door (TTD) feature; side-by-side; side-by-side with TTD; bottom-mount freezer, and compact. For dishwashers: built-in, under sink, portable, counter-top, and compact. For clothes washers: top-load versus front-load. And for clothes dryers: gas versus electric.

Throughout this paper, we report "product price" on the basis of an average revenue variable we constructed from the total quantity sold and total revenue variables associated with a product. All prices in this paper are deflated to 2013 dollars using the Consumer Price Index (CPI) from the Bureau of Labor Statistics (BLS).

Energy use data

The NPD data do not include a consistent measure of the energy use of each appliance model. We were generally able to construct this attribute for four of the five case appliances (with the exception of clothes dryers) by leveraging data from the Federal Trade Commission (FTC), which runs the Energy Guide energy consumption labeling program established under the 1975 EPCA, as described in section 2.3. The FTC collects data on appliance energy use using the same test procedures that the DOE uses for MEPS. This means that not only are FTC energy use data available according to the product classes used in MEPS, but FTC data also provide several other important variables for energy use calculations, such as product type, capacity, and Btus (in the case of room ACs), that can be usefully matched to the NPD data. Unfortunately, FTC energy use data are only available starting in 2003.

In three of the four case appliances that could be matched to FTC data, the FTC energy use metric is the same as the energy use metric employed in the MEPS we analyze. The exception is clothes washers. For this product, the FTC reports kWh per year energy use, while the MEPS we

[37] We cross-validated these "product types" using data from the Federal Trade Commission and the clothes washer manuals. For refrigerators, we found the FTC data on product design attributes to be more reliable than NPD data.

analyze use the metric of modified energy factor (MEF, described above in section 2.3).[38] We were able to define a consistent MEF variable for all models for which we observe annual kWh consumption, however, by leveraging observed MEF data for clothes washers from the California Energy Commission (CEC) and the EStar program. As the CEC and EStar data do not cover all clothes washer products, we had to estimate a proxy MEF by modeling the observed functional relationship between the annual kWh energy consumption from the FTC data and the MEF from the CEC and EStar data.[39]

Once the energy use data from FTC, CEC, and EStar were matched to the unmasked NPD data by model number and date, the final match rate for each appliance was: room ACs 82%; refrigerators 92%; dishwashers 95%; and clothes washers 96%.

QUALITY AND RELIABILITY METRICS

For all its richness regarding model price and attributes at the time of sale, the NPD data says little about consumer satisfaction with purchased models after they are regulated. For this, we turned to third-party testing and survey data. We constructed two data series from material in the 1987-2014 volumes of *Consumer Reports* (CR) magazine. We chose this time period because it spans the effective dates of all of the federal MEPS that affect the case appliances, and even allows a consideration of baseline quality a few years before each MEPS.

Quality

Each month, CR publishes reviews, rankings, and buying advice for a variety of consumer products, a selection of which the magazine evaluates in its in-house testing laboratory. In its evaluations, the laboratory reports a detailed description of each tested model, including the approximate retail price, size, and special attributes. It also provides ratings of various aspects of product performance and energy use, reporting test results on a 1-5 scale (with excellent = 5).[40] Appendix E presents a detailed list of the ratings variables used by CR magazine in its evaluations of the case appliances over time; in our analyses, we focus on those metrics that span the most years.[41] We also consider CR's "overall score" of products, a measure the magazine has provided for almost all of the case appliances since 1994 (Appendix E shows that dishwashers were the only exception, with overall score reported for the first time in 1993). The overall score is presented on a scale of 1-100 (with best = 100), as derived by joint consideration of the ratings and other aspects of the product, and it reflects the model's relative quality amongst all the tested models in a given time period. Although CR's scoring methodology changes for certain appliances at certain points in time, these changes are generally documented enough to use CR

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[38] The MEF incorporates the "remaining moisture content" of the clothes at the end of the wash cycle in addition to the traditional Energy Factor, which reports on machine and water heater energy consumption.

[39] The MEF is roughly Cobb-Douglas in annual kWh energy consumption and capacity (cubic feet). Using the capacity data and annual energy consumption from the FTC, we estimate the following statistical model: $\ln(MEF) = \alpha + \beta \ln(kwh) + \gamma \ln(capacity) + \varepsilon$. We used the predicted values from this model to generate the proxy MEF we employ in our analysis. The fit of this modeled relationship is strong, with an R^2 of 0.84.

[40] Occasionally, CR reports test results only for its recommended models, rather than for all tested models.

[41] We were able to obtain and code CR data for all years except one month of 2003 (November). The five case appliances are reviewed by CR almost every year. In those years when CR did not review a product, it was generally because the market situation was considered to be relatively unchanged since the last review.

ratings to serve as a consistent metric of product quality, and presumably a proxy for consumer satisfaction, over time.

Note that we did not match the CR data to the NPD data. Not only does much of the time period covered by CR testing extend beyond the period covered by the NPD data, but the results of any matching effort would only include the subset of unmasked NPD products that CR chose to test. Such an effort might generate interesting results in future research, however, particularly if we can identify similar product models to those tested by CR by decoding families of products that share certain model number patterns.

Reliability

The CR survey research center collects annual information on the satisfaction of CR readers with various products. In most years, the magazine accompanies its published review of the case appliances with information from this survey that pertains to product repair history, by brand. The magazine reports on the percentage of a brand's products of a certain category (i.e., refrigerators, clothes washers, etc.) and sometimes sub-category (i.e., side-by-side refrigerators, front-loading clothes washers, etc.) which were bought new, usually over the previous five years, and which were "ever repaired or had a serious problem that was not repaired." In presenting its findings, CR also presents information of statistical relevance, such as: the number of products reported on (generally in the tens of thousands); the fact that the data have been standardized to eliminate differences linked to age and usage; and the differences in percentage points that should be considered meaningful. Although CR is careful to explain that "a brand's history can't take into account recent design changes, and repair rates within a brand may vary" and that brands may not be included in the ratings because of insufficient data, CR does say that its brand repair histories have generally been "quite consistent over the years."

These data were useful to us in gauging whether overall product reliability increased or decreased throughout the period in which MEPS were in force. In future work, we may do a more detailed analysis of brand reliability as it compares to the brand's portfolio of more- and less-efficient products.

DETAILED DESIGN DATA

We used two different data sources to assist us in assessing product design as it relates to other aspects of a consumer's experience with a case appliance (i.e., price, energy use, quality at the time of purchase, reliability). First, we leveraged the "product types" used in the NPD data (see above) in order to improve our understanding of consumer preferences and technological developments.

Second, as mentioned above, for one product (clothes washers), we constructed a dataset of the features identified in the product manuals of 1,109 clothes washer models sold in the U.S. in 2003-11. This set of manuals represented 95% of the unmasked NPD data (1,165 clothes washer models), which accounted for 29% of units sold in the U.S. over this period. To characterize features, we developed a code scheme that was informed by concerns that more efficient clothes washers might require tradeoffs in product quality and reliability, as articulated by petitioners advocating the overturning of the 2001 MEPS.[42] Appendix F contains materials relevant to the

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[42] As detailed in section 2.1, these petitioners considered the 2007 second tier of the 2001 MEPS to be an example of risky technology-forcing. In the language of the 1996 Process Rule, if the petitioners' view that the standard could

development of our code scheme; two coders provided initial feature coding, which we later refined. For all its unique richness and detail, it is important to note that the coded feature data that emerged from this process is best understood as a source only of the technical characteristics of a product that a manufacturer explicitly discusses in a manual.

3.2 Analytical Approaches

When detailed regulatory analysis expectations were available, such as product price and market share of efficient products, our research approach was to compare expectations to observations, in keeping with the retrospective review format. When these expectations were not available, we reported trends in quality (including reliability), product design, and product features, keeping in mind the policy context of each product, as summarized in Table 3.

Here we provide more detail on how we performed comparisons and constructed trends that were relevant to our research questions.

Ex Ante/Ex Post Comparisons of Price and Efficiency

To assess product price retrospectively and in relation to product energy use, we followed a multi-step process. Here we describe elements of that process that are common across products (with the exception of clothes dryers, for which we do not have energy data). Following this general description, we provide more product-specific detail, as supplemented by Appendix C.

The retrospective review approach we followed across products involved several steps. First, we matched the *ex post* price of each model in the NPD data to the appropriate *ex ante* rulemaking price projection. We did this by mapping the model's energy use and product class to its corresponding energy efficiency level, as reported in the rulemaking's trial standard levels (TSLs). Second, we calculated the difference between the observed and expected prices, grouping the results based on ranges of product energy use in the market. When the price difference was a negative number, the result reflected that the projected price overestimated the observed price. Third, we used monthly sales data to calculate a monthly sales-weighted average price difference for each given product class and TSL.[43] When the sales-weighted average price difference was a negative number, the result reflected that projections overestimated the prices of a given product class and TSL on average, based on the purchases actually made by consumers. A reporting convention we employ is to use the practice established in Harrington, Morgenstern et al. (2000) of assessing a projection as accurate if the observation falls in a range of plus or minus 25% of the projection. Fourth, we used the panel of prices across individual model numbers tracked over time in monthly intervals to advantage in our analyses. Specifically, in retrospectively analyzing the explanatory power of efficiency level on product price, we employed a fixed effects estimation approach in order to isolate the time-varying effect that product energy use had on model price (or in the aggregate, the price of a group of models categorized by product or, in later analyses, product design type).[44] Fifth, in order to understand

be expected to reduce product performance and/or reliability was generally accepted, it would indicate a lower consumer utility from compliant products that would reduce the economic justification of the standard.

[43] Weighting was based on the market share of each product over the full length of time it existed on the market.

[44] To illustrate how a seemingly stable model-level characteristic can have a time-varying effect on model price at the retail level that the NPD Group captures, we consider the example of a refrigerator model, manufactured over several years, that incorporates through-the-door (TTD) water and ice features. In this example, time-varying effects

the relative importance of the assumptions that accompany our sales-weighting of prices and to observe the difference between within-model price changes and changes to average product prices due to turnover in the mix of models,[45] we ran four regression models for each appliance category (i.e., with the product's price either sales-weighted or not, and with or without a fixed-effect estimation).

Note that to assess energy use retrospectively for all products, we calculated the difference between the observed energy use of each model in the NPD data (with the exception of clothes dryers) and the appropriate standard level, expressing the result as a percentage difference from the standard. When the percentage difference was a negative number, the result reflected that the product used less energy than required by the MEPS. In the case of clothes washers, we were able to perform an additional analysis, checking regulatory projections of market share by efficiency level against real-world observations.

Room ACs

In the rulemaking analysis, Room AC product classes are based on unit cooling capacity in British thermal units (Btus) and the existence of louvered sides (products lacking louvered sides are designed to be built in to walls). Product energy use is expressed as an energy efficiency ratio (EER) of cooling capacity (in Btus) per hour, divided by electrical input power (in Watts). We were able to match these *ex ante* definitions relatively easily to the *ex post* data, as we know whether each Room AC model in the NPD data is a window or built-in unit, and we know from the FTC data the Btu capacity and the EER energy usage.

Refrigerators

In the rulemaking analysis, refrigerator price projections are provided for a variety of TSLs for each of a large number of product classes based on one assumed adjusted volume (AV) level. The MEPS themselves are assessed based on a real-world refrigerator's AV, but we do not know what functional form refrigerator prices are projected to have with respect to volume and energy use. In the *ex post* data, we do not observe AV in the NPD data and cannot differentiate the price projections by real-world product AVs. For matching and price difference calculations, we used the assumption that every refrigerator has the reference AV used in defining the TSL price projections.

Dishwashers

In the rulemaking analysis, dishwasher product classes are compact, standard size without internal heater, and standard size with internal heater. In the *ex post* data, we do not observe if a dishwasher has an internal heater. The vast majority of dishwashers in the NPD data, however,

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related to the TTD features could include: reduced costs to manufacture models with TTD over time because of manufacturing process improvements for TTD; increased costs to manufacture models with TTD because of supply shortages for necessary components; increased consumer preferences for fast access to cold water because of health fads; or decreased consumer preferences for TTD due to undesirable performance attributes of refrigerators incorporating that feature, such as higher repair rates.

[45] The results without fixed effects capture both the change in product price attributed to changes in the price of models with certain characteristics (here energy use, later product design and features) as they remain on the market over time, as well as the change in product price as a result of the changing mix of product models with these characteristics over time. The results with fixed effects, by contrast, capture the change in product price attributed only to changes in the price of models as they remain on the market over time. We present the results of fixed effect analyses as "within-model" results.

are built-in dishwashers (as opposed to portable, counter-top, etc.), which means that they are likely to include a heating element. For matching and price difference calculations, we differentiated products based on compact versus standard-size, and for the standard-size models we applied the TSL projections for product classes with internal heaters.

Clothes Washers

In the rulemaking analysis, clothes washer product classes are compact and standard-size, and the TSL levels are based on the MEF energy use metric. In the *ex post* data, we know capacity in the NPD data and we used CEC and EStar data to construct our proxy MEF variable, as described above. This made matching and price difference calculations relatively straightforward.

Clothes Dryers

In the rulemaking analysis, clothes dryer product classes are compact and standard size electric dryers as well as compact and standard size gas dryers. In the *ex post* data, we know from the NPD data whether a dryer is electric or gas, but we do not observe any energy usage data. For price difference calculations, we ran two bounding scenarios. In the lower bound scenario, we compare the lowest price projection against the NPD observations; this projection assumes the lowest possible energy usage. In the upper bound scenario, we compare the highest price projection against the NPD observations; this projection assumes the highest possible energy usage.

QUALITY, RELIABILITY, PRODUCT DESIGN AND PRODUCT FEATURES

To assess quality at the time of purchase retrospectively, we were interested in the magnitude of shifts in CR ratings across regulatory changes. Once we collected and coded all the relevant CR data, we followed a three step analytical process. First, we divided the available 1987-2014 CR data for each product into time periods that were defined by the effective dates of each federal MEPS (see Table 3 for the full list of MEPS effective dates). Second, we assessed the nature of the data we had available for each product in each time period, and settled on the final time periods we would analyze. Table 6 shows the full set of pre- and post- time periods defined by the effective dates of federal MEPS for each product, with the time periods we chose to analyze highlighted in red. Finally, we calculated the difference in each quality metric across each regulatory change, conducting a difference-in-means test to determine the statistical significance of the change. We report the quality difference results as a percentage change in order to account for the use by CR of different scales for different metrics (e.g., the overall score is on a 1-100 scale, while most performance ratings are on a 1-5 scale).

Table 6: MEPS-defined time periods for quality analysis of CR data

Product	**Time Periods for CR Quality Analysis**
Room ACs	1987-1989; 1990-1999; 2000-2014
Refrigerators	1987-1989; 1990-1992; 1993-2000; 2001-2014
Dishwashers	1987; 1988-1993; 1994-2009; 2010-2012; 2013-2014
Clothes Washers	1987; 1988-1993; 1994-2003; 2004-2006; 2007-2010; 2011-2014
Clothes Dryers	1987; 1988-1993; 1994-2014

To assess reliability (i.e., quality after purchase, as reflected in repair rates) retrospectively, we were interested in first-order trends across the full period of time during which a product has been subject to federal MEPS.

To delve more deeply into the role of technical change in understanding the observed attributes of technologies in the marketplace, we returned to our analysis of product price and energy use at a more refined level that allowed us to better understand the effects of model characteristics such as product design and feature incorporation. As above, we ran four regression models (i.e., regressions either with or without fixed effects, focusing on product prices that were either sales-weighted or not) to understand the effect on each product's price of its energy use in model groups associated with product design.

In considering the relevant model groupings, we turned to the concept of "product design architecture," which resonates with an important thread in the innovation and manufacturing literatures (see, e.g., Henderson and Clark 1990, Ulrich 1995, Murmann and Frenken 2006).[46] It also resonates with the clothes washer standards petition discussed in Section 2.3, which revealed that regulatory stakeholders had expectations of product performance and reliability that were tied to the orientation of the product's architecture. Specifically, front-loading clothes washers with a horizontal-axis orientation to their "design architecture" were expected to have lesser performance and reliability than the long-dominant design of clothes washers in the U.S., which was top-loading clothes washers with a vertical-axis orientation to their design architecture. In our analyses with relevance to product design, we therefore tried to pay particular attention to any associations with the orientation of a design architecture, although only one other product that we study – refrigerators – exhibits as clear a distinction in that regard as clothes washers (i.e., refrigerators can be distinguished by the location of the freezer above, to the side, or below the refrigerator compartment).

In a concluding set of analyses, we conducted exploratory research on how the price and energy use of a regulated product over time might connect to the evolution of model design sub-elements. Our analyses focused on those physical components (i.e., "features," or "technical characteristics") of clothes washers which we could identify in product manuals. These technical characteristics interact across interfaces to deliver a product's functions, or "performance attributes."

4 RESULTS

4.1 Product price and energy use

PRICE

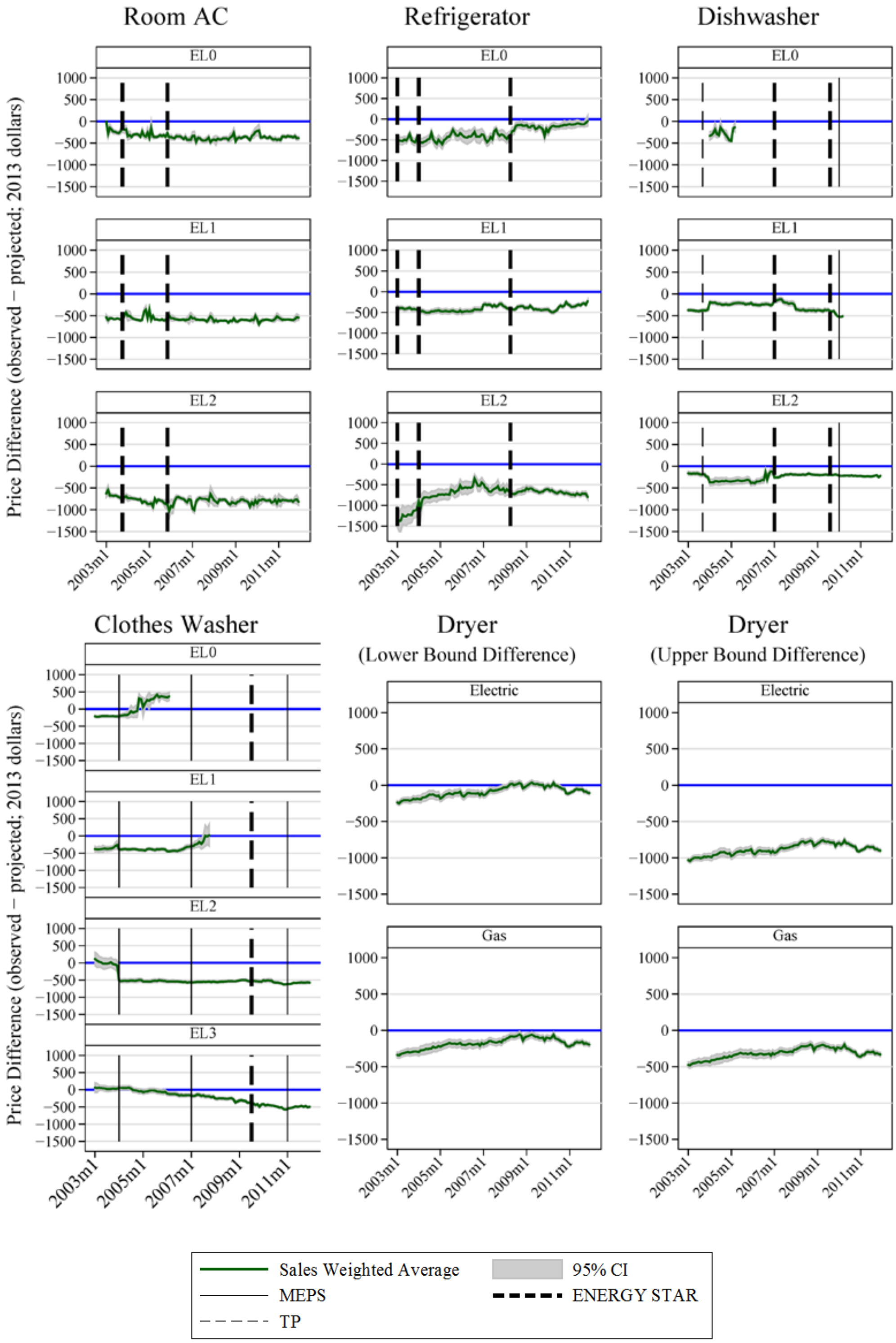
We found that the regulatory analyses over-estimated the prices of all five of the case appliances, which is consistent with the hypothesis we had for our first research question.

In order to better understand the relationship between price, energy use, and technical change under MEPS, we delved into this result in more detail. We began by comparing the price of

[46] According to Ulrich (1995), "product architecture" is informally defined as "the scheme by which the function of the product is allocated to physical components." More formally, it is defined as "(1) the arrangement of functional elements; (2) the mapping from functional elements to physical components; [and] (3) the specification of the interfaces among interacting physical components." Ulrich (1995) defines a physical component as a "separable physical part or subassembly" that can be linked to a product's function (i.e., something it does) through mappings of "one-to-one, many-to-one, or one-to-many." Interacting components are connected by a physical interface, the specification of which "defines the protocol for the primary interactions across the component interfaces, and the mating geometry in cases where there is a geometric [as opposed to a non-contact] connection."

models as grouped by their efficiency levels against the corresponding regulatory price projections. Figure 5 presents the monthly sales-weighted average prices of our products, comparing them against the projected prices for a given efficiency level. It uses a presentation style that allows for cross-product comparison, which is based on displaying the difference between the sales-weighted average price of each product (the green line) and the projected price for that product (the blue line, where that difference is zero). The background includes relevant MEPS and EStar effective dates (the black lines associated with specific points in time on the x-axis). For every product but clothes dryers (for which we do not have energy data), Figure 5 uses panels to group retrospective price comparisons according to the energy use of models on the market as they compare to the effective standard. These panels are ordered from least efficient to most efficient in Figure 5 (i.e., worse than the standard or "below-standard," at or better than the standard or "at-standard", and much better than the standard or "exceed standard").[47] For clothes dryers, Figure 5 presents two figures connected with the bounding scenarios discussed in Section 3.2, in which the first figure uses the lowest projected prices associated with the lowest clothes dryer energy use, while the second figure uses the highest projected prices associated with the highest clothes dryer energy use. Both figures present differences between observed and projected prices in panels associated with the type of clothes dryer (electric versus gas).

[47] For clothes washers, we present four efficiency panels, allowing us to distinguish between models that are worse than the 2004 tier of the 2001 MEPS, models that are between the efficiency levels of the 2004 and 2007 tiers, models that are better than the 2007 tier, and models that are much better than the 2007 tier.



Note: TP refers to "Test Procedure" and indicates the date that the test procedure was changed for Dishwashers. EL0 – EL3 indicate different efficiency levels for the various products. These levels are defined in Table 7.

Figure 5: Retrospective review of regulatory price projections by efficiency level

Table 7: Definition of Efficiency Levels (ELs) by product

Product	Definition of Efficiency Level (EL)	Model Count within EL
Room ACs		
EL0	Uses more energy than 2000 minimum standard level	163
EL1	Meets or uses less energy than 2000 standard level	352
EL2	Efficiency exceeds 2000 standard level by 10% or more	290
Refrigerators		
EL0	Uses more energy than 2001 minimum standard level	983[48]
EL1	Meets or uses less energy than 2001 standard level	3470
EL2	Efficiency exceeds 2001 standard level by 20% or more	712
Dishwashers		
EL0	Uses more energy than 1994 minimum standard level	15
EL1	Meets or uses less energy than 1994 standard level	527
EL2	Efficiency exceeds 1994 standard level by 30% or more	1665
Clothes Washers		
EL0	Uses more energy than 2004 minimum standard level	119
EL1	Uses more energy than 2007 minimum standard level	116
EL2	Meets or uses less energy than 2007 standard level	270
EL3	Efficiency exceeds 2007 standard level by 30% or more	611

The decomposition of product price trends by efficiency level in Figure 5 is particularly interesting for what it says about how standards work for less efficient products. The top panel in each of the four products for which we have energy data presents the prices of models sold with energy levels worse than a federal MEPS; this is also true for the second panel of the clothes washer figure. In each set of these obsolete product models (EL0), the federal MEPS either came into effect before the period of time for which we have usable NPD model data – i.e., before 2003, true for room ACs (MEPS effective 2000), refrigerators (MEPS effective 2001), and dishwashers (MEPS effective 1994) – or during that period (i.e., clothes washers - MEPS effective 2004 and 2007). The sale of products with energy use levels eliminated by the standard may reflect: the sale of the inventory of models manufactured before the standard; imprecision in the matching of products to the relevant standard level (see footnote 48); or it may reflect instances in which a standard was violated. We see across the top panels of EL0 products in Figure 5 that prices were at or below the regulatory price projections for all but the clothes washers made obsolete by the 2004 standard. Observed prices either held generally steady (in the case of Room ACs and dishwashers), or rose slightly (in the case of refrigerators, clothes washers, and in the various clothes dryer scenarios).

Note that in the case of clothes washer prices – the only example of a sustained regulatory price *under*estimate in Figure 5 – the increase in the sales-weighted average price difference (the green line) is being driven by the least expensive of the non-compliant models dropping out of the

[48] While these counts make it appear that a large number of products (particularly for refrigerators) were out of compliance with the standard, this is misleading. This is the case for two reasons: first, this is because the standard is imposed on the manufacture of new products; if inventory of products whose energy use exceed the new standard following change, there is no restriction to them being sold off in the market. Second, particularly in the case of refrigerators, the mapping of models to the relevant standard level is imprecise. This is because the standard for refrigerators is a function of the adjusted volume (AV) of refrigerators, which is a measure we do not observe in the data. We therefore matched models to their relevant standard level based on the assumption that all models had the reference AV used in the rulemaking analysis. This is therefore likely to indicate some error in the precise designation of models across these EL categories.

market first. By the time the green line becomes higher than the projected price, only a few models are left in the market. This pattern is similar for refrigerators, and a similar effect occurred for the clothes washer models that were worse than the 2007 standard (the second panel), sales of which died off in 2008 just as the green line became higher than the projected price.

The comparison between observed and predicted prices for products that meet or are more efficient than federal MEPS (EL1) is presented in the second-to-last panel of each product figure in Figure 5. The regulatory analyses over-estimated the prices of the EL1 products, but the overall price trends of these “at-standard” products are not otherwise consistent. In the case of room ACs and refrigerators, the observed prices of EL1 products were generally constant, at well below the projected price. This is also true in the clothes washer case for EL2 products (at the 2007 standard level), after a distinct discontinuous price drop from projected levels at the time of the 2004 standard.

The bottom panel of each product figure in Figure 5 depicts the comparison between observed and predicted prices for products that are considerably more efficient than federal MEPs by a range of 10-30% or more (EL2, or EL3 in the case of clothes washers). These “exceed-standard” products are those most identified with the EStar program, and such products existed in the U.S. market throughout the time period for which we have NPD data. The regulatory analyses over-estimated the prices of the EL2/EL3 products much as they generally over-estimated the other products, when grouped by efficiency level. In the case of room ACs, the observed prices of EL2 products were generally flat, at well below the projected price. The EL2 dishwashers were also generally flat, but closer to projections than room ACs and with a fairly sharp price drop early in the period, around the time of an EStar event. The EL2 refrigerator prices began far below projected prices and generally stayed that way, increasing through the end of 2006 and then gradually decreasing through the end of the period. Finally, the EL3 clothes washer prices started the period at about the same level as the projected prices, but gradually became less expensive than projected throughout the time period.[49]

Table 8 provides a more fine-grained analysis of the extent to which the regulatory analyses overestimated the prices of models, as grouped according to their efficiency levels (ELs). It uses the convention established in Harrington, Morgenstern et al. (2000) of assessing a projection as accurate if the observation falls in a range of plus or minus 25% of the projection. In this table, which considers the proportion of model observations that are significantly overestimated, accurately estimated, and significantly underestimated, it is clear that regulatory projections significantly over-estimated the majority of price observations across all efficiency levels. The significantly over-estimated observations for each product are: more than 95% of observations for room ACs; 54-66% of observations for refrigerators; 42-72% of observations for dishwashers; and 50-81% of observations for clothes washers.[50] Even in the single product

[49] Estimations of both the average and within-model (i.e., with fixed-effects) price trends across these products and efficiency levels are presented in Appendix G.

[50] In the case of clothes dryers, in the lower bound scenario 34-46% of observations were significantly overestimated, while in the upper bound scenario 58-91% of observations were significantly overestimated. The lower bound scenario exhibits the most even distribution between significant over-estimates, accurate estimates, and significant under-estimates displayed in this table, although the incidence of significant over-estimates and accurate estimates dwarf the incidence of significant under-estimates.

efficiency level in which less than half the observations were significantly over-estimated – the EL3 dishwashers – the largest share of observations were significantly overestimated, with only 31% accurately estimated and 26% significantly underestimated.

Table 8: Summary of accuracy of regulatory impact analysis projections

Product	Efficiency Level	*Ex ante* Significantly Underestimates *Ex post*[51]	*Ex ante* Accurately Estimates *Ex post*[52]	*Ex ante* Significantly Overestimates *Ex post*[53]
Room ACs	EL0	0%	4%	96%
Room ACs	EL1	0%	1%	99%
Room ACs	EL2	0%	1%	99%
Refrigerators	EL0	22%	24%	54%
Refrigerators	EL1	14%	27%	59%
Refrigerators	EL2	12%	21%	66%
Dishwashers	EL0	6%	20%	72%
Dishwashers	EL1	22%	28%	50%
Dishwashers	EL2	26%	31%	42%
Clothes Washers	EL0	23%	27%	50%
Clothes Washers	EL1	14%	11%	75%
Clothes Washers	EL2	2%	17%	81%
Clothes Washers	EL3	8%	41%	51%
	Product type and price assumption			
Clothes Dryers	Electric, lower bound assumption	29%	37%	34%
Clothes Dryers	Gas, lower bound assumption	13%	41%	46%
Clothes Dryers	Electric, higher bound assumption	0%	9%	91%
Clothes Dryers	Gas, higher bound assumption	6%	37%	58%

Energy

Figure 6 compares the monthly sales-weighted average energy use of the case appliances to the relevant federal MEPS for each product (clothes dryers are absent here because we do not have energy use data for this product). As in Figure 5, we use a presentation style that allows for cross-product comparison, which is based on displaying the percentage difference between the sales-weighted average energy use (the green line) and the federal MEPS (the blue line), on a background that includes relevant MEPS and EStar effective dates (the black lines associated with specific points in time on the x-axis). Note that for clothes washers, the federal MEPS level presented in Figure 6 is that of the 2007 tier of the 2001 standard.

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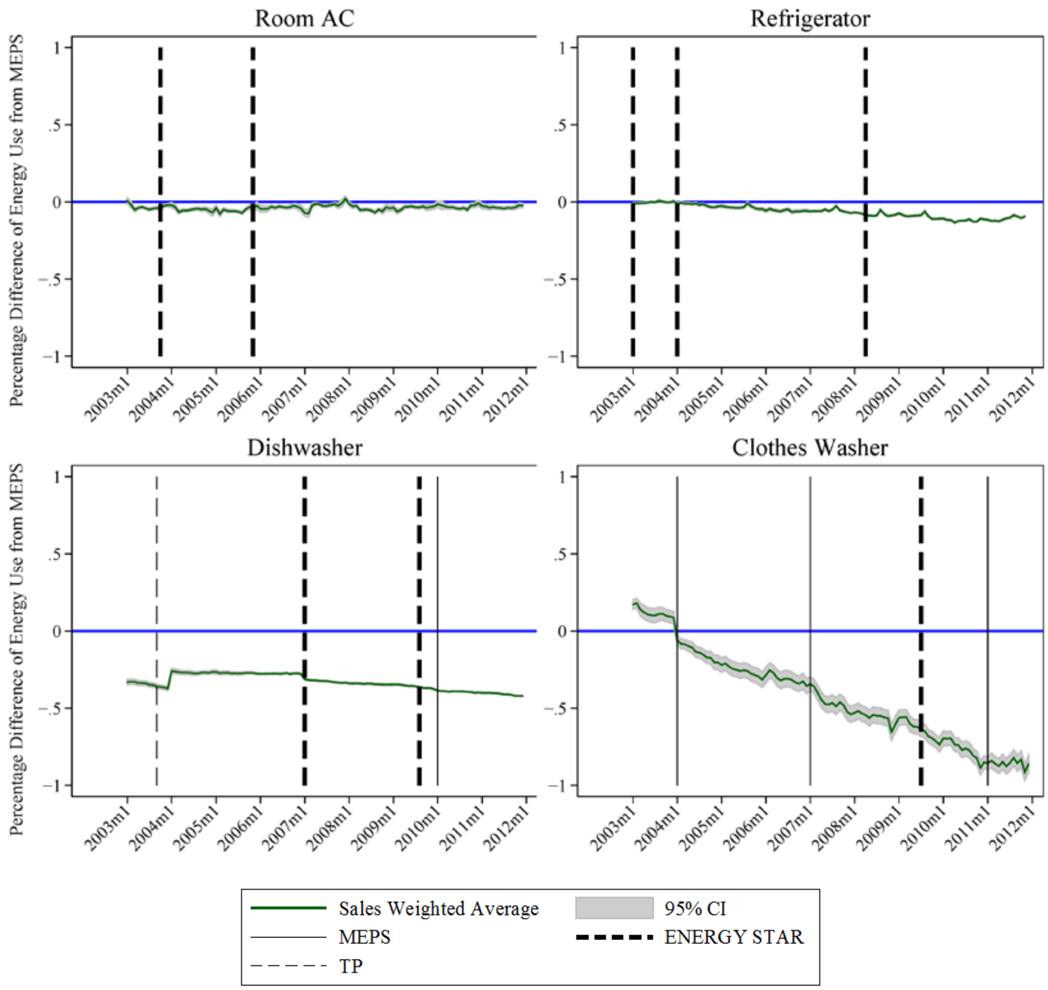
[51] Observed prices are more than 25% above projected prices.

[52] Observed prices are within 25% of projected prices.

[53] Observed prices are more than 25% below projected prices.



Note: TP refers to "Test Procedure" and indicates the date that the test procedure was changed for Dishwashers.

Figure 6: Comparison of the expected standard level energy use of products against market outcomes

The monthly sales-weighted average energy use of these products was better than the standard, a condition that held for almost all the data points in our study period and was consistent with the hypothesis we held for our second research question. More specifically, product energy use trends compare to federal MEPS as follows. For room ACs, energy use is below – but quite close to – the standard level and holds remarkably steady over time. For refrigerators, energy use is similarly below (but close to) the standard at the outset of our study period, but it gradually drops further below the standard over time. For dishwashers, energy use is much lower than the standard at the outset of the study period and steadily drops lower than the standard starting in 2007, around the time of an EStar event. For clothes washers, the trend is quite different than in the other three cases. Although average energy use is above the standard level from the start of our study period until the 2004 tier of the 2001 standard, a discontinuous energy use improvement occurs at the time of that standard. From that point on, sales-weighted average clothes washer energy use is below the standard level, following an improvement trajectory throughout the study period that is considerably stronger than in the other products we study. Indeed, by 2011, the sales-weighted average energy use of clothes washers on the market is about 100% better than that allowed by the 2007 standard. These results suggest that clothes

washers in 2011, when the energy use improvement trend flattened out, were using, on average, approximately 304 kWh/year less than the 2007 standard. The flattening out of energy use improvement in clothes washers corresponds with the 2011 federal MEPS, which focused on water efficiency, as well as with a few other developments in the market, such as the reemergence of top-loading machines as the dominant design in the U.S. market and the success of an international trade case on price dumping which was brought by Whirlpool against imports from Asia and Mexico.

As mentioned in Section 3.2, in the case of clothes washers we were able to perform an additional analysis that compared regulatory projections of market share by efficiency level against real-world observations. Figure 7 follows the panel display approach established in Figure 5, employing four efficiency panels for clothes washers that allow us to distinguish between models with energy use that is worse than the 2004 tier of the 2001 MEPS, models with energy use that is between the efficiency levels of the 2004 and 2007 tiers, models with energy use that is better than the 2007 tier, and models with energy use that is much better than the 2007 tier. Figure 7 also follows the basic presentation approach of Figure 5 and Figure 6, which is to display the actual market share associated with models of a given efficiency level using a green line and the projected market share for those models using a blue line, all on a background that includes relevant MEPS and EStar effective dates (the black lines associated with specific points in time on the x-axis).

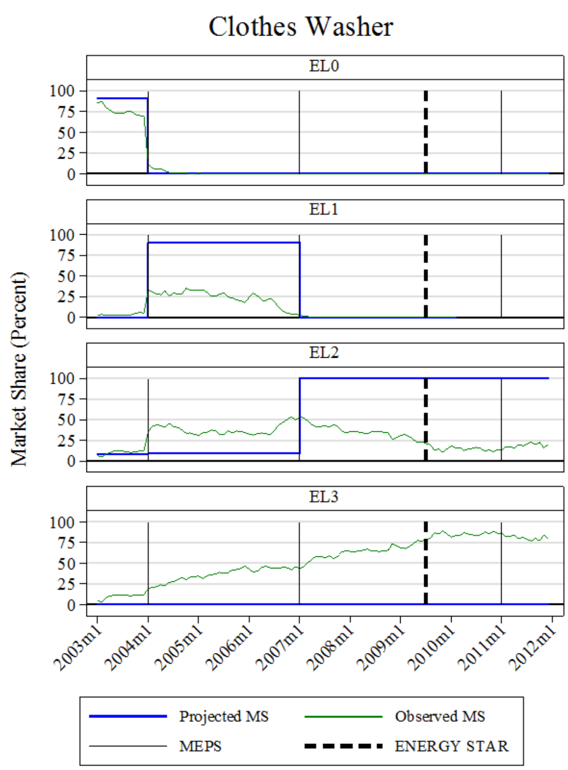


Figure 7: Comparison of projected clothes washer market shares by efficiency level against market outcomes

Figure 7 notably demonstrates that rulemaking projections underestimated how enthusiastically consumers would purchase high-efficiency products.[54] At the beginning of our study period, most clothes washers purchased in the U.S. had energy use that was worse than the 2004 standard level (or EL0). In 2004, the market share of below-standard products plummeted to zero. When the market share for below-standard clothes washers evaporated, it was not replaced solely by products with the next-lowest energy efficiency, as predicted in the rulemaking analyses and reflected in the second panel of below-standard products for the 2007 tier. Instead, that market share was replaced somewhat evenly between products in three efficiency groupings: models with energy use acceptable between 2004 and 2007 (EL1); models with energy use that would be acceptable in 2007 (EL2); and models with energy use that exceeded the standard by more than 30% (EL3). By the time the 2007 tier came into effect, this latter set of products – those displayed in the bottom panel of Figure 7 – were the dominant products in the U.S. clothes washer market, rather than absent from the market as projected by regulators (who had predicted that at-standard products would have 100% of the market starting in 2007). In fact, the highest-efficiency (EL3) products exhibited a steady increase in market share from 2003 to 2010, by which time more than 75% of U.S. clothes washer sales were in this energy use group.

4.1 Product quality and design

Quality

As mentioned in the discussions of quality, reliability, and product design above in Section 3.2, the concern that the 2001 clothes washer MEPS would cause "risky" technology-forcing showed how concerns about the impact of efficiency policy on product quality and reliability could be associated not just with a product like a clothes washer but with a type of product *design*, like top-loading or front-loading (i.e., oriented on a vertical or a horizontal axis). This emphasis highlighted a variable that has been studied in the innovation literature in the past, namely the design architecture of a product (see definition in footnote 46, above, as well as discussion in section 3.2).

We pay special attention to quality metrics as they relate to product design types, and in particular, product design types that can be clearly associated with product design architecture. Table 9 presents the product design types we considered when performing our analysis of quality changes – as demonstrated in CR ratings – before and after a change in a federal MEPS. Product design types highlighted in red are most clearly associated with visible variations in product design architecture.

Table 9: Product design types considered in CR quality analysis

Product	**Product Types**
Room ACs	Small (<7,000 Btu/hr); Medium (7-9,000 Btu/hr); Large (>9,000 Btu/hr)
Refrigerators	Top-Mount, Side-by-Side with Through-the-Door Ice; Bottom-Freezer; and Built-In
Dishwashers	Standard
Clothes Washers	Top-Loading; Front-Loading
Clothes Dryers	Gas Dryer; Electric Dryer

[54] This high-level of consumer adoption implies a perception of aggregate product quality that likely extends beyond the regulated attribute of the product. It may accurately reflect the introduction by manufacturers of new innovations in non-regulated aspects of the product, as well as strategic decisions by manufacturers regarding the overall menu of products they offer for sale.

Figure 8 addresses our third question of how product quality at the time of sale was affected by MEPS changes. It presents the statistically significant changes in the CR-assessed quality of products of the design types listed in Table 9 as new federal MEPS became effective over time, with the exception of changes that occurred concurrently with a change in a relevant CR test.[55] It uses a presentation style that allows for cross-product comparison. For each product design type in Table 9, Figure 8 displays the percent change in a long-standing CR metric between time periods defined by effective MEPS if the change passed a difference-in-means test (at least at the $p<0.1$ level, although most results are $p<0.01$, as is more fully displayed in Appendix I) and the CR metric itself did not undergo a concurrent change. The results in Figure 8 are displayed against a baseline of no change in quality, with our assessment of improvements to the consumer experience oriented to the right of that baseline and detractions from the consumer experience oriented to the left.

[55] See Appendix E for the full list of metrics CR assessed for each product by year. See Table 6 for the relevant periods of time we assessed, based on the effective dates of federal MEPS. See Appendix H for basic statistics on changes in CR ratings before and after a MEPS change, by product.

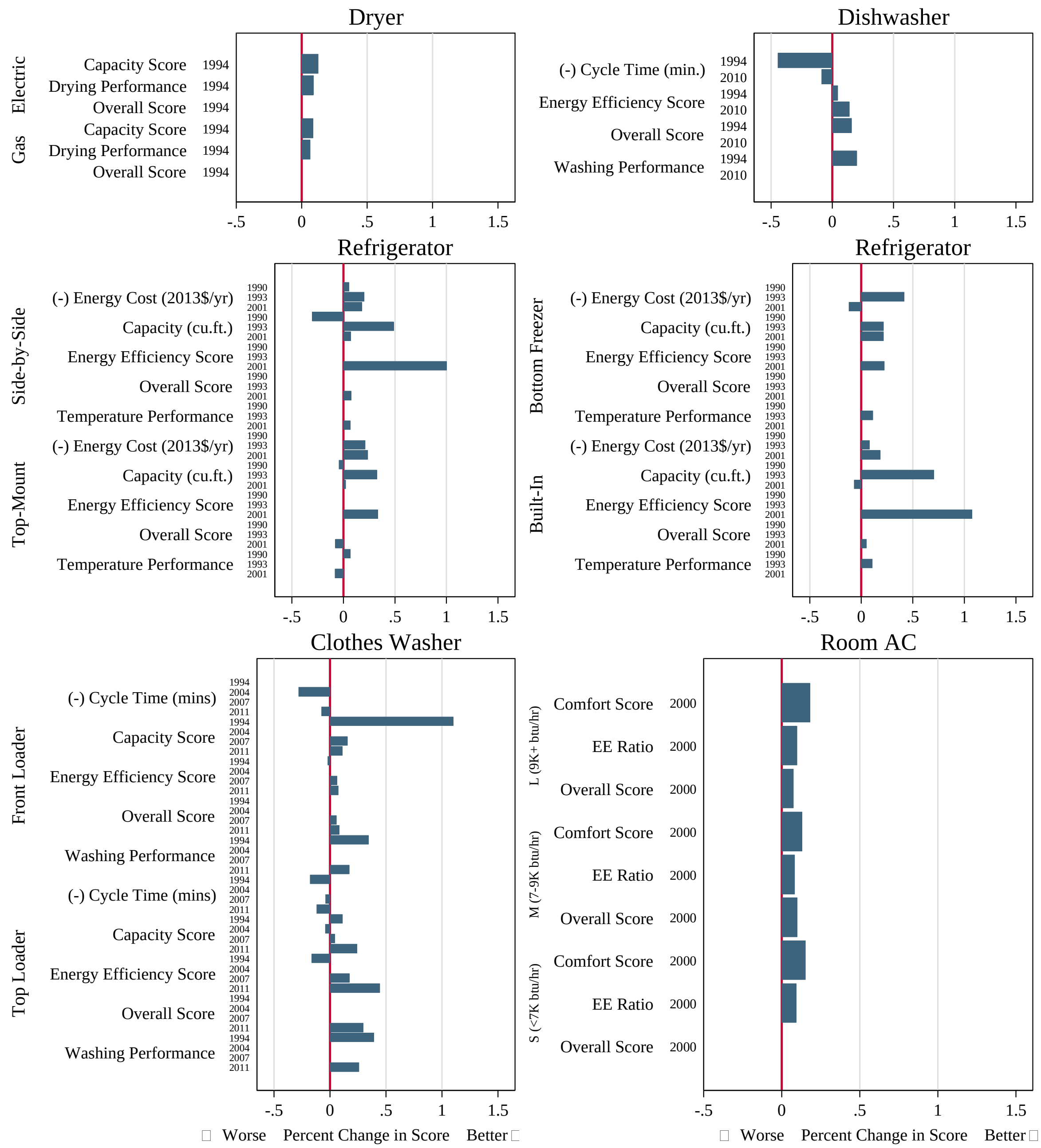


Figure 8: Statistically-significant quality changes across MEPS with no concurrent changes in the underlying CR metric.
Notes: * = Not assessed before 1994. **= Not assessed before 1998.

Figure 8 provides a useful visualization of the extent to which our products tended to improve in quality with the advent of new MEPS, consistent with our hypothesis. For all five case appliances, improvements in the main variables assessed as important to the consumer experience by CR over time dominated deteriorations, with few exceptions. For room ACs, regardless of product design variation according to capacity (which is tied to product class in the MEPS), all of the long-standing variables CR assessed improved after the 2000 MEPS came into

effect (comfort by 13-18%, energy efficiency ratio by 8-10 %, and overall score by 1-10%).[56] This simple story also holds true for the main variables CR assessed for both gas and electric clothes dryers as the 1994 MEPS came into effect (i.e., the capacity and drying performance for gas dryers improved 9% and 2%, respectively, while the capacity and drying performance of electric dryers improved 13% and 9%, respectively). Note that CR did not report the third variable, overall score, for any of our products (except dishwashers) before 1994, so we have no basis of pre/post comparison for clothes dryers at the time of the 1994 MEPS (we report the variable in Figure 8 for visual consistency with the other products).

For standard dishwashers, the story is more mixed. Across the two MEPS changes we consider there are clear improvements, with dishwashers after the 1994 MEPS slightly improving (4%) in CR's energy efficiency score and improving more substantially in CR's overall score (16%) and assessment of washing performance (20%). Similarly, dishwashers after the 2010 MEPS improved on CR's energy efficiency score by 14%. The only detraction to the consumer experience with dishwashers that we observe with MEPS changes is in cycle time, with a 45% slowing of cycle time after the 1994 MEPS and an 8% slowing in cycle time after the 2010 MEPS. Note that although Appendix I presents statistically significant declines in the overall score and washing performance of dishwashers after the 2010 MEPS, we do not include them in Figure 8. This is because there could not be a clear interpretation of these declines due to a simultaneous change in CR's scoring methodology in 2011 toward stricter washing tests, resulting in lower washing performance results in 2011 than 2010.[57]

For refrigerators and clothes washers, which have the most visible architectural distinctions of the five products we study, interpretation of the Figure 8 quality shifts requires an initial discussion of market context. Although our NPD market data, coupled with energy data, only cover 2003 to 2012, we are able to extend our perspective by engaging with Mauer, deLaski et al. (2013), which provides useful trends for refrigerators dating back to 1987 and for clothes washers dating back to 1995.[58]

Three major elements of long-term refrigerator design trends in the U.S. market are worth noting here. First, there has been a major shift in the dominant door configuration of refrigerators between 1987 and 2012. "Top-mount" refrigerators (with the freezer above the refrigerator compartment) represented 73% of the U.S. market when NAECA was passed in 1987, maintained a 60-70% market share through 1998, but dropped to about 35% of the market by 2012 (see Mauer, deLaski et al. 2013, Figure 3). Today, instead of the dominant design in the U.S., they are typically "low-end units that are put into housing units such as apartments, where the purchaser is not the user of the product," according to an industry expert (ibid.). Over the last decade, "bottom-mount" refrigerators (with the freezer below the refrigerator) have significantly cut into the market share of top-mounts, rising from 10% of the market in 2002 to about 30% of the market in 2012 (note that from 1987 until at least 1998, their U.S. market share was less than

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[56] The only exception was a statistically insignificant (and slight) improvement in overall score for small room ACs.

[57] CR changed its scoring methodology in 2011, although the changes are not documented in detail. As an example of the effect this change had, the worst performing dishwasher (GE GLD408R) in CR in 2010 had an overall score of 53, but in 2011, the same model had been downgraded to an overall score of 45.

[58] Mauer, deLaski et al. (2013) assembles market data for refrigerators from two sources, the Association of Home Appliance Manufacturers ("AHAM"; through 2002) and the FTC's Appliance Energy Data (for 2012). The authors provide clothes washer market data from CEC's Historical Appliance Database.

2%; ibid.). Meanwhile, “side-by-side” refrigerators (with the freezer adjacent to the refrigerator) have represented an important third option throughout the time period; a little over 25% of the market in 1987, they have comprised 30-40% of the market since then (ibid.).

The second and third refrigerator design trends worth noting – capacity increases and the growing incorporation of through-the-door (TTD) features providing ice and/or water – are also tied to door configuration. Refrigerator capacity has generally been growing, but the trend is different for different door configurations. Top-mounts are the smallest design (on average, 17-18 cubic feet) with little change in capacity over the period (see Mauer, deLaski et al. 2013, Figure 4). Bottom-mounts have bigger capacity, with a relatively steep increase in capacity between 2002 and 2012 of 20 to 22 cubic feet (ibid.). Side-by-sides are the largest design throughout the period, growing from 22 cubic feet in 1987 to almost 25 cubic feet today (ibid.). Meanwhile, TTD features diffused throughout the refrigerator design mix in 1987-2012, although this is primarily the case for side-by-sides and bottom-mounts, as few top-mounts have historically incorporated TTD features. According to Table 1 in Mauer, deLaski et al. (2013), the majority of side-by-side models had TTD in 1998 (75%), 2002 (81%), and 2012 (86%), while a significant share of bottom-mount models (35%) today have TTD (although none had the feature in 1998 or 2002).

Two major elements of long-term clothes washer design trends in the U.S. market are worth noting here. First, there has been considerable movement in the dominant architecture of clothes washers between 2003 and 2012. Whereas top-loading machines (“top-loaders,” with a vertical axis) held about 100% of the market in 1987-2003 (Mauer, deLaski et al. 2013), front-loading machines (“front-loaders,” with a horizontal axis) had surpassed them in market share by about 2008. Within the next three years, however, top-loaders had returned to a higher market share than front-loaders, with a growth trend that continued through at least 2012. Second, clothes washer capacity has generally been growing between 2003 and 2012 (see Mauer, deLaski et al. 2013 figure 12).

As a reference for some of these market trends, Figure 9 presents the changing U.S. market share of some of the more prominent refrigerator and clothes washer designs, as observed in the 2003-12 NPD data.

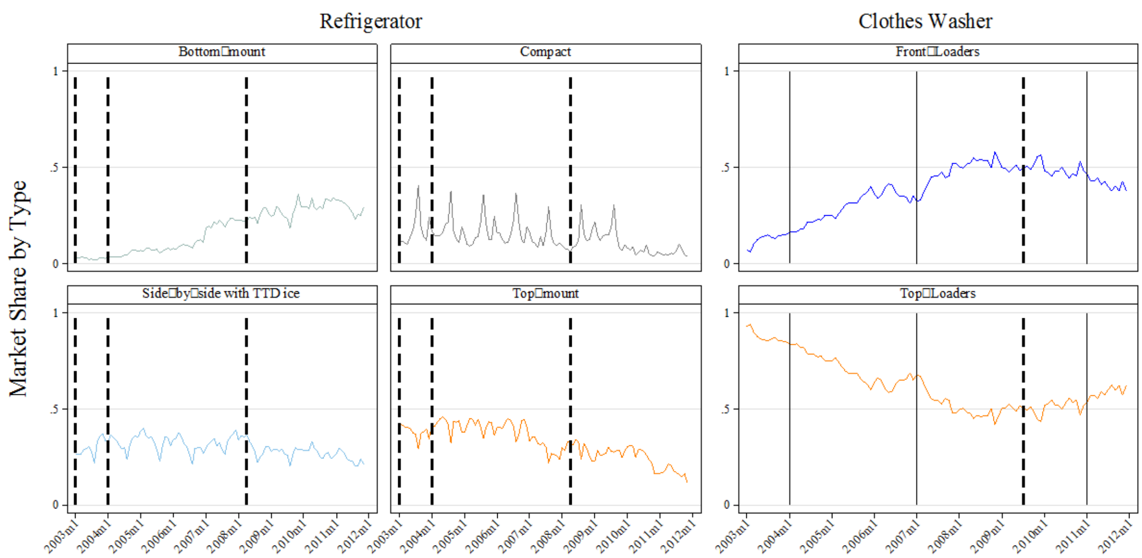

Figure 9: Market share of refrigerator and clothes washer product types over study period

For all four refrigerator product design types we consider, Figure 8 shows that consumers primarily benefited across the 1990, 1993, and 2001 MEPS events on most of the refrigerator quality indicators *Consumer Reports* has assessed over time (namely energy cost, capacity, energy efficiency score, overall score, and temperature performance). The results are so striking that we will only detail here particularly large improvements and the one somewhat notable exception to the general trend. Product quality gains greater than 20% occurred with: energy costs across the 1993 MEPS for top-mounts, side-by-sides, and bottom-freezers; energy costs across the 2001 MEPS for top-mounts; energy efficiency scores across the 2001 MEPS for all four designs; capacity across the 1993 MEPS for all four designs; and capacity across the 2001 MEPS for bottom-freezers. Meanwhile, the only product quality loss greater than 20% occurred with the capacity of side-by-sides across the 1990 MEPS.

For clothes washers, just like the other products, Figure 8 shows that consumers primarily benefited across federal MEPS events (i.e., in 1994, 2004, 2007, and 2011) for both top-loading and front-loading clothes washers. We will only discuss particularly large improvements and diminishments in product quality here. Product quality gains greater than 20% occurred with: washing performance with the 1994 MEPS for both top-loaders and front-loaders; washing performance with the 2011 MEPS for top-loaders; capacity for front-loaders with the 1994 MEPS; capacity with top-loaders with the 2011 MEPS; energy efficiency score with the 2011 MEPS for top-loaders; and overall score with the 2011 MEPS for top-loaders. The only product quality loss greater than 20% was front-loader cycle times with the 2004 tier 1 of the 2001 MEPS. This is in keeping with the cycle time issues with dishwashers, although increasing clothes washer tub capacity trends (discussed above) and declining clothes dryer cycle times documented in an industry expert interview in Mauer, deLaski et al. (2013) have worked to counteract any resulting increase in consumer laundry time overall. Note that although Appendix I presents statistically significant declines in the overall score and washing performance of both top-loaders and front-loaders after the 2004 tier 1 MEPS, we do not include them in Figure 8 because CR changed its testing procedure at the time to become stricter in washing tests, resulting in lower washing performance results in 2005 than 2004, a decline that also affected overall score.[59]

Reliability

Figure 10 addresses our fourth research question, which is how product reliability has changed since appliances have been regulated. It shows first-order trends in the reliability of recently purchased models of four of our case study products (all but room ACs) over the time MEPS have been in effect, according to reports by CR's readership in annual surveys.[60] Consistent with our hypothesis, the repair rates displayed in Figure 10 generally improved for all of our products

[59] The major change CR incorporated was to test models using the maximum possible load size using the adjustable water level, a feature that had become prevalent in most models. The final washing performance score was based on both the testing result from a normal load (8lb) and a maximum load (depending on the washer capacity), with a 50/50 weighting. The effect of the change is illustrated in the energy efficiency ratings of models like the Maytag MAH7500a, which dropped from a 4-point score to a 3-point score.

[60] CR stopped reporting reliability data for room ACs in 1993. According to the magazine, room ACs have extremely low repair rates.

from the beginning of MEPS implementation in the late 1980s, so that almost all the product design types we consider have repair rates of 10-12% (the less-repair prone outliers today are dryers and top-mount refrigerators, while the more-repair prone outlier is side-by-side refrigerators with TTD ice). The reliability trends for dishwashers and clothes dryers were relatively straightforward over the study period, as was the case with the other quality metrics CR reports. For dishwashers, repair rates were worse before the first federal MEPS in 1988, and exhibited a sizable improvement after that MEPS event, with only modest variation (a slight decline in the repair rate from 1990-2000, a slight increase from 2002-12). For clothes dryers, the two product types of gas and electric dryers mirrored each other almost exactly, in a fairly similar trend to that exhibited by dishwashers. Clothes dryer repair rates were at their worst at the time of the first MEPS event in 1988, exhibited a sizable improvement through the second MEPS event in 1994, and then their improvement rate leveled off and generally flattened from 1998-2012.

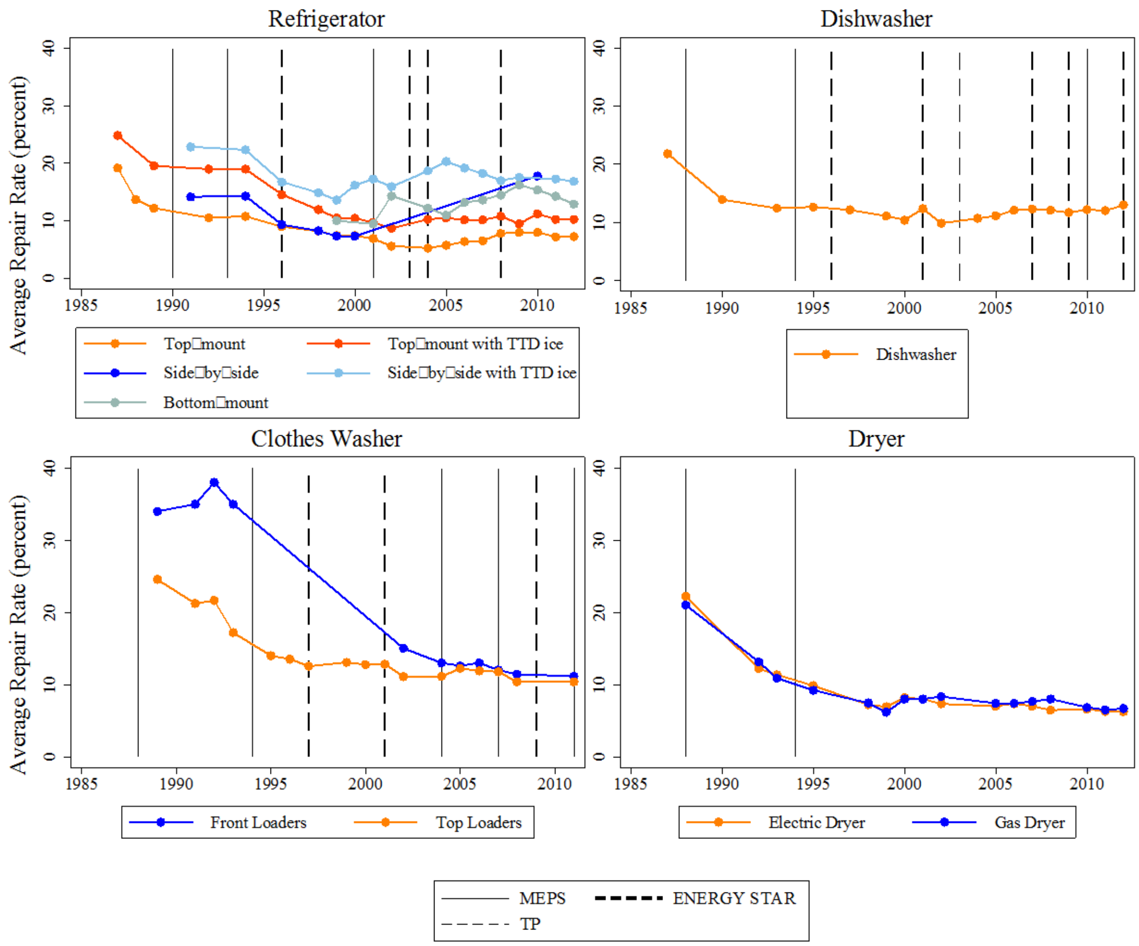

Figure 10: Product reliability trends

For the two products with greater variation in their product architectures, however, there is more variation in reliability rates. For clothes washers, the repair rates of both top-loaders and front-loaders were in their highest range around the time of the first federal MEPS in 1988, and exhibited a sizable improvement across the second federal MEPS in 1994. For the dominant design in the U.S., top-loaders, repair rates leveled off starting about 1995 (see definition of dominant design in footnote 25). For front-loaders, the repair rate in the late 1980s and early

1990s was notably higher than the top-loader repair rate, although it should be noted that this time period coincides with that design orientation representing only a tiny percentage of the U.S. market. After a hiatus in presenting front-loader repair rates (1994-2001), CR revealed in 2002 that front-loader repair rates were comparable to top-loader repair rates, and the two rates have been indistinguishable (and flat) since 2005.

Refrigerator repair rates paint a much more complicated picture. Figure 10 presents trends for the three product types presented in both Table 9 and Figure 9 – top-mounts, side-by-sides (both with and without TTD) and bottom-mounts – as well as trends for top-mounts with TTD ice, which had a much smaller market share than the other products (as did side-by-side refrigerators without TTD ice, which appears likely to be why CR stopped presenting reliability data in 2001-09, as well as in 2011-12). Top-mounts, which start the period depicted in Figure 10 as the dominant refrigerator design, exhibited a very similar repair trend to dishwashers: repair rates were at their worst before the first federal MEPS in 1990 (although already improving rapidly), then flattened to a lower level after that MEPS event, with only modest variation afterwards (a slight decline from 1992-2004, a slight increase from 2004-12). Meanwhile, side-by-sides without TTD ice had slightly higher repair rates than top-mounts when their reliability scores were first reported by CR in the early 1990s, after the first MEPS, but in 1996-2000, after the second MEPS, their repair rates were indistinguishable from top-mounts.

The incorporation of TTD ice features into a refrigerator's product architecture appears to increase the chances that the refrigerator will need a significant repair at some point in time. The repair rates of both top-mounts with TTD ice and side-by-sides with TTD ice (the design with the second-largest U.S. market share throughout the period covered in Figure 10) appear to generally parallel those of their respective door configuration types without TTD ice, but at much higher levels overall. This cannot be said with full confidence about side-by-sides with TTD ice, however, as we lack data on repair rates for side-by-sides without-TTD ice in 2001-2009. It was during this period that repair rates for side-by-sides with-TTD ice increased noticeably, peaking in 2005 – four years after the third federal MEPS – at levels seen ten years earlier. By 2010, when CR again reported repair rates for side-by-side without TTD ice, both types of side-by-side refrigerator had the same repair rate, with side-by-side models with TTD ice declining slightly in 2006-2012.

Finally, for bottom-mounts, which had an insignificant market share through the early 2000s but now account for more U.S. sales than top-mounts, the repair rate increased from levels slightly higher than top-mounts and side-by-sides without TTD ice before the 2001 MEPS, until the rate peaked in 2009, at about the same level as side-by-sides with TTD ice. This increase in significant repairs may partially reflect the rapid incorporation into bottom-mounts of more repair-prone TTD ice features. Today, bottom-mount refrigerators have repair rates higher than top-mounts but lower than side-by-sides with TTD ice.

PRODUCT DESIGN

In this section we address our fifth and sixth questions, both of which relate to product design and regulation.

Our fifth question asks about the effectiveness of two ways to differentiate appliance price trends, namely product "efficiency levels" (ELs, defined previously in Table 7) and product design architectures. We focused on two products, refrigerators and clothes washers, as they provide good illustrations of the concept of differing product design architectures. Note that

overall, we found that within-model (i.e., with fixed effects) average prices declined for the refrigerators and clothes washers that U.S. consumers bought over the 2003-11 period.[61]

There can be many reasons for declines in within-model price trends. While a model remains on the market, its specific components, interfaces, and mappings do not change. Price declines over time in a given appliance model therefore reflect such things as: (1) model pricing decisions; (2) the costs of model assembly (e.g., through learning-by-doing); and (3) the costs of the model's components and interfaces. These changes are likely to be the result of the actions of different firms (e.g., original equipment manufacturers (OEMs), suppliers of components and interfaces) and possibly different units within these firms (e.g., OEM assembly plants, OEM corporate suites, etc.).

Figure 11 motivates the deeper statistical analysis that follows. It illustrates within-model price trends for refrigerators and clothes washers as differentiated by product design category.[62]

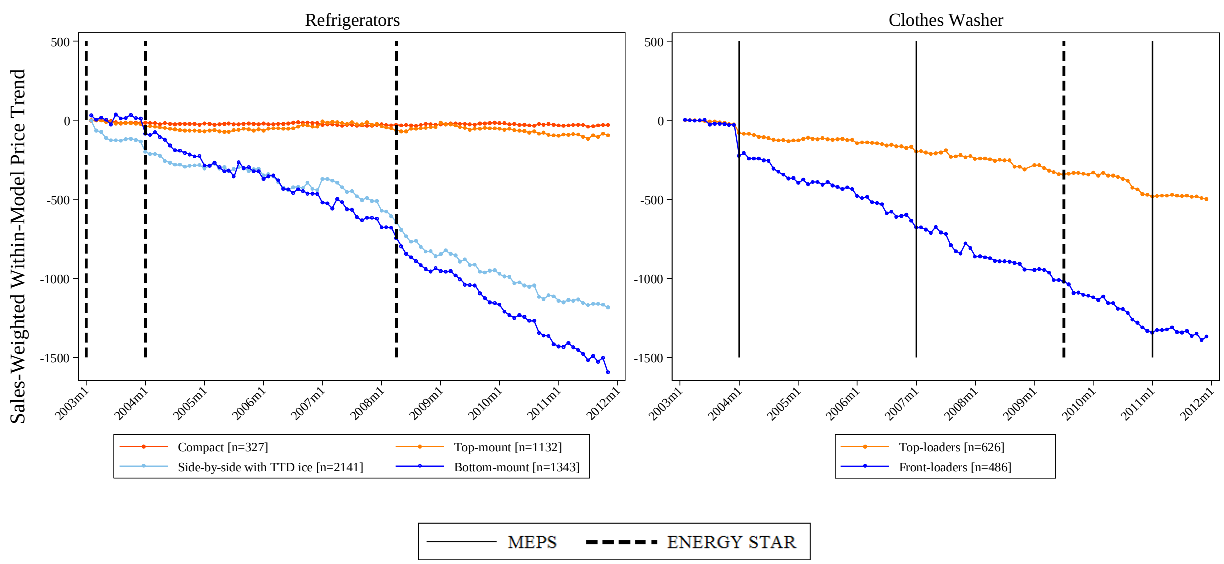

Figure 11: Within-model price trends over time, as differentiated by product type

MODEL DETAIL

The efficiency-level estimation approach we employ is consistent with the DOE's focus on defining cost-efficiency curves in the engineering analysis step of the MEPS rulemaking process. It relies on the idea that innovation related to improved product efficiency will translate in a noticeable way to differential trends in price, as revealed in the marketplace. Meanwhile, the product design estimation approach we employ has parallels to the DOE's emphasis on the importance of product categories in efficiency regulation and resonates with the literature relating to product architecture and design cycles.

[61] As a reminder, footnotes 44 and 45 explain that "within-model" price trends capture the change in product price attributed only to changes in the price of models with certain characteristics as they remain on the market over time, rather than as the mix of models on the market change (i.e., within-model price trends control for fixed effects).

[62] The figure presents the result for refrigerators focusing only on Compact, Top-mount freezer, bottom-mount freezer, and side-by-side with through the door ice (TTD), as these are the only categories with a substantial number of models. The other categories (top-mount with TTD and side-by-side without TTD) have very few models. The regression results below are presented with all product categories included, however.

Our efficiency level–based price trend results are generated using an ordinary least squares regression estimation of Equation 1 and Equation 2. In these equations p_{it} is the deflated price of model i in month t (recall that all prices in this paper are deflated to 2013 values using the Consumer Price Index (CPI) from the Bureau of Labor Statistics (BLS), as mentioned in section 3.13.2); j is an index over the J efficiency levels (or ELs); D^j are a set of indicator variables equal to one if model i is of EL j; and finally, tr_t is a linear time trend increasing by one unit each month. In addition, in Equation 2, γ_i is a model-specific fixed-effect. The parameters estimated in the regressions are $\alpha, \delta, \beta_1, \dots, \beta_{J-1}$, and $\eta_1, \dots, \eta_{J-1}$. The omitted EL in all cases is EL0. The two sets of regressions (with and without fixed-effects) are run both with and without sales-weighted prices. In the case in which prices are sales-weighted, the weights are based on the market share of each product over its entire lifetime in the market. The standard errors are clustered by model in all cases.

Equation 1

$$p_{it} = \alpha + \delta tr_t + \sum_{j=1}^{J-1} \beta_j {D^j}_{it} + \sum_{j=1}^{J-1} \eta_j (tr * D^j)_{it} + \varepsilon_{it}$$

Equation 2

$$p_{it} = \alpha + \delta tr_t + \sum_{j=1}^{J-1} \eta_j (tr * D^j)_{it} + \gamma_i + \varepsilon_{it}$$

The coefficients of primary interest in the regressions are the δ and $\eta_1, \dots, \eta_{J-1}$. The interpretation of δ is the dollar amount by which the prices of the omitted category change each month. In the case of Equation 1, this is on average, including any change based on exit or entry. In the case of Equation 2, the within-model price trend estimate isolates the average rate by which prices of existing models are changing, and does not take into account any change in average prices based on model entry and exit. The $\eta_1, \dots, \eta_{J-1}$ estimates are interpreted relative to the trend of the omitted category. To illustrate: in the case of clothes washers, η_{EL1} is interpreted as the dollar amount by which EL1 prices change each month relative to the same change in EL0 model prices, on average.

Our product design-based price trend results are generated using the same basic approach as in Equation 1 and Equation 2, only with j an index over the J product designs, rather than efficiency levels. The omitted category in the case of refrigerators is top-mount refrigerators, while the omitted category for clothes washers is top-loaders. Note that both of these omitted categories have historically been the dominant designs of these products in the U.S., which is relevant to the sixth research question we address.

MODEL RESULTS

Table 10 and Table 12 present the efficiency level modeling results for refrigerators and clothes washers, respectively, while Table 11 and Table 13 present the product design modeling results in the same order.[63]

[63] Appendix G presents the full set of model results of our analysis of product price and efficiency level, while Appendix J presents the full set of model results for our analysis of product price and design. The product designs

For refrigerators, we see from Table 10 and Table 11 that there is a more pronounced differentiation of product price trends by product design rather than by efficiency level. The primary differentiation in within-model price trend by efficiency level occurs between the second-least efficient (EL1) and least efficient (EL0) levels, with EL1 models declining $1.5-3.2 per month faster than EL0 declines.[64] When considering differentiation by product design, however, within-model price declines by product design have relatively faster drops against the baseline of top-mount price reduction; these range from $5-16 per month, depending on design and whether the result is un-weighted or weighted by sales.[65] This result is consistent with our hypothesis for our fifth research question.

Table 10: Regression results of refrigerator prices by EL

Dependent Variable: Price ($2013)	(1) Un-weighted	(2) Un-weighted	(3) Sales Weighted	(4) Sales Weighted
El 1	146.9		259.2**	
	(147.2)		(128.7)	
EL 2	-187.9		-310.5**	
	(191.9)		(150.0)	
tr (linear time trend)	-2.220	-6.595***	-0.970	-4.188***
	(1.946)	(0.479)	(1.537)	(0.662)
tr x EL 1	1.942	-1.473***	3.643*	-3.187***
	(2.068)	(0.492)	(1.877)	(0.815)
tr x EL 2	4.671*	-0.231	7.719***	-0.968
	(2.573)	(0.670)	(2.036)	(1.259)
Constant	1,435***	2,001***	591.9***	1,215***
	(138.3)	(19.64)	(107.1)	(33.98)
Model fixed effects	No	Yes	No	Yes
Observations	95,790	95,790	95,790	95,790
R-squared	0.006	0.098	0.092	0.192
Number of Models	5,732	5,732	5,732	5,732

Standard errors clustered by model in parentheses. Omitted Category: EL 0. * sig. at p<0.1; ** sig. at p<0.05; *** sig. at p<0.01

Table 11: Regression results of refrigerator prices by product design

Dependent Variable: Price ($2013)	(1) Un-weighted	(2) Un-weighted	(3) Sales Weighted	(4) Sales Weighted
Compact	-416.7***		-391.5***	

we consider are those in Table 9, with certain exceptions that pull from the broader set of NPD product types (see Section 3.1). For refrigerators, the designs are those in the table with the exception of built-ins and the addition of compact refrigerators.

64 In the un-weighted results, EL1 within-model prices drop $1.5 per month faster than the EL0 declining trend of $6.6 per month. In the sales-weighted results, EL 1 within-model prices drop $3.2 per month faster than than the EL0 declining trend of $4.2 per month.

65 In the un-weighted results, within-model prices of side-by-side, side-by-side with TTD, and bottom-mount designs declined faster than the declining trend for top-mount refrigerators of $1.4 per month (at rates of $5, $10.7, and $10.9 per month, respectively). In the sales weighted results, within-model prices of side-by-side, side-by-side with TTD and bottom-mount designs declined faster than the declining trend for top-mount refrigerators of $1.2 per month (at rates of $7.3, $9.9, and $16, respectively).

	(54.05)		(25.38)	
Top-Mount w/ TTD Ice	261.6*		52.19	
	(151.0)		(59.85)	
Side-by-side	2,644***		4,235***	
	(536.7)		(1,149)	
Side-by-side w/ TTD Ice	1,312***		810.2***	
	(94.25)		(62.87)	
Bottom-Mount	1,304***		1,276***	
	(141.6)		(147.0)	
tr (linear time trend)	-0.583	-1.356***	-0.229	-1.147***
	(0.408)	(0.210)	(0.354)	(0.216)
tr x Compact	2.114***	1.173**	0.549	0.979***
	(0.814)	(0.488)	(0.403)	(0.229)
tr x Top-Mount w/ TTD Ice	4.803	-3.932***	7.702***	-2.677***
	(4.581)	(1.119)	(2.537)	(0.764)
tr x Side-by-side	18.01**	-5.034***	-28.11	-7.253***
	(8.678)	(1.739)	(19.04)	(1.386)
tr x Side-by-side w/ TTD Ice	-3.193**	-10.65***	-2.184**	-9.883***
	(1.346)	(0.553)	(0.901)	(0.815)
tr x Bottom-Mount	-1.290	-10.85***	-2.598	-15.96***
	(1.776)	(0.541)	(1.889)	(1.213)
Constant	696.8***	2,095***	506.5***	1,303***
	(31.29)	(20.23)	(20.71)	(22.93)
Model fixed effects	No	Yes	No	Yes
Observations	87,778	87,778	87,778	87,778
R-squared	0.298	0.152	0.549	0.392
Number of Models	5,009	5,009	5,009	5,009

Standard errors clustered by model in parentheses. Omitted Category: Top-Mount. * sig. at p<0.1; ** sig. at p<0.05; *** sig. at p<0.01

This is interesting because product design for refrigerators is not strongly associated with energy efficiency. This can be seen in the energy use distributions across refrigerator product designs which are depicted in Figure 12. Although the figure shows that side-by-side models tend to be the least efficient, and compact models tend to be the most (at least in terms of overall energy use), there is significant overlap in the energy efficiency distributions of these models. Indeed, the distributions of bottom-mount and top-mount models according to efficiency are completely overlaid throughout the time period, which is noteworthy when considering that it is these product designs that exhibited some of the highest product-design based price trend differentiation.

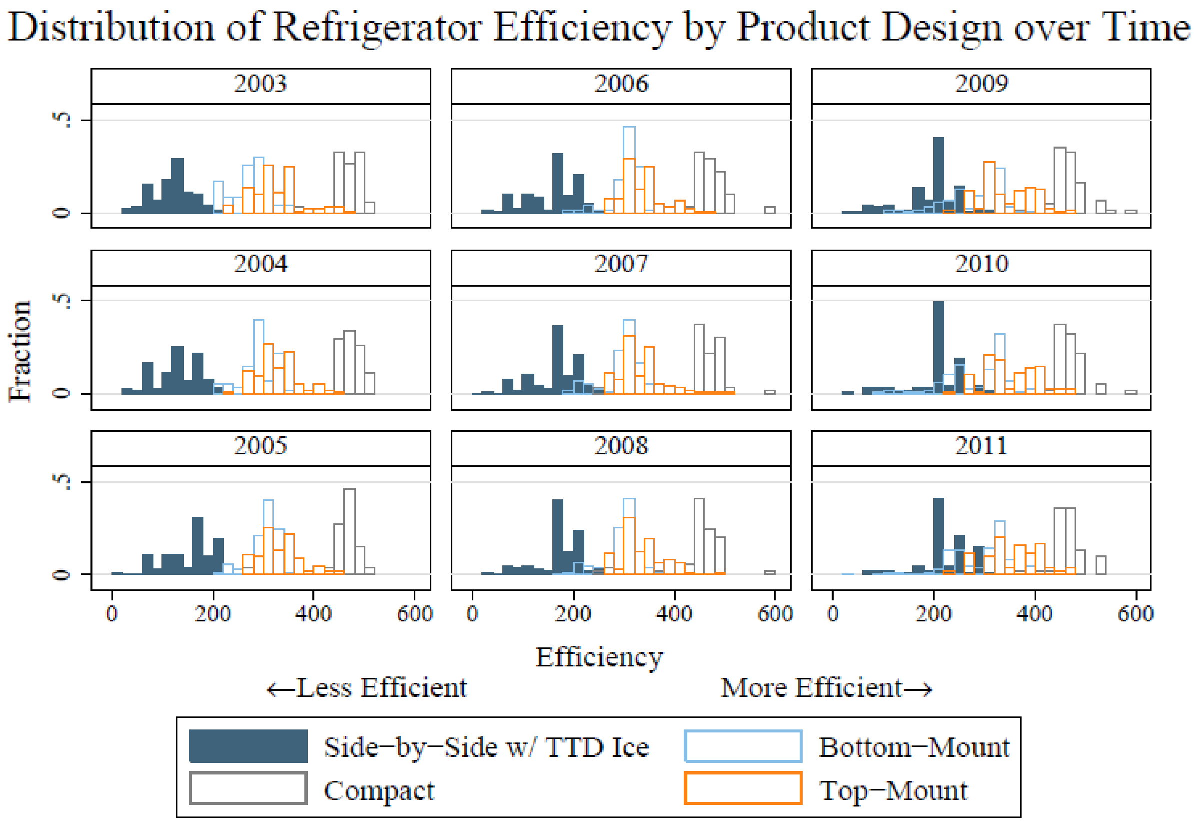

Figure 12: Changing distribution of the energy efficiency of different refrigerator designs over time
Note: The maximum observed energy use for all refrigerators in our data was 790 kWh/year. Our "Efficiency" construct is defined as the degree to which a product uses less energy than this maximum (i.e., a product's "efficiency" is defined as 790 kWh/year – the observed kWh/year for that product). To illustrate: The "efficiency" of a product using 790 kWh/year would be 0, while the "efficiency" of a product using 400 kWh/year would be 790-400=390.

The relative strength of the differentiation of product price trends by product design, rather than by efficiency level, in refrigerators is particularly informative for the engineering analysis step of the rulemaking process, as will be discussed below.

Meanwhile, for clothes washers, we see from Table 12 and Table 13 that both the highest efficiency level (EL3) and the front-loading product design can be said to largely drive the steepness of the product's within-model price decline over time.[66] Although the differentiation in product price trend is slightly more prominent when product design is considered, as opposed to efficiency levels, the results are qualitatively similar. This result is modestly consistent with our hypothesis for our fifth research question.

Table 12: Regression results of clothes washer prices by EL

[66] In the un-weighted results, EL 3 within-model prices drop $7.7 per month faster than the baseline decline of $3.9 per month, while front-loader prices drop $9 per month faster than top-loader prices, which are declining at a rate of $4 per month. In the sales-weighted results, EL 3 within-model prices drop $5.6 per month faster than the baseline decline of $5.2 per month, while front-loader prices drop $8.4 per month faster than top-loader prices, which are declining at a rate of $4.2 per month.

Dependent Variable: Price ($2013)	(1) Un-weighted	(2) Un-weighted	(3) Sales Weighted	(4) Sales Weighted
EL 1	-6.137		23.37	
	(58.56)		(34.17)	
EL 2	126.2**		184.7***	
	(61.75)		(69.38)	
EL 3	750.1***		816.1***	
	(58.98)		(49.42)	
tr (linear time trend)	0.995	-3.878***	0.609	-5.180***
	(3.402)	(1.228)	(3.014)	(1.613)
tr x EL 1	-1.579	1.423	-2.295	3.212**
	(3.672)	(1.226)	(3.122)	(1.631)
tr x EL 2	-3.538	0.801	-3.197	2.174
	(3.488)	(1.315)	(3.137)	(1.699)
tr x EL 3	-6.581*	-7.711***	-6.891**	-5.570***
	(3.444)	(1.339)	(3.064)	(1.763)
Constant	553.7***	1,339***	397.4***	1,085***
	(37.10)	(23.65)	(22.24)	(26.24)
Model fixed effects	No	Yes	No	Yes
Observations	21,481	21,481	21,481	21,481
R-squared	0.307	0.438	0.524	0.549
Number of Models	1,079	1,079	1,079	1,079

Standard errors clustered by model in parentheses. Omitted Category: EL 0. * sig. at p<0.1; ** sig. at p<0.05; *** sig. at p<0.01

Table 13: Regression results of clothes washer prices by product design

Dependent Variable: Price ($2013)	(1) Un-weighted	(2) Un-weighted	(3) Sales Weighted	(4) Sales Weighted
Front-Load	731.3***		761.1***	
	(61.98)		(50.16)	
tr (linear time trend)	-0.0505	-3.982***	0.0771	-4.158***
	(0.353)	(0.341)	(0.387)	(0.527)
tr x Front-Load	-5.126***	-9.022***	-5.809***	-8.408***
	(0.763)	(0.681)	(0.639)	(0.809)
Constant	582.5***	1,326***	465.0***	1,059***
	(23.56)	(22.83)	(29.33)	(23.09)
Model fixed effects	No	Yes	No	Yes
Observations	21,481	21,481	21,481	21,481
R-squared	0.309	0.443	0.469	0.556
Number of Models	1,079	1,079	1,079	1,079

Standard errors clustered by model in parentheses. Omitted Category: Top-Load. * sig.at p<0.1; ** sig. at p<0.05; *** sig. at p<0.01

This result would not have been surprising to anyone involved in the efforts in the 1990s to bring front-loading clothes washers to the U.S., including manufacturers interested in product differentiation and a range of utilities and other organizations interested in reducing appliance

energy use. [67] This is because clothes washer product design and energy use were highly correlated in the case of front-loading machines at that time. The earliest panel in Figure 13, below, illustrates this fact, with starkly different distributions of energy use between top-loading and front-loading clothes washers in 2003. At this point in time, high-efficiency was indeed a strong proxy for a front-loading clothes washer; this had clearly changed by 2011, however.

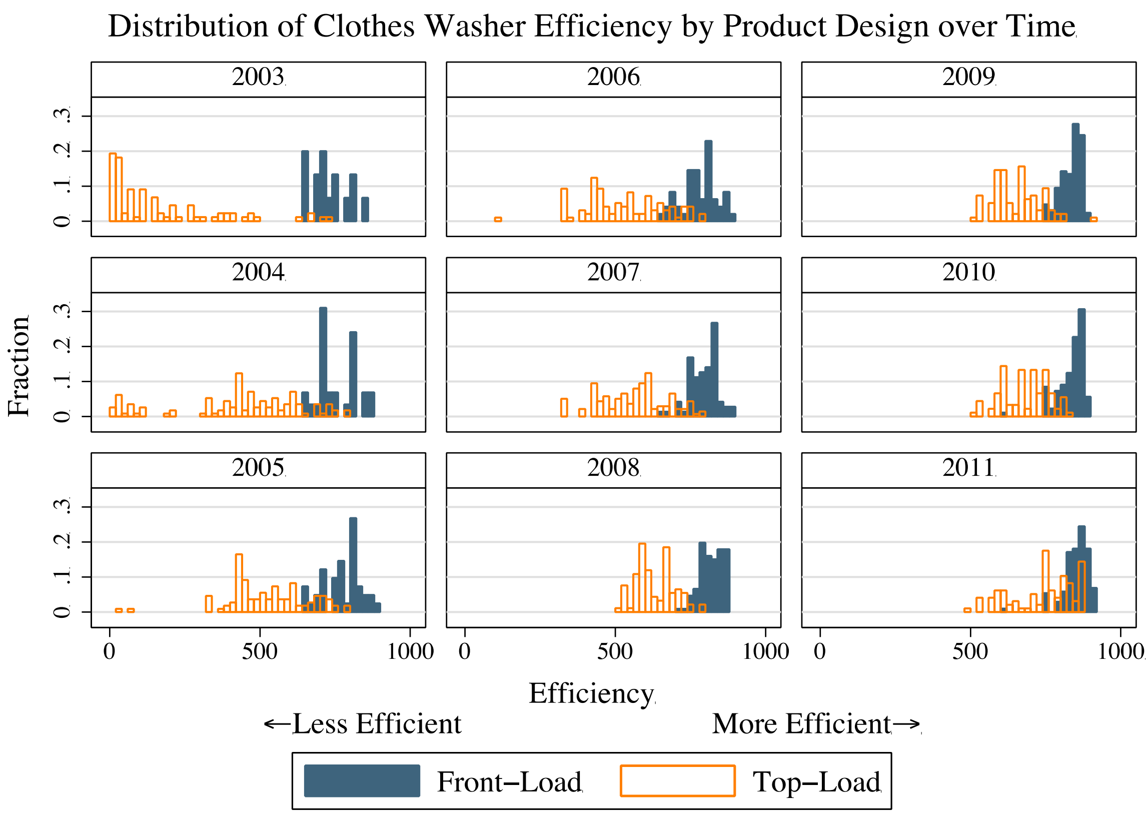

Figure 13: Changing distribution of the energy efficiency of different clothes washer designs over time
Note: The maximum observed energy use for all clothes washers in our data was 1,000 kWh/year. Our "Efficiency" construct is defined as the degree to which a product uses less energy than this maximum (i.e., a product's "efficiency" is defined as 1,000 kWh/year – the observed kWh/year for that product). To illustrate: The "efficiency" of a product using 1,000 kWh/year would be 0, while the "efficiency" of a product using 400 kWh/year would be 1,000-400=600.

Figure 13 speaks to our sixth research question, which considered the incorporation of the concept of "technology-forcing" in MEPS rulemakings (see definition in section 1.1). As we noted in section 2.3, there are several opportunities in the rulemaking analysis process for

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[67] One prominent effort was "The High-Efficiency Laundry Metering and Marketing Analysis" (THELMA) project. THELMA was a collaborative project of 28 electric, gas, water, and wastewater utilities and organizations that was conceptualized in 1993, convened through the Electric Power Research Institute, and concluded in 1998 (Shel Feldman Management Consulting et al. 2001). THELMA involved multiple research activities related to front-loader adoption, including laboratory testing of several clothes washer models market research, and impact analysis of how models operated in real-world conditions. The market research was particularly thorough, involving focus groups, telephone surveys, written surveys, one-week diaries of laundry behavior, a laundry demonstration center, in-home tests over seven weeks (with extensive journaling), and an interview-based study of distribution channels (Hagler Bailly Consulting et al. 1997).

individual efficiency-enabling design options to be eliminated from consideration on the basis that they are not either currently commercially viable or expected to be commercially viable (as assessed by certain criteria) by the time a new MEPS would come into effect. Expectations of technology-forcing effects from the stringent second phase of the 2001 clothes washer MEPS (to come into effect in 2007) provided us with an opportunity to assess how well stakeholders were able to predict the future commercial success or failure of the two clothes washer product architectures, front-loading and top-loading machines. Note that top-loading machines had long been the dominant design in the U.S. market by the time of the 2001 MEPS.

The initial expectations of the fate of top-loading machines under phase two of the 2001 MEPS can be gleaned from the letter to the DOE Secretary from the Competitive Enterprise Institute (CEI) in support of a petition to overturn the 2001 MEPS. As referenced in section 2.3, the CEI letter quotes the 2001 Final Rule as saying that "the original manufacturer data assumed that all clothes washers at … [the 2007 standard] would be [front-loading] horizontal-axis machines," and that in certain tables in the rulemaking analysis documentation the "DOE assumes that top loaders will no longer be sold once the 2007 standard takes effect" (Competitive Enterprise Institute 2001).

The first panel of Figure 13, which shows how far apart top-loaders and front-loaders were with respect to energy efficiency in 2003, illustrates why that expectation seemed reasonable around the time the 2001 MEPS was passed. But the last panel of Figure 13, which shows a strong overlap between the energy efficiency of top-loaders and front-loaders by 2011, makes that expectation seem unreasonable in hindsight. Consistent with our hypothesis, the dominant design was able to adapt in relatively short order to the MEPS requirements.

The issue of technology-forcing in MEPS is more than a simple question of whether products exist that can meet required energy efficiency levels, however. The petitioner concerns regarding the second phase of the 2001 clothes washer MEPS extended to the unregulated quality dimensions of top-loading products that were able to meet the standard. The CEI letter stated that "any market shift from 'tried and true' models [top-loaders] to unproven ones [front-loaders] is very likely to result in increased maintenance costs," despite the lengthy existence of front-loaders on the European market. Although the "change in position" of the Final Rule regarding the projected market share of top-loaders in 2007 reflected the fact that "manufacturers have already begun offering top-loading … washers that would meet the 2007 standard," the letter questioned the idea "that these new ultra-efficient top-loading models provide all the performance characteristics consumers demand."

Our retrospective review findings regarding our third and fourth research questions address this directly. Figure 8 shows no notable ill effects to the top-loading and front-loading machines available for sale in the U.S., as reported by CR across the 2007 MEPS change, and Figure 10 shows no noticeable uptick in significant clothes washer repairs for new purchases in the four years following the MEPS standards.

Product Features

This section addresses our seventh question, which considers how well informed the MEPS rulemaking process is regarding product design. We begin by discussing how the MEPS rulemaking process currently treats design through its construct of efficiency-enabling "design options," which are analogous to the "technical characteristics" concept used to refer to the components, sub-systems, and interfaces in a product's architecture, following Murmann and

Frenken (2006).[68] We then present two simple analyses of *ex post* data on the features of clothes washer models sold in the U.S. in 2003-11: we examine the incidence of feature correlation and explore the connection between product features, price, and energy efficiency.

PRODUCT FEATURES AND THE MEPS RULEMAKING PROCESS

Several parts of the MEPS rulemaking process address efficiency-enabling design options. At the outset of the process, the DOE identifies the full set of "technologically feasible" design options.[69] The DOE then "screens out" candidate design options for various reasons based on expectations of commercial viability and the need to insure against a future involving tradeoffs between efficiency and the unregulated product attributes that consumers value.[70] In the engineering analysis that follows this screening analysis, models "predict the efficiency impact of any one or combination of design options on the product" as part of calculating the relationship between the product's cost and its efficiency. Depending on the rulemaking, three approaches are used to calculate this relationship (see footnotes 4 and 26). The first approach involves calculating the incremental costs of adding specific design options to a baseline model. The second and third approaches do not focus specifically on design options: the second approach calculates the relative costs of achieving increases in energy efficiency levels, without regard to the particular technical features involved; and the third tallies the manufacturing costs associated with a detailed bill of materials derived from product tear-down, which is inclusive of all technical features, including those that are also design options. After the engineering analysis, design options are discarded from further consideration based on either: the screening criteria listed above; a longer expected payback than the average life of the product; or a cost that is expected to increase product life-cycle costs. Surviving design options, when combined together in at least three groupings, then inform the selection of candidate energy efficiency standard levels for each product category; these are then analyzed regarding their economic impacts on consumers and the nation.[71]

After candidate standard levels are determined, the MEPS rulemaking process puts less emphasis on product design. When it does consider design, it focuses on the whole product, instead of product technical features like design options, and it considers product design primarily in relationship to product attributes like price. For example, in 2011 (after our point-of-sale data ends) the DOE began incorporating a "price-learning adjustment" in its assessments of the economic impact of candidate standard levels on consumers over a five year period (the LCC

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[68] More detail on the MEPS rulemaking process was provided in section 2.3 and in Appendix A. Although lacking a strict definition, in practice, design options include a loose range of product technical characteristics, including both sub-systems and components. See footnote 7 for more on product architecture.

[69] As described in section 2.3, to be "technologically feasible," a design option must be "incorporated in commercial products or in working prototypes."

[70] As described in section 2.3, to not be screened out, a candidate design option must: (i) be practical for mass production in commercial products, with reliable installation and servicing "on the scale necessary to serve the relevant market at the time of the effective date of the standard"; (ii) not have adverse impacts on product utility to significant subgroups of consumers or make unavailable any covered product type "with performance characteristics (including reliability), features, sizes, capacities, and volumes that are substantially the same as products generally available in the U.S."; and (iii) not have adverse impacts on health and safety.

[71] The three basic design option groupings are: (1) the most energy efficient combination; (2) the least life-cycle cost combination; and (3) the combination with a maximum 3-year payback.

analysis; see section 2.3) and on the U.S. economy over a thirty year period (the NIA; ibid.). As discussed in section 1.1 and in Taylor and Fujita (2013), this adjustment deflates the agency's projections based on a factor derived from fitting the traditional functional form of an organizational learning curve to price index and quantity data for a covered product.[72] This deflator approach is rooted in the idea that the direct effect of regulation – increasing the market for efficient products – should be expected to have the secondary effect of stimulating organizational learning and other forces that can drive down the prices of new designs.[73]

This idea is not unique to the DOE, nor is its motivation, which is to correct for the often-observed tendency for regulatory cost projections to over-estimate *ex post* costs, a tendency that has potentially been attributed, at least in part, to technical change (see section 1.1).[74] The EPA and NHTSA have also employed a cost-deflator approach based on learning curves in the domain of vehicle air pollution and fuel economy regulation. Unlike the DOE, however, these agencies differentially deflate the costs of individual components of a "package" of compliance-enabling technologies, in an approach that is more consistent with the MEPS rulemaking focus on design options.

Product Feature Analyses

In this section we present the results of two analyses of the detailed technical characteristics of a regulated product that was sold in the U.S. in 2003-11. We explored product design at this level of analysis because of its relevance to the treatment of design options in the MEPS rulemaking and because of potential interest in substituting the EPA/NHTSA deflator approach – which is based on technical characteristics – for the DOE deflator approach.

The construction of the datasets used in our analyses was labor-intensive. We employed a long-standing and generally consistent data source: the manuals for 1,109 clothes washer models for which we had point-of-sale data. To generate useful data, we downloaded and coded the technical characteristics, or "features," presented in these clothes washer manuals. Appendix F provides background information on code scheme development. In Appendix K, Table K1 shows the overall list of features we identified. We grouped these features into seven functional clusters, which are also listed in Table K1. These functional clusters made it possible to provide a clearer presentation of the changing market share of front-loading and top-loading clothes

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[72] The data source generally used for product price is the Producer Price Index (PPI) series that contains the given product. Although in some cases, a PPI series is available for a specific product, in other instances a PPI series only exists for a set of products that includes the specific product (e.g. household laundry equipment, which includes the clothes washers of interest for MEPS, etc.). The data sources generally used for product quantity proxy past U.S. manufacturing output through the metric of U.S. shipments data (which include data on U.S. domestic production plus imports). These data come primarily from manufacturing trade associations (e.g., the Association of Home Appliance Manufacturers (AHAM); the Gas Appliance Manufacturers Association; the Air Conditioning, Heating, and Refrigeration Institute; etc.), as obtained either directly through data request or through industry publications.

[73] Observations of declining appliance prices over time also played a role (see Desroches, Garbesi et al. 2013).

[74] Recall that over the past forty years, about three-quarters of the 60+ U.S. regulatory cost estimates that have been retrospectively reviewed have proven to be significantly inaccurate, where significant inaccuracy is defined as *ex post* costs falling outside the range of +/- 25% of *ex ante* estimates, in keeping with a benchmark established in Harrington, Morgenstern et al. (2000). The majority of inaccurate regulatory cost projections have been over-estimates of the costs of regulation, and Simpson (2011) was unable to reject the null hypothesis that this robust finding was evidence of systematic bias.

washers which incorporate each coded feature; these presentations are provided in Appendix K, figures K1-K7.

For our first analysis, we examined the incidence of feature correlation in regulated clothes washers sold in the U.S. between 2003 and 2011. This was relevant to any econometric analyses we might attempt. It was also informative about how the various technical features of clothes washers might interact, in keeping with the product architecture concept. Figure 14 presents a correlation matrix of the coded clothes washer features.

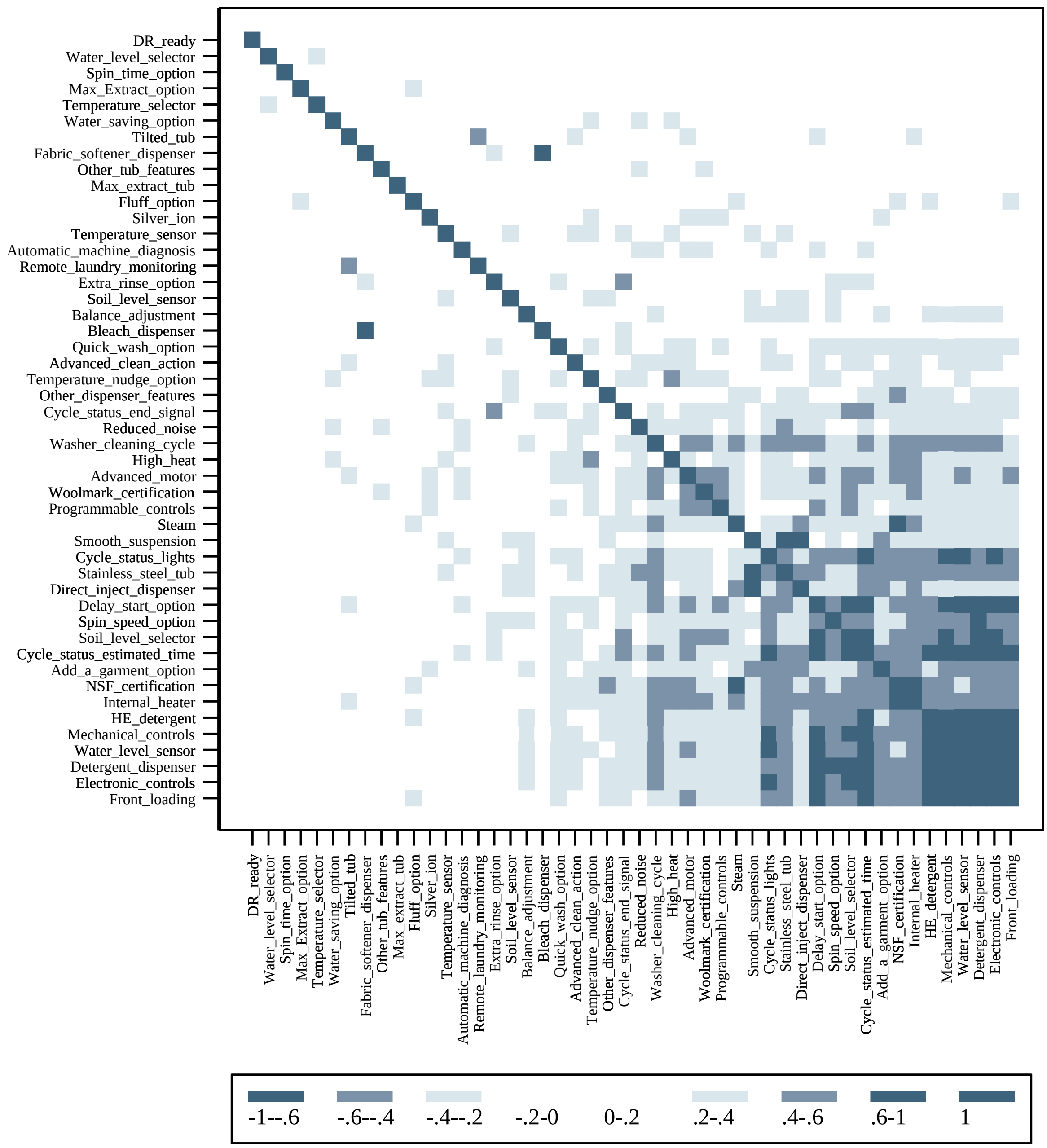

Figure 14: Correlation matrix of clothes washer features

A basic takeaway of Figure 14 is that there is a very high degree of correlation in clothes washer features, as evidenced by the number of features with correlation coefficients of 0.40 or more. This raised concerns for us regarding the approach the MEPS rulemaking process takes to screening out individual design options on the basis of their expected future commercial viability. It also caused us to question the types of design option combinations assessed in the MEPS engineering analyses that inform cost-efficiency relationships and candidate standard levels.

For our second analysis, we explored the connection between product features, price, and energy efficiency as it relates to the MEPS rulemaking process. Recall that at the start of that process, design options are identified in existing commercial products that have the potential to enhance energy efficiency. In the first part of our exploration, we wanted to see if we could duplicate one aspect of this by identifying the energy efficiency-enabling technical features of clothes washers prior to statistically assessing the connections between features and product energy use.

We found this task to be very challenging despite the fact that we were informed about clothes washer energy use through our reading of DOE Technical Support Documents, industry analyst reports, and literature on MEPS retrospective reviews such as Nadel and deLaski (2013) and its sister publication, (Mauer, DeLaski et al. 2013), which drew heavily on industry interviews. It quickly became clear that features that contribute to energy use often contribute to other product performance attributes as well. For example, we felt the following features were likely to be relevant to clothes washer energy use as well as to other product performance attributes: “advanced motor”; “stainless steel tub”; “spin speed option”; “water level sensor”; and “temperature nudge option.” Other features had less obvious linkages to product energy use but might be relevant, such as “delay start option,” a feature that gives consumers greater flexibility in the timing of their laundry work but can also facilitate electricity load-shifting, which is a desired outcome of demand-side management programs.

In the face of this complexity, we developed what we thought was an inclusive decision rule to identify energy-related features. Given that a feature can have only three conceivable roles regarding product energy use – it can affect product energy use, it cannot affect product energy use, or it can affect both product energy use and other product performance attributes (e.g., cleaning power, fabric care, product durability, etc.) – we eliminated only those features that we thought had no connection to product energy use. The features that we thought, prior to our statistical analysis, were relevant to energy use were: “advanced motor,” “stainless steel tub,” “advanced clean action,” “steam,” “spin speed option,” sensor features (“water level sensor,” “soil level sensor,” and “temperature sensor”), and nudge features (“water-saving option,” “Max Extract option,” “temperature nudge option,” and “quick wash option”). Note that most of the features we identified in our “prior grouping of energy-relevant features” fall in the more densely correlated quadrant of the auto-correlation matrix in Figure 14, with the exception of a few sensors.

Figure 15 shows the degree of correlation between clothes washer features and the average energy consumption and average price of the models that incorporate each feature. In this figure, features in the prior grouping of energy-relevant features are identified with an asterisk, which makes it apparent how inaccurate we were in identifying energy-relevant features. Of the 10 features that are strongly correlated with product efficiency, we only identified 2 as energy-related, and we were very surprised to learn how highly correlated some of the features we did not identify were with product energy use (e.g., detergent dispensers). This result, as well as the

high degree of feature correlation in clothes washers, raised questions for us about the accuracy of the approach taken in the MEPS rulemaking to design option identification and screening. We hope to pursue these questions in future research.

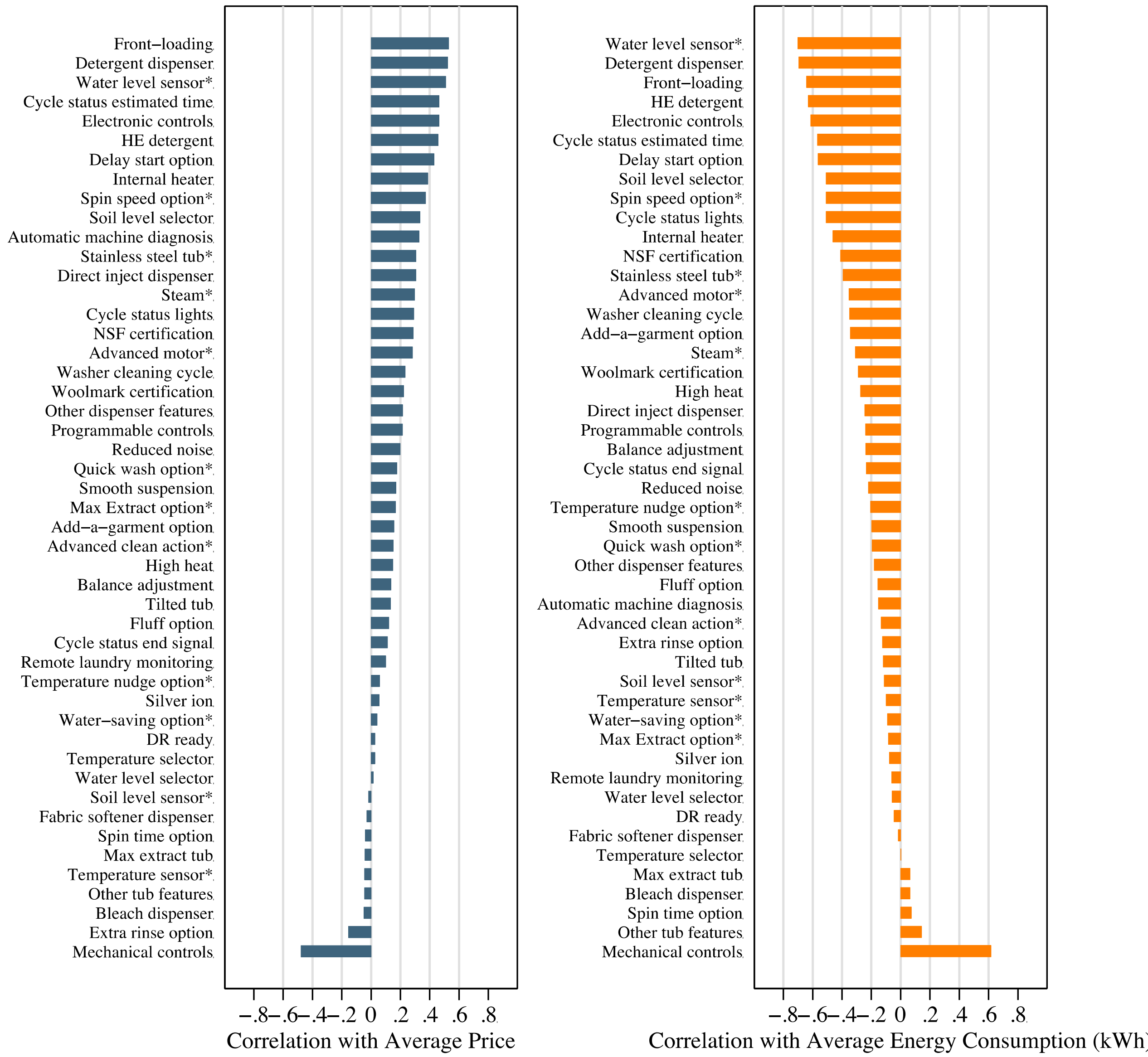

Figure 15: Degree of correlation between clothes washer features, product price, and product energy consumption

<u>Note</u>: Features we coded as "energy-related" are highlighted with an asterisk.

Figure 15 has a more subtle implication for the price-adjustment approach of the DOE. In the correlations between features and product price, the top ten most correlated features are the same as those most correlated with product energy use (although in a different order). But the strength of the correlation between features and energy use is higher than it is between features and price. For example, more features have strong (i.e., >0.4) correlations with reduced product energy consumption (13) than with increased product price (7). This is interesting to juxtapose with the results regarding question five, which demonstrated that within-model price trends for

refrigerators and clothes washers were better differentiated by product design at the level of product architecture (i.e., product categories, following the rulemaking process) than by product efficiency level. This suggests that more can be projected from individual features about a product's efficiency than its price, which makes intuitive sense given that product price involves more than the costs associated with a product's architecture, it also involves strategic decisions by firms as to the market value of a product, taken as whole. The implication for adjustments of regulatory cost projections seems to be that applying differential learning curve adjustments to compliance-enabling component parts and then summing those adjusted numbers, as in the EPA/NHTSA approach, might introduce more error than applying a learning curve adjustment derived from the product's price, as in the DOE approach.[75]

5 Discussion

Here we summarize our main results and discuss how they contribute to scholarship on regulation and innovation, as well as what they imply for the MEPS rulemaking process. In these latter two sections, we highlight questions for future research where appropriate.

5.1 Summary of Results

The seven main research questions we addressed in this study broke down into two groups, with the first four consistent with the traditional analytical focus of retrospective reviews regarding the burdens and benefits of regulation, and the latter three dealing with issues related to the interplay between regulation and product design. The first four questions focused on the price and quality of regulated products, with quality considered in both its regulated (i.e., energy use) and unregulated (i.e., performance) dimensions. The latter three questions addressed issues related to the interplay between regulation and product design which are not often called out in traditional retrospective reviews, despite their relevance to policy-relevant topics like rulemaking accuracy and regulatory-induced innovation.

Our first question asked how accurate MEPS rulemaking cost projections were when compared to the price of products sold in the U.S. market after regulation. Our results were consistent with our hypothesis, which was that projections would over-estimate observed prices, consistent with well-established findings in the general retrospective review literature (see, e.g., Harrington 2006, Simpson 2011). *Ex ante* regulatory cost projections significantly over-estimated the majority of model price observations across all efficiency levels. By product, significantly over-estimated observations accounted for: > 95% of room AC observations; 54-66% of refrigerator observations (depending on product type); 42-72% of dishwasher observations; and 50-81% of clothes washer observations.[76] In addition, we found that within-model (i.e., with fixed effects) average prices declined for the refrigerators and clothes washers that U.S. consumers bought over the 2003-11 period.

Our second question asked how energy efficient purchased products were after regulation. We addressed this in comparison with various MEPS for all the case appliances except clothes dryers (for which we lacked data on energy use). We also addressed this in comparison with expectations of product market share contained in the rulemaking analysis for one product,

[75] Sensitivity analysis would also be easier with the DOE approach.

[76] Clothes dryers had to be modeled in a different way, but the results were similar.

clothes washers. The results were generally consistent with our hypothesis that post-regulatory product energy use would at least match the minimum standards (and by analogy, MEPS rulemaking projections), in keeping with previous retrospective reviews of the effectiveness of MEPS (see Dale, Antinori et al. 2009, Nadel and deLaski 2013). We found that the monthly sales-weighted average energy use of the four relevant case appliances was better than the standard for almost all the data points in our study period. In the case of clothes washers, we found that regulatory analyses underestimated how enthusiastically U.S. consumers would buy highly efficient products.

Our third and fourth questions asked how the unregulated quality dimensions (e.g., performance, capacity, etc.) of products offered for sale changed with MEPS. Our third question asked about quality at the time of sale and how it changed across MEPS events, while our fourth question asked about the post-purchase reliability of regulated products over time. The results were generally consistent with our hypothesis that we would not see significant tradeoffs regarding product performance and reliability, in general, in keeping with broader innovation and manufacturing trends as well as with previous retrospective reviews of MEPS. Indeed, in most cases, the statistically significant changes that occurred in third-party quality variables across MEPS events represented improvements in product quality. Similarly, the rate of significant repairs over five years of product ownership generally declined from the time appliances were first subject to federal MEPS.

Our fifth question asked whether observed within-model price trends could be better differentiated by either product design or by product efficiency level in two products which could easily be distinguished by different architectures (i.e., refrigerators with different freezer locations and clothes washers with different spin axes. The results, which were relevant to certain MEPS rulemaking analyses, were consistent with our hypothesis, as there was a stronger effect of product design versus product efficiency levels in differentiating the within-model product price declines mentioned above.

Our sixth question asked about the accuracy of pessimistic expectations of technological change at the time of passage of a clothes washer MEPS, the second phase of which was considered likely to be technology-forcing (see definition in Nentjes, de Vries et al. 2007). The results were consistent with our hypothesis that these expectations were too pessimistic and the regulation would not be stringent enough to eliminate a dominant product architecture from sale in the U.S., as the MEPS rulemaking process tends to work against technology-forcing. Instead, we found that the dominant design of clothes washers in the U.S. – top-loading machines – evolved rapidly in the face of regulation.

Finally, our seventh question explored the treatment of product design in the MEPS rulemaking process and in clothes washers available in the U.S. market. In the rulemaking process, individual design options are eliminated from regulatory assessments for various reasons related to current and expected commercial viability and the maintenance of product performance attributes of value to consumers. Surviving design options are combined for analyses related to the determination of cost-efficiency curves. In addition, starting in the year our point-of-sale data ends, the DOE began adjusting its product analyses based on a price-learning relationship derived from a price index and shipments data on one or more regulated products, limiting the design-level analysis to that of the whole product rather than individual design options.

Meanwhile, in clothes washers available in the U.S. market, we observed a high degree of feature correlation, as well as many features with high degrees of correlation with both product energy use and product price (although a slightly stronger correlation with product energy use). These observations have potential implications for the validity of current rulemaking approaches and for the empirical literature on the Porter Hypothesis, as will be discussed below.

5.1 Implications for the MEPS Rulemaking Process

The traditional purpose of retrospective reviews of regulation is to use the contrast between regulatory expectations and outcomes to inform future rulemakings. Here we reflect on what our findings in the areas of product price, quality, and design after regulation imply for the MEPS rulemaking process. To do this, we briefly return to the statutory language that underlies the MEPS rulemaking process. As mentioned in section 2.3, the original 1975 EPCA called for efficiency targets that are "the maximum percentage improvement" that is "technologically feasible and economically justified." Although EPCA has been modified many times, these basic criteria still guide the MEPS rulemaking process.

Our first four questions are relevant to the way that MEPS have been shown to be "economically justified" through the rulemaking process. As mentioned in Appendix A, when the first EPCA amendments were brought in as part of the 1978 NECPA, "economic justification" became the result of a determination by the DOE that "the benefits of the standard exceed its burdens." This determination was to be based on seven factors: (1) the economic impact of the standard on manufacturers and consumers; (2) a comparison of the savings and costs associated with the standards (i.e., lifetime operating cost savings versus any increases to initial price and/or maintenance costs); (3) projected energy savings; (4) any lessening of the utility or the performance of the covered products; (5) any lessening of competition; (6) the U.S. need to save energy; and (7) "any other factors the Secretary considers relevant."

The results of our first question, which revealed a significant degree of overestimation involved in projecting the price of regulated products, support the economic justification of standards. Our results speak in particular to factor 1, as they imply that the economic benefits of MEPS to consumers are possibly being underestimated.[77] Our overestimation results also address the concerns that seem inherent to part of factor 2 as they imply that the initial price of regulated products may be lower-than-expected. In addition, our finding of within-model price declines (i.e., product-level price declines without consideration of model entry or exit) for refrigerators and clothes washers imply that these lower-than-expected prices may decline further as they remain on the market.

The results of our second question, which revealed that the energy efficiency of products purchased after regulation exceeded the standards as well as market projections (in the one case appliance for which those projections were made), speak directly to factor 3, or the projected energy savings associated with standards. Our results imply that these projected energy savings may have been underestimated over the years. Future work might follow-up on this at an aggregate level to better assess the energy impact of standards.

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[77] We note, however, that to our knowledge, the second part of factor 1, the economic impact of standards on manufacturers, has not been the subject of retrospective review. As we mentioned in section 2.3, we hope to address this in future work.

The results of our third and fourth questions speak both to factor 4 regarding concerns about lessening the utility or performance of covered products, as well as to part of factor 2 regarding concerns about the maintenance cost effects of standards. The results of our third question show that for the models tested and reported on by *CR*, product performance at the time of sale often improved across MEPS. This implies that the MEPS rulemaking process succeeded in ensuring that product utility and performance were not lessened by standards, at least if judged by the availability of high-quality, efficient appliances on the U.S. market. Meanwhile, the results of our fourth question show that product reliability has improved considerably since our case appliances were first covered under federal MEPS, at least according to the incidence of major repairs. Although this suggests that maintenance costs may have declined over this time period, we note that our data do not attribute a dollar value to significant repair incidents.

Our fifth question is primarily relevant to the economic justification for MEPS, particularly with respect to the concern of factor 2 regarding the initial price of regulated products. As mentioned above, the within-model price declines we observed were the subject of our question five analysis. We found that product design architecture (i.e., the freezer location in refrigerators and the spin orientation of clothes washers) was a better way to differentiate these within-model price declines than was product efficiency levels, although in refrigerators there was a stronger case for this. Recalling that within-model price declines over time reflect such things as OEM and supplier pricing decisions, as well as the costs of model assembly (e.g., through learning-by-doing), our results for these two products indicate that there can be more occurring regarding price at the level of the product sub-category than with respect to products as grouped by their efficiency attributes. This has potential implications for technical elements of the rulemaking process, including the engineering analysis determination of cost-efficiency relationships for use in economic analyses as well as the price-learning adjustment developed by the DOE to help counteract the influences that contribute to product cost projection errors.

Our final two questions are relevant to the statutory requirement that efficiency targets be "technologically feasible." As mentioned in sections 2.3 and 4.1, the implementation of this criterion in the rulemaking process initially involves identifying design options in current commercial products and working prototypes. There is a present bias to this process that locks into rulemaking consideration only those technologies that are the result of prior product development cycles; this is despite the many years that will take place between design option identification and the time a new standard will come into effect, not to mention the fast pace of general technical change (which has been enabled by new information and communication technologies). In the second step of the rulemaking process, design options are screened out not because of present conditions but because of future projections. Screening criteria include whether an option is expected to be practicable to be manufactured, installed, and serviced at scale and whether it is expected to allow for the preservation of product performance.

The results of our sixth question addressed technological feasibility issues at the level of the product, rather than the design option. They showed the return to dominance of the top-loading clothes washer design after a stringent regulation and compared this outcome to early expectations of rulemaking analysts that were picked up on by petitioners interested in remanding the standard. The rapid, and generally unexpected, adaptation of this product design to stringent MEPS raises interesting questions about the appropriate level of product design (i.e., the whole product, the product architecture sub-category, or the product feature) to assess regarding technological feasibility. It also raises questions of whether a technology that was

similarly distinguished by product architecture but not the dominant design, with all that entails regarding the market power and resources likely to be available to its manufacturer, would have been able to similarly adapt. This appears to be a subject worth future exploration.

From our seventh question results, a few insights emerged about product design under regulatory conditions that present potential avenues for future research. First, the high degree of feature correlation in clothes washers hints at a need to refine the rulemaking analysis approach to identifying and screening individual design options, as well as to reconsider how design option combinations are composed for use in the engineering analysis. Future research on whether high feature correlation holds in other appliances and what the engineering and business rationales are for various feature combinations may be useful in supporting any potential analytical refinement. Second, the contribution of many clothes washer features to both energy use and other aspects of product quality raised questions for us about the effectiveness of the rulemaking process approach to identifying efficiency-enabling design options. Third, the relative strength of the correlation between features and energy use, rather than price, when combined with the results of question five about the relationship between product architecture and within-model price trends, suggests that product architecture is likely to be a more a more promising innovation concept to explore in future efforts to refine rulemaking cost estimates. Differentiating projected price trends by product design (or product class, to use the MEPS rulemaking term) might provide more nuance and accuracy than the somewhat broad price-learning adjustment currently employed by DOE. It would also appear to account better for non-learning dynamics in the appliance industry than the somewhat narrow adjustment approach currently employed by the EPA and NHTSA.

5.2 Contribution to Scholarship on Regulation and Innovation

The relationship between regulation and innovation is potentially bi-directional: regulation can affect innovation as well as be affected by it. Here we consider how our results fit with these two ways of thinking about this relationship.

As we discussed in section 1.1, the economic and legal literatures that inform regulatory analyses are not resolved regarding the expected influence of regulation on the rate and direction of technical change. The first contention that dominates the debate is that innovation can be induced to both public and private benefit by well-designed regulation (see, e.g., the "Porter Hypothesis," as articulated in Porter and Van der Linde 1995). The second is that information asymmetry between regulators and the regulated regarding private sector business operations, including innovation management, implies that regulation should be expected to hinder innovative activities (see, e.g., Stewart 1981).

Of these two contentions, the preponderance of evidence we report in this working paper is more consistent with the first. The products purchased by consumers after regulation had unexpectedly low prices and unexpectedly high levels of energy efficiency. In most cases, the models offered for sale in the U.S. also saw statistically significant improvements in product quality across MEPS events, according to CR tests. Over the longer term, within-model prices declined while product reliability improved. And the efficiency distributions of top-loading clothes washers rapidly evolved in a period where MEPS were becoming increasingly stringent. Additional research, however, is needed to attribute these trends more directly to the influence of regulation (see, e.g., Spurlock 2013)

Our post-regulatory product price, efficiency, and quality results, however, when combined with

our finding that many clothes washer features contribute both to energy use and other aspects of product quality, point to an intriguing potential mechanism to explain differential occurrences of regulatory-induced innovation. In a slightly different take on the literature synthesized in Murmann and Frenken (2006), product energy use could be considered a “core” product performance attribute, which many technical characteristics of a product contribute to. Setting a lower limit on this core performance attribute through MEPS may not only constrain the acceptable range of a product’s energy use, but may also prompt product designers to weight product energy use more prominently against other performance attributes. This second effect should be expected to prompt at least some degree of ancillary problem-solving in technical issues involving other product performance attributes which energy-related features also affect. If these technical issues are insoluble, perhaps trade-offs should be expected in these other product performance attributes. But if they are not insoluble, new solutions should be expected to deliver product performance attributes that benefit from fresh takes on topics ranging from how to incorporate exogenous innovations in fast-moving areas such as electronics, material science, etc. to ways to meet and shape consumer preferences through product design.

With respect to the effects of innovation on policy, our results suggest several new research avenues. First, our results on the adaptiveness of a dominant product design to stringent standards raises questions of whether this can be observed across many products; what role the advantages of dominant design (e.g., market power, slack resources for innovation, etc.) have in this adaptiveness; and what the public rulemaking record has to say about the politics of “technology-forcing” regulation. A related research project would compare the screening analysis projections that certain design options would be technically infeasible over the standard-setting time horizon to the commercial adoption (or lack thereof) of these screened-out design options.

Second, the MEPS rulemaking process discussed in section 2.3 and Appendix A allows specific technical features to define new product classes that are subject to tailored performance standards (see the progress of the TTD feature from a MEPS exception to a MEPS category, as related in section 2.3 and footnote 24). These feature-defined product categories raise interesting questions of the degree to which MEPS are truly “performance-based,” as opposed to “technology-based”; these two terms have considerable meaning in the literature on regulation and innovation. Note that the existence of feature-defined regulatory categories may also provide a strategic incentive for firms to introduce new non-regulated product features (e.g., TTD features), and may also generally affect their approaches to bundling energy-related features with other features. Both subjects merit further investigation.

Third, our project highlighted a few locations in the rulemaking process in which business information on technology shaped regulatory expectations (i.e., the screening analysis, the engineering analysis, the manufacturer impact analysis, etc.). In future work, it would be interesting to assess the kind of information exchange that occurs in these parts of the rulemaking process, given the importance of the mediating variable of information asymmetry to the school of thought regarding the expectation that regulation should hamper innovation.

One final topic is important to raise here because of its possible pertinence to the gap between the expectations and observations of MEPS-compliant product price, energy use, and quality that have been presented in this project. That topic is the possible influence of behavior. It may well be that regulators and other stakeholders to the rulemaking process are more risk averse in their perceptions of the future of technological change than is warranted by available evidence. There

are a number of environmental factors that shade the rulemaking process (e.g., political pressures, legal constraints, limited analytical resources, etc.) and could be contributing to a general pessimistic bias. It may be valuable to use behavioral techniques to test whether this is the case, to what extent it might color rulemaking assumptions and outcomes, and consider the possible interventions that could be used to address any systematic biases.

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APPENDIX A: BACKGROUND ON REGULATION

This appendix summarizes much of the history of U.S. federal minimum efficiency performance standards, or MEPS and provides an introduction to the regulatory analysis process as it has evolved in the U.S. Department of Energy (DOE) since the "Process Rule."

History of U.S. Federal MEPS

The origins of U.S. federal MEPS trace back to European MEPS, as well as to MEPS at the U.S. state level. As reviewed in Nadel (2002), "there are unconfirmed reports that Poland may have adopted mandatory minimum energy efficiency standards for a range of electrical appliances as early as 1962." The first confirmed account of appliance standards occurred in 1966, however, with a French refrigerator MEPS. Later in the 1960s and early 1970s, appliance standards became a favored instrument of efficiency advocates and states like California and New York, in order to help combat a number of regional policy challenges related to rapid growth in electricity demand (Nadel and Goldstein 1996).

The public concern about energy security, the high energy prices which accompanied the 1970s oil crises, and the existence of state-level MEPS that affected at least part of the U.S. appliance market, all contributed to the establishment of federal MEPS in the 1975 Energy Policy and Conservation Act (EPCA) (Pub. L. No. 94-163). Federal MEPS were designed to preempt, or "supersede" state standards, but they took some time to get underway for a variety of reasons, including institutional ones. The requirements in EPCA 1975 were amended in the National Energy Conservation Policy Act (NECPA) of 1978 (Pub. L. No. 95-619), as a result of a variety of developments including delays in establishing test procedures and the reorganization of the Federal Energy Administration (FEA) into the Department of Energy (DOE). Just before leaving office in 1980, the Carter Administration proposed the first federal MEPS for a number of appliances (Nadel and Goldstein 1996).

Final MEPS were not issued before the Carter Administration left office, however, and the incoming administration made several attempts to prevent their issuance (Nadel and Goldstein 1996). Although each failed in the courts, the net effect was to delay the advent of federal appliance MEPS for several years. These attempts included: an effort to get Congress to de-authorize federal MEPS; an effort to indefinitely delay the issuance of final rules; and a move to define the statutory threshold of "significant" energy savings to be too high to require any appliance MEPS to be set (this effort is today known as the "no-standards" standards) (ibid). But multiple ongoing state standard-setting efforts throughout the 1980s put pressure on manufacturers and prompted them to negotiate for new, preemptive federal legislation.

The 1987 National Appliance Energy Conservation Act, P.L. 100-12 (NAECA) was the result, its design influenced by negotiations amongst a coalition of manufacturers, retailers, non-profit environmental organizations, state energy offices, consumer organizations, utilities, home builders, and others (Nadel and Goldstein 1996).[1]. In NAECA, the threshold criteria for setting a MEPS was set at "the maximum energy efficiency levels that are technically feasible and economically justified" for a given product class. Classes are separated according to the criteria of the "(1) type of energy used, or (2) capacity or other performance-related features such as those that provide utility to the consumer or others."

[1] EPAct 1992 also incorporated water efficiency standards for the first time.

New products were added to the coverage of federal appliance MEPS in 1988 (National Appliance Energy Conservation Amendments of 1988, P.L. 100-357) and again in 1992 (the 1992 Energy Policy Act, P.L. 102-486 (EPAct 1992). In 1995 and 1996, however, DOE conducted a review of the process for developing appliance MEPS and suspended several rulemakings indefinitely as a result (see “Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products,” 61 FR 36974 (July 15, 1996) 10 CFR 430 Appendix A to Subpart C, or the “Process Rule”). Note that several elements of the Process Rule have been superseded or supplemented by more recent practices.

The next most significant legislative and regulatory events related to MEPS occurred starting in the mid-2000s, with the Energy Policy Act of 2005, P.L. 109-58 (EPAct 2005); and the Energy Independence and Security Act of 2007, P.L. 110-140 (EISA). Note that EISA established the first water efficiency standards for dishwashers and clothes washers, to come into effect in 2010 and 2011, respectively. Later standards were issued through the support of a consensus agreement known as the “Joint Petition” and are discussed in the context of specific case products in the main text of this paper.

The Regulatory Analysis Process

In this section of the appendix, we provide more detail on the objectives of the Process Rule (“Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products,” 61 FR 36974 (July 15, 1996) 10 CFR 430 Appendix A to Subpart C) and on some of the detailed considerations that the Process Rule calls for in determining a proposed standard level.

Process Rule Objectives

The objectives section of the Process Rule provides a useful overview of the guiding principles for DOE regulatory analysis. Table A1 presents a condensed version of the ten objectives listed in the Process Rule. It also justifies and/or elaborates on these objectives using other language from the Process Rule as well as occasional reference to other sources. Finally, Table 1 provides a concordance between the Process Rule objectives and the section(s) of the Process Rule in which various objective(s) are realized.

Table A1: Objectives of the 1996 Process Rule, their justification, and how they were realized

Objective(s)	Justification and/or Elaboration	Manifestation(s) in the Process Rule-Defined Analysis
(a) Provide for early input from stakeholders (c) Increase use of outside technical expertise	“Increased and earlier involvement by interested parties and increased use of technical experts should minimize the need for re-analysis.” (Process Rule p. 488)	Most steps in the rulemaking analysis begin with identifying relevant issues in consultation with interested parties, particularly through a peer review group.
(b) Increase predictability of the rulemaking timetable (j) Reduce time and cost of developing standards	A 2007 GAO report stated that “DOE has missed all 34 of the deadlines for rulemaking that have come due for the 20 consumer products and industrial equipment categories with deadlines that have passed. … Of the 34 rules with missed deadlines, 11 were issued late, and the other 23 have not been issued at all. Delays in meeting deadlines range from about 2 months to 15 years.” (U.S. GAO	Section 2 (“Scope”), Section 3 (“Setting priorities for rulemaking activity”), and Section 6 (“Effective date of a standard”) all directly relate to this objective.

	2007) The MEPS rulemaking process today is generally estimated to last about 3 years from initiation to final rule adoption, with compliance dates typically 3-5 years after final rule adoption.	
(d) Eliminate problematic design options early in the process	Some design options might be "impractical" for "manufacture, installation, or service" or could "present unacceptable problems with respect to … consumer utility or safety." (Process Rule p. 487) Some of these concerns resonate with the 1975 EPCA and the 1978 NECPA.	This occurs in the "Screening analysis," which is one of the earliest steps in the process established under the Process Rule.
(e) Fully consider non-regulatory approaches	EPCA 1975 required consideration of the likely sufficiency of energy use labeling "to induce manufacturers to produce, and consumers… to purchase" efficient products. The Process Rule adds to that an interest in understanding "the effects of market forces and voluntary programs" as part of accurately assessing the "incremental impacts of a new or revised standard." (Process Rule p. 487)	Section 12 ("Consideration of non-regulatory approaches") speaks directly to this objective.
(f) Conduct thorough analysis of impacts	Not interested just in aggregate costs and benefits, but in considering "the variability of impacts on significant groups of manufacturers and consumers." Also interested in reporting "the range of uncertainty associated with these impacts" and taking into account "cumulative impacts of regulation on manufacturers." (Process Rule p. 487)	Section 4 ("Process for developing efficiency standards and factors to be considered"), Section 10 ("Principles for the analysis of impacts on manufacturers"), and Section 11 ("Principles for the analysis of impacts on consumers") all speak directly to this objective
(g) Use transparent and robust analytical methods	Interest in using "qualitative and quantitative analytical methods that are fully documented for the public and produce results that can be explained and reproduced, so that the analytical underpinnings for policy decisions … are as sound and well-accepted as possible." (Process Rule p. 487)	Section 4, Section 9 ("Principles for the conduct of engineering analysis"), Section 10, Section 11, and Section 13 ("Crosscutting analytical assumptions")[2] all speak directly to this objective
(h) Articulate policies to guide selection of standards	Interest in "elaborating on the statutory criteria for selecting standards, so that interested parties are aware of the policies that will guide these decisions." (Process Rule p. 487)	Section 5 ("Policies on selection of standards") directly responds to this objective
(i) Support efforts to build	"Standards with broad-based support are	Section 8 ("Joint stakeholder

[2] Section 13 details a number of analytical assumptions that should be made across product MEPS. These include tying economic assumptions, energy price, and demand trends to the most current Annual Energy Outlook (AEO) published by the Energy Information Administration (EIA). Section 13 also ties product-specific energy efficiency trends to forecasts by EIA's "residential and commercial demand model in the National Energy Modeling System (NEMS)." It uses different discount rates for residential consumers and commercial users and provides the appropriate approximation and scenarios the DOE should use in its analysis. It also provides certain analytical notes for national NPV calculations, manufacturer impacts, and emission rates of "carbon, sulfur oxides, and nitrogen oxides." These emissions, although part of the benefit-burden analysis required in the rulemaking process, are prohibited from being given monetary values.

consensus on standards	likely to balance effectively the economic, energy, and environmental interests affected by standards" (Process Rule p. 488)	recommendations") as well as parts of Section 4 and Section 5 speak to this objective

Considerations for Determining a Proposed Standard

Section 5(e) of the Process Rule refers to a combination of considerations that inform how a proposed standard is determined. These considerations include several articulated in Section 5, some of which refer to statutory language, as well as nine factors established in Section 4. We elaborate on these considerations in this Appendix because they are important to an understanding of the MEPS rulemaking process and because the complexity of the exposition in the Process Rule makes these provisions somewhat difficult for the layperson to access.

First, we focus on Section 5(e) of the Process Rule, as it provides a helpful reminder of the statutory requirements of EPCA. In the 1975 EPCA, "any new or revised standard must be designed to achieve the maximum improvement in energy efficiency that is determined to be technologically feasible and economically justified." In the main body of this report, we elaborate somewhat on the Process Rule's interpretation of technological feasibility. Here we elaborate on its interpretation of economic justification, which represents a milestone in the evolution of the MEPS rulemaking process.

When the original 1975 EPCA was passed, a standard was determined to be economically justified if "the savings in operating costs throughout the estimated average life of the covered product" outweighed "(i) any increase to purchasers in initial charges for, or maintenance expenses of, the covered product which is likely to result from the imposition of the standard; (ii) any lessening of the utility or the performance of the covered product; and (iii) any negative effects on competition." By the time of the first EPCA amendments, which were brought in as part of the 1978 NECPA, economic justification became the result of a determination by the DOE that "the benefits of the standard exceed its burdens." In making this determination, the agency would have to consider seven factors, which included

> "(1) the economic impact of the standard on the manufacturers and on the consumers of the products subject to such standard, (2) the savings in operating costs throughout the estimated average life of the covered products in the type (or class), compared to any increase in the price of, or in the initial charges for, or maintenance expenses of, the covered products which are likely to result from the imposition of the standard, (3) the total projected amount of energy savings likely to result directly from the imposition of the standard, (4) any lessening of the utility or the performance of the covered products likely to result from the imposition of the standard, (5) the impact of any lessening of competition determined in writing by the Attorney General that is likely to result from the imposition of the standard, (6) the need of the Nation to conserve energy, and (7) any other factors the Secretary considers relevant."

In Section 5 of the Process Rule, there are several ways to conceive of whether a standard level is economically justified. First, it is justified if "the benefits exceed the burdens." Second, it is "rebuttably presumed" to be justified "if the payback period is three years or less." Third, unless there are specific outweighing benefits, a candidate standard level would not be considered justified if it is determined that any of the following eight conditions hold: (A) it will "result in a negative return on investment for the industry,… significantly reduce the value of the industry, or … cause significant adverse impacts to a significant subgroup of manufacturers (including small manufacturing businesses)"; (B) it will "be the direct cause of plant closures, significant losses in domestic manufacturer employment, or significant losses of capital investment by domestic manufacturers"; (C) it will have "an adverse impact on the

environment or energy security"; (D) it would "not result in significant energy conservation relative to non-regulatory approaches"; (E) it is not "consistent with the policies relating to practicability to manufacture, consumer utility, or safety"; (F) it is not "consistent with the policies relating to consumer costs"; (G) it will "have significant adverse impacts on a significant subgroup of consumers (including low-income consumers)"; and (H) it would "have significant anti-competitive effects."

The specificity of conditions (A) and (B) in Section 5(e) provide some insight into the evolving nature of the treatment of manufacturers in MEPS since they began in 1975. Manufacturers under the 1975 EPCA were referred to only as subject to information reporting requirements, prohibitions, and penalties. Under the 1978 NECPA, however, the burden on manufacturers was listed as the very first item to consider when assessing a potential MEPS, while a path was made to exempt a subset of manufacturers from MEPS. By the time of the 1996 Process Rule, the burden on manufacturers had become a key element of several parts of the rulemaking process. These included: (a) the screening analysis, as applied at several points in the rulemaking (design options were to be eliminated if they were expected to be impracticable to manufacture, install, or service by the time the final rule became effective); (b) the conditions for assessing candidate standard levels (see Section 4 and Section 10, as detailed in the table below); and (c) the conditions for determining proposed standard levels, as discussed above. Note that the prominence of manufacturer burdens in the 1996 Process Rule may be seen as consistent with other contemporaneous developments in which the burdens of regulation on taxpayers were particularly politically salient. Probably the most significant of these contemporaneous developments was the major revision to the 1980 Paperwork Reduction Act (Pub. L. No. 96-511) that occurred in 1995 (the Paperwork Reduction Act amendments, Pub. L. 104-13), the year before the Process Rule.

We conclude this section by presenting Table A2, which elaborates on the nine factors the Process Rule calls for use in selecting a proposed standard in addition to the considerations noted above from Section 5.

Table A2: The nine factors the Process Rule states should be used in selecting proposed standards

Factors	Notes
(i) Consensus stakeholder recommendations	This is consistent with objective i of the Process Rule, as discussed in the table above.
(ii) Impacts on manufacturers	Section 4 says that these include "estimated impacts on cash flow; assessment of impacts of manufacturers of specific categories of products and small manufacturers; assessment of impacts on manufacturers of multiple product-specific federal regulatory requirements…; and impact on manufacturing capacity, plant closures, and loss of capital investment." In addition, Section 10 says that the DOE will seek "input on the present and past industry structure and market characteristics," and on the treatment of cost issues that are sometimes "difficult to estimate, manufacturer-specific, and usually proprietary." In order to "predict the number of products sold and their sale price" to "make manufacturer cash flow calculations," the DOE will draw on sources that include "actual shipment and pricing experience; data from manufacturers, retailers, and other market experts; financial models; and sensitivity analyses." Potential impacts of candidate standard levels to be analyzed will include "industry net present value, with sensitivity analyses based on uncertainty of costs, sales prices, and sales volumes; cash flows, by year; [and] other measures of impact, such as revenue, net income and return on equity." The DOE will "use the Government Regulatory Impact Model (GRIM)" as "a starting point" and will

	consider "research required to update key economic data."[3]
(iii) Impacts on consumers	Section 4 says that these include "impacts based on national average energy prices and energy usage; impacts on subgroups of consumers based on major regional differences in usage or energy prices and significant variations in installation costs or performance; sensitivity analyses using high and low discount rates and high and low energy price forecasts; changes to product utility and other impacts of likely concern to all or some consumers…; estimated life-cycle cost with sensitivity analysis; and consideration of the increased first cost to consumers and the time required for energy cost savings to pay back these first costs."
(iv) Impacts on competition	Section 4 does not elaborate on this as a factor in determining a proposed standard level, but gives a role to the Department of Justice (DOJ) in analyzing whether a proposed standard level should be amended before becoming a final standard. Meanwhile, Section 5 describes a role for both the DOE and the DOJ in assessing whether a proposed standard level is "economically justified" in its discussion of policies that combine with the factors in this table to inform decisions about proposed standard levels in the NOPR.
(v) Impacts on utilities	Section 4 says that these include "estimated marginal impacts on electric and gas utility costs and revenues."
(vi) National energy, economic, and employment impacts	Section 4 says that these include "estimated energy savings by fuel type; estimated net present value of benefits to all consumers; and estimates of the direct and indirect impacts on employment by appliance manufacturers, relevant service industries, energy suppliers, and the economy in general."
(vii) Impacts on the environment and energy security	Section 4 says that these include "estimated impacts on emissions of carbon and relevant criteria pollutants, impacts on pollution control costs, and impacts on oil use."
(viii) Impacts of non-regulatory approaches	Section 4 says that these include "impacts of market forces and existing voluntary programs in promoting product efficiency, usage, and related characteristics in the absence of updated efficiency standards."
(ix) New information related to the factors used for screening design options.	No additional detail is provided

Appendix A References

Nadel, S. (2002). "Appliance and Equipment Efficiency Standards." Annual Review of Energy and the Environment **27** (1): 159-192.

Nadel, S. and D. Goldstein (1996). Appliance and Equipment Efficiency Standards: History, Impacts, Current Status, and Future Directions. Washington, D.C., American Council for an Energy-Efficient Economy and the Natural Resources Defense Council.

U.S. GAO (2007). "Energy Efficiency: Long-standing Problems with DOE's Program for Setting Efficiency Standards Continue to Result in Forgone Energy Savings." Washington, D.C.

[3] The GRIM model, which is still in use, was originally developed by Arthur D. Little (ADL) Consulting in 1991-93 under contract to the Association of Home Appliance Manufacturers, the Gas Appliance Manufacturers Association, and the Air-Conditioning and Refrigeration Institute. For more information, contact Navigant Consulting (the former Metzler Group), which acquired the ADL Advanced Energy Systems practice in 2002 and is currently the lead contractor for MEPS manufacturing impact analyses.

APPENDIX B: DETAILS OF MEPS FOR CASE APPLIANCES

Table B1. MEPS for Room ACs, Effective 10/1/00

Product Class	Minimum EER *(Btu/h-W)*
1. Without reverse cycle, with LS, and less than 6,000 Btu/h	9.7
2. Without reverse cycle, with LS and 6,000 to 7,999 Btu/h	9.7
3. Without reverse cycle, with LS and 8,000 to 13,999 Btu/h	9.8
4. Without reverse cycle, with LS and 14,000 to 19,999 Btu/h	9.7
5. Without reverse cycle, with LS and 20,000 Btu/h or more	8.5
6. Without reverse cycle, without LS, and less than 6,000 Btu/h	9.0
7. Without reverse cycle, without LS and 6,000 to 7,999 Btu/h	9.0
8. Without reverse cycle, without LS and 8,000 to 13,999 Btu/h	8.5
9. Without reverse cycle, without LS and 14,000 to 19,999 Btu/h	8.5
10. Without reverse cycle, without LS and 20,000 Btu/h or more	8.5
11. With reverse cycle, with LS, and less than 20,000 Btu/h	9.0
12. With reverse cycle, without LS, and less than 14,000 Btu/h	8.5
13. With reverse cycle, with LS, and 20,000 Btu/h or more	8.5
14. With reverse cycle, without LS, and 14,000 Btu/h or more	8.0
15. Casement-Only	8.7
16. Casement-Slider	9.5

Table B2. MEPS for Refrigerators, Refrigerator-Freezers, and Freezers, Effective 7/1/01

Product Class	Energy Standard Equations for Maximum Energy Use (kWh/yr)
1. Refrigerators and refrigerator-freezers with manual defrost.	8.82AV+248.4 0.31av+248.4
2. Refrigerator-freezers—partial automatic defrost.	8.82AV+248.4 0.31av+248.4
3. Refrigerator-freezers—automatic defrost with top-mounted freezer without through-the-door ice service and all-refrigerator—automatic defrost.	9.80AV+276.0 0.35av+276.0
4. Refrigerator-freezers—automatic defrost with side-mounted freezer without through-the-door ice service.	4.91AV+507.5 0.17av+507.5
5. Refrigerator-freezers—automatic defrost with bottom-mounted freezer without through-the-door ice service.	4.60AV+459.0 0.16av+459.0
6. Refrigerator-freezers—automatic defrost with top-mounted freezer with through-the-door ice service.	10.20AV+356.0 0.36av+356.0
7. Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service.	10.10AV+406.0 0.36av+406.0
8. Upright freezers with manual defrost.	7.55AV+258.3 0.27av+258.3
9. Upright freezers with automatic defrost.	12.43AV+326.1 0.44av+326.1
10. Chest freezers and all other freezers except compact freezers.	9.88AV+143.7 0.35av+143.7
11. Compact refrigerators and refrigerator-freezers with manual defrost.	10.70AV+299.0

	0.38av+299.0
12. Compact refrigerator-freezer—partial automatic defrost.	7.00AV+398.0 0.25av+398.0
13. Compact refrigerator-freezers—automatic defrost with top-mounted freezer and compact all-refrigerator—automatic defrost.	12.70AV+355.0 0.45av+355.0
14. Compact refrigerator-freezers—automatic defrost with side-mounted freezer.	7.60AV+501.0 0.27av+501.0
15. Compact refrigerator-freezers—automatic defrost with bottom-mounted freezer.	13.10AV+367.0 0.46av+367.0
16. Compact upright freezers with manual defrost.	9.78AV+250.8 0.35av+250.8
17. Compact upright freezers with automatic defrost.	11.40AV+391.0 0.40av+391.0
18. Compact chest freezers.	10.45AV+152.0 0.37av+152.0
Product Class	Made Effective Through OHA Exception Relief
5A. Refrigerator-freezer—automatic defrost with bottom-mounted freezer with through-the-door ice service.	5.0AV+539.0 0.18av+539.0
10A. Chest freezers with automatic defrost.	14.76AV+211.5 0.52av+211.5

AV: Adjusted Volume in ft^3; av: Adjusted Volume in liters (L)

Table B3. MEPS for Dishwashers, Effective 5/14/94

Product Class	Energy Factor (cycles/kWh)
Compact Dishwasher	0.62
Standard Dishwasher	0.46

Table B4. MEPS for Residential Clothes Washers, Effective 1/1/04 and 1/1/07

	Standards Effective Date	
	January 1, 2004	**January 1, 2007**
Top-loading standard and front-loading	1.04 MEF	1.26 MEF
Top-loading compact	0.65 MEF	-

Table B5. MEPS for Residential Clothes Dryers, Effective 5/14/94

Product Class	Minimum EF (lb/kWh)
Electric, Standard (4.4 ft3 or greater capacity)	3.01
Electric, Compact (120 V) (less than 4.4 ft3 capacity)	3.13
Electric, Compact (240 V) (less than 4.4 ft3 capacity)	2.90
Gas	2.67

APPENDIX C: *EX ANTE* PROJECTIONS OF PRICE AND ENERGY USE

Table C1. Projected Prices and Energy Use for Room AC MEPS Design Options, Effective 10/1/00

Standard Level		Design Option	Retail Price ($2013)	Field Energy Use (kWh/yr)
< 6000 Btu/hr, w/o reverse cycle, w/louvered sides				
	0	baseline	663.32	378.5
	1	Evaporator/Condenser enhanced fins	664.41	358.3
	2	PSC Fan Motor	673.20	334.4
2000 Std. Level	sup.	Supplemental Level	681.83	321.3
	3	Evaporator/Condenser Grooved Tubes	682.08	320.9
	4	Add Subcooler	694.49	311.7
	5	Increase Evaporator/Condenser Coil Area	784.94	300.2
	6	BPM Fan Motor	999.28	294.9
	7	Variable Speed Compressor	1419.57	265.4
6000-7999 Btu/hr, w/o reverse cycle, w/louvered sides				
	0	baseline	720.00	471.1
	1	Evaporator/Condenser enhanced fins	722.55	452.8
	2	PSC Fan Motor	731.25	424.9
	3	Evaporator/Condenser Grooved Tubes	743.30	412.3
2000 Std. Level	sup.	Supplemental Level	745.46	410.7
	4	Add Subcooler	757.28	402.0
	5	Increase Evaporator/Condenser Coil Area	851.87	385.7
	6	BPM Fan Motor	1067.68	379.3
	7	Variable Speed Compressor	1480.72	341.4
8000-13999 Btu/hr, w/o reverse cycle, w/louvered sides				
	0	baseline	882.68	694.1
	1	Increase Compressor EER to 10.8	901.88	666.4
2000 Std. Level	sup.	Supplemental Level	906.48	660.3
	2	Add Subcooler	908.89	657.2
	3	Evaporator/Condenser Grooved Tubes	923.88	640.0
	4	Increase Evaporator/Condenser Coil Area	1028.12	590.0
	5	BPM Fan Motor	1242.84	580.3
	6	Variable Speed Compressor	1657.17	522.3
14000-19999 Btu/hr, w/o reverse cycle, w/louvered sides				
	0	baseline	1092.53	1062.8
	1	Increase Compressor EER to 10.8	1127.69	986.8
2000 Std. Level	sup.	Supplemental Level	1127.93	986.3
	2	Condenser Grooved Tubes	1140.44	958.9
	3	Add Subcooler	1154.55	943.0
	4	Increase Evaporator/Condenser Coil Area	1447.45	890.6
	5	Increase Compressor EER to 11.3	1551.67	863.1
	6	Increase Compressor EER to 11.4	1599.86	856.1
	7	BPM Fan Motor	1852.06	832.3

	8	Variable Speed Compressor	2308.11	749.1
> 20000 Btu/hr, w/o reverse cycle, w/louvered sides				
	0	baseline	1532.41	1572.7
	1	Increase Compressor EER to 10.9	1553.52	1542.5
2000 Std. Level	sup.	Supplemental Level	1568.62	1521.7
	2	Add Subcooler	1569.53	1520.4
		Increase Compressor EER to 11.5	1711.65	1457.4
	4	Increase Evaporator/Condenser Coil Area	1910.29	1372.6
	5	Increase Compressor EER to 11.7	1982.29	1314.7
	6	BPM Fan Motor	2302.25	1289.6
	7	Variable Speed Compressor	2947.36	1160.6
W/ reverse cycle, w/ louvered sides				
	0	baseline	1229.95	750.2
2000 Std. Level	sup.	Supplemental Level	1235.76	743.5
	1	Add Subcooler	1239.45	739.3
	2	Increase Compressor EER to 10.8	1261.52	721.6
	3	Increase Evaporator/Condenser Coil Area	1404.63	680.7
	4	BPM Fan Motor	1697.85	666.1
	5	Variable Speed Compressor	2263.80	599.5
6000-7999 Btu/hr, w/o reverse cycle, w/o louvered sides				
	0	baseline	797.01	382.1
2000 Std. Level	sup.	Supplemental Level	802.64	375.9
	1	Increase Compressor EER to 10.8	806.31	372.0
	2	Add Subcooler	812.96	366.6
	3	BPM Fan Motor	1068.62	350.7
	4	Variable Speed Compressor	1556.45	315.6
	5	Increase Evaporator/Condenser Coil Area	2397.99	293.7
8000-13999 Btu/hr, w/o reverse cycle, w/o louvered sides				
2000 Std. Level	sup.	Supplemental Level	987.95	677.3
	0	baseline	995.52	654.4
	1	Add Subcooler	1001.83	636.5
	2	Increase Compressor EER to 11.09	1014.67	631.6
	3	BPM Fan Motor	1272.78	610.0
	4	Variable Speed Compressor	1769.05	549.0
	5	Increase Evaporator/Condenser Coil Area	2620.52	519.4
W/ reverse cycle, w/o louvered sides				
2000 Std. Level	sup.	Supplemental Level	1247.96	711.6
	0	baseline	1255.44	694.0
	1	Condenser Enhanced Fins	1260.38	682.7
	2	BPM Fan Motor	1575.45	657.8
	3	Variable Speed Compressor	2184.21	592.1
	4	Increase Evaporator/Condenser Coil Area	3094.83	556.6

Table C2: Projected Prices and Energy Use for Top-Mount Auto-Defrost Refrigerator-Freezer (AV=606.0 L) MEPS Design Options, Effective 7/1/01

Standard Rule Based on Adjusted Volume (AV)	Standard Level at Reference AV		Option	Projected Retail Price (2013$)	Annual Energy Use (kWh)
		0	BASELINE	920.94	700.86
		1	0 + 5.45 EER Compressor	951.20	620.13
		2	1 + Reduce Condenser Motor Power	963.65	594.45
		3	2 + Add 1/2" Insulation to Doors	973.73	572.43
		4	3+ Reduce Evaporator Motor Power	991.84	543.07
		5	4 + Improve Evaporator Fan Efficiency	994.03	539.40
		6	5 + Add 1/2" Insulation to Walls	1027.55	495.37
0.35AV+276	488.1	7	6 + Reduce Gasket Heat Leak	1035.87	484.36
		8	7 + Add 1" Insulation to Doors	1044.76	473.35
		9	8 + Add 1" Insulation to Walls	1071.64	444.00
		10	9+ Increase Condenser Area	1081.71	436.66
		11	10 + Adaptive Defrost	1101.92	425.65
		12	11 + Increase Evaporator Area	1110.46	421.98
		13	7 + Increase Evaporator Area	1044.34	477.02
		14	13 + Increase Condenser Area	1054.42	469.69
		15	14 + Adaptive Defrost	1074.63	458.68
		16	2+ Reduce Evaporator Motor Power	981.70	561.42
		17	16 + Improve Evaporator Fan Efficiency	983.89	557.75
		18	17 + Reduce Gasket Heat Leak	992.21	546.74
		19	18 + Increase Evaporator Area	1000.66	539.40
		20	19 + Increase Condenser Area	1010.74	532.07
		21	20 + Vacuum Panels on Walls & Doors	1143.18	432.99
		22	21 + Adaptive Defrost	1163.39	421.98

Table C3. Projected Prices and Energy Use for Top-Mount Auto-Defrost Refrigerator-Freezer with Through-the-Door Features (AV=726.8 L) MEPS Design Options, Effective 7/1/01

Standard Rule Based on Adjusted Volume (AV)	Standard Level at Reference AV		Option	Projected Retail Price (2013$)	Annual Energy Use (kWh)
		0	BASELINE	1738.85	795.37
		1	0 + Reduce Condenser Motor Power	1750.47	759.58
		2	1+ Reduce Evaporator Motor Power	1767.52	723.79
		3	2 + 5.60 EER Compressor	1785.49	703.91
		4	3 + Reduce Load for TTD Features	1819.01	672.09
		5	4 + Adaptive Defrost	1841.29	656.18
		6	5 + Add 1" Insulation to Doors	1924.16	620.39
0.36AV+356	617.648	7	6 + Reduce Gasket Heat Leak	1951.74	612.44

	8	7 + Add 1" Insulation to Walls	2472.29	520.97
	9	8 + Improve Evaporator Fan Efficiency	2478.48	516.99
	10	9 + Increase Condenser Area	2585.07	509.04
	11	10 + Increase Evaporator Area	2735.00	505.06
	12	5 + Reduce Gasket Heat Leak	1868.87	648.23
	13	12 + Add 1/2" Insulation to Doors	1943.04	628.34
	14	13 + Improve Evaporator Fan Efficiency	1949.23	624.37
	15	14 + Add 1/2" Insulation to Walls	2322.67	568.69
	16	15 + Increase Condenser Area	2429.20	556.76
	17	16 + Increase Evaporator Area	2579.11	552.78
	18	4 + VPI to Walls and Doors	1950.34	548.81
	19	18 + Adaptive Defrost	1972.69	536.88
	20	19 + Reduce Gasket Heat Leak	2000.27	528.92
	21	20 + Increase Condenser Area	2106.86	520.97
	22	21 + Increase Evaporator Area	2256.77	516.99

Table C4. Projected Prices and Energy Use for Side-by-Side Auto-Defrost Refrigerator-Freezer (AV=737.8 L) MEPS Design Options, Effective 7/1/01

Standard Rule Based on Adjusted Volume (AV)	Standard Level at Reference AV		Option	Projected Retail Price (2013$)	Annual Energy Use (kWh)
		0	BASELINE	1751.80	761.19
		1	0 + 5.60 EER Compressor	1783.79	699.75
		2	1+ Reduce Evaporator Motor Power	1805.53	662.20
		3	2 + Reduce Condenser Motor Power	1820.67	641.72
0.17AV+507.5	632.926	4	3 + Adaptive Defrost	1839.56	624.66
		5	4 + Add 1" Insulation to Walls	1996.96	518.84
		6	5 + Enhanced Evaporator HT Surface	2002.49	512.01
		7	6 + Add 1" Insulation to Doors	2039.65	488.12
		8	7 + Reduce Gasket Heat Leak	2062.03	474.47
		9	8 + Increase Condenser Area	2077.71	467.64
		10	4 + Add 1/2" Insulation to Walls	1930.00	559.80
		11	10 + Enhanced Evaporator HT Surface	1935.55	552.98
		12	11 + Add 1/2" Insulation to Doors	1958.61	539.32
		13	12 + Improve Evaporator Fan Efficiency	1962.13	535.91
		14	13 + Increase Condenser Area	1977.82	529.08
		15	14 + Reduce Gasket Heat Leak	2000.25	518.84
		16	4 + Increase Condenser Area	1855.17	614.42
		17	16 + Enhanced Evaporator HT Surface	1860.72	607.59
		18	17 + Vacuum Panel Insulation in W & D	2037.28	515.43
		19	18 + Improved Evaporator Fan Efficiency	2040.80	512.01
		20	19 + Reduce Gasket Heat Leak	2063.24	501.77

Table C5. Projected Prices and Energy Use for Side-by-Side Auto-Defrost Refrigerator-Freezer with Through-The-Door Features (AV=740.9 L) MEPS Design Options, Effective 7/1/01

Standard Rule Based on Adjusted Volume (AV)	Standard Level at Reference AV		Option	Projected Retail Price (2013$)	Annual Energy Use (kWh)
		0	BASELINE	1928.51	799.93
		1	0 + Add 1/2" Insulation to Doors	1938.50	768.41
		2	1 + 5.60 EER Compressor	1955.16	725.06
		3	2 + Reduce Condenser Motor Power	1966.26	697.48
		4	3 + Increase Evaporator Area	1970.86	685.66
0.36AV+406	672.724	5	4 + Increase Condenser Area	1977.97	669.89
		6	5 + Add 1" Insulation to Doors	1986.27	654.13
		7	6 + Reduce TTD Features Load	1992.21	638.37
		8	7 + Reduce Evaporator Motor Power	2008.57	618.67
		9	8 + Improve Evaporator Fan Efficiency	2010.96	614.73
		10	9 + Add 1" Insulation to Walls	2095.79	531.97
		11	10 + Reduce Gasket Heat Leak	2111.68	516.21
		12	11 + Adaptive Defrost	2122.87	508.33
		13	5 + Reduce TTD Features Load	1983.91	654.13
		14	13 + Reduce Evaporator Motor Power	2000.27	634.43
		15	14 + Improve Evaporator Fan Efficiency	2002.66	630.49
		16	15 + Add 1/2" Insulation to Walls	2053.58	583.20
		17	16 + Adaptive Defrost	2064.72	571.38
		18	17 + Reduce Gasket Heat Leak	2080.61	555.62
		19	0 + Increase Evaporator Area	1933.04	784.17
		20	19 + 5.60 EER Compressor	1949.63	736.88
		21	20 + Reduce Condenser Motor Power	1960.75	709.30
		22	21 + Increase Condenser Area	1967.86	693.54
		23	22 + Reduce TTD Features Load	1973.87	681.71
		24	23 + Improve Evaporator Fan Efficiency	1976.26	677.77
		25	24 + Reduce Evaporator Motor Power	1992.55	654.13
		26	25 + Adaptive Defrost	2003.67	642.31
		27	26 + VPI on Doors and Walls	2133.43	531.97
		28	27 + Reduce Gasket Heat Leak	2149.32	516.21

Table C6. Projected Prices and Energy Use for Bottom Mount Auto Defrost Refrigerator-Freezer (AV=686.0 L) MEPS Design Options, Effective 7/1/01

Standard Rule Based on Adjusted Volume (AV)	Standard Level at Reference AV		Option	Projected Retail Price (2013$)	Annual Energy Use (kWh)

		0	BASELINE	1509.17	714.81
		1	0 + Reduce Evaporator Motor Power	1526.55	669.62
		2	1 + 5.60 EER Compressor	1544.64	624.43
		3	2 + Reduce Condenser Motor Power	1556.87	603.89
0.16AV+459	568.76	4	3 + Add 1" Insulation to Walls	1649.19	521.73
		5	4 + Add 1/2" Insulation to Doors	1673.86	501.19
		6	5 + Reduce Gasket Heat Leak	1691.33	488.86
		7	6 + Add 1" Insulation to Doors	1696.76	472.43
		8	7 + Adaptive Defrost	1727.44	460.11
		9	8 + Increase Evaporator Area	1752.43	451.89
		10	9 + Increase Condenser Area	1783.58	443.67
		11	3 + Add 1/2" Insulation to Doors	1581.61	587.46
		12	11 + Add 1/2" Insulation to Walls	1655.91	534.05
		13	12 + Reduce Gasket Heat Leak	1673.38	521.73
		14	13 + Improve Evaporator Fan Efficiency	1683.34	517.62
		15	14 + Increase Evaporator Area	1708.35	509.40
		16	15 + Adaptive Defrost	1739.03	497.08
		17	16 + Increase Condenser Area	1770.09	484.75
		18	3 + Reduce Gasket Heat Leak	1574.32	591.56
		19	18 + VPI Insulation to Walls and Doors	1690.85	476.54
		20	19 + Increase Evaporator Area	1715.85	468.32
		21	20 + Adaptive Defrost	1746.53	456.00
		22	21 + Improve Evaporator Fan Efficiency	1756.50	451.89
		23	22 + Increase Condenser Area	1787.63	443.67

Table C7. Projected Prices and Energy Use for Compact Manual Defrost Refrigerator-Freezer (AV=46.19 L) MEPS Design Options, Effective 7/1/01

Standard Rule Based on Adjusted Volume (AV)	Standard Level at Reference AV		Option	Projected Retail Price (2013$)	Annual Energy Use (kWh)
		0	BASELINE	259.35	315.00
		1	0 + Enhanced Condenser HT Surface	259.98	308.06
		2	1 + Enhanced Evaporator HT Surface	261.14	301.13
		3	2 + Reduce Gasket Heat Leak	263.40	295.29
0.35AV+250	266.1665				

Table C8. Projected Prices and Energy Use for Dishwasher MEPS Design Options, Effective 5/14/94

Standard Level	Design Options	Projected Retail Price (2013$)	Annual Energy Use (kWh/year)
Standard Dishwasher 115V			

	0	Baseline	590.89	715.6
	1	Reduce Water Use	620.44	597.7
	2	1 + Improv. Motor	636.20	585.0
	3	1 + Booster Heater(2)	659.83	513.8
1994 Std. Level	4	5 + Improv. Motor	675.59	501.1
	5	6 + Fill Control	707.10	489.5
Standard Water Heating Dishwasher 115V				
	0	Baseline	630.29	636.1
	1	Reduce Water Use	659.83	534.1
	2	1 + Reduce Booster Use(3)	667.71	513.2
1994 Std. Level	3	2 + Improv. Motor	683.47	500.5
	4	3 + Fill Control	714.98	488.9
Compact Dishwasher 115V (4)				
	0	Baseline	512.11	467.3
	1,2	Reduce Water Use	541.65	397.0
	3	1 + Reduce Booster Use(3)	549.53	382.5
1994 Std. Level	4	2 + Improv. Motor	565.29	371.1
	5	3 + Fill Control	596.80	363.0

Note:
(1) Add booster heater and heat 40% of hot water from 120F to 140F
(2) Add booster heater and heat 20% of hot water from 120F to 140F
(3) Reduce booster heater from 40% to 20% of incoming 120F water
(4) Compact dishwashers are water heating dishwashers.

Table C9. Projected Prices and Energy Use for Clothes Washer MEPS Design Options, Effective 1/1/04

Standard Level	Description	MEF Cut-Off	Projected Retail Price (2013$)
	Pre-Baseline	0.72	611.06
	Baseline	0.82	611.12
	5% improvement	0.86	611.31
	10% improvement	0.91	613.61
	15% improvement	0.96	621.90
	20% improvement	1.02	653.56
2004 Std. Level	22% improvement	1.04	687.66
	25% improvement	1.09	775.60
	35% improvement	1.26	959.03
2007 Std. Level	35% improvement	1.26	959.18
	45% improvement	1.49	1106.26
	50% improvement	1.63	1125.43

Table C10. Projected Prices and Energy Use for Clothes Dryer MEPS Design Options, Effective 5/14/94

Standard Level		Design Options	Projected Retail Price ($2013)	Energy Use (kWh/yr)
Standard Electric Dryer				
	0	Baseline	679.5	1120.0
	1	Automatic Termination	715.8	987.1
1994 Std Level	2	1 +Insulation	743.0	967.4
	3	2 +Recycle Exhaust	881.6	907.2
	4	2 +Microwave	1142.1	715.5
	5	2 +Heat Pump	1425.2	338.2
Compact Electric Dryer (120V)				
	0	Baseline	566.3	462.2
	1	Automatic Termination	602.5	406.5
1994 Std Level	2	1 +Insulation	632.4	398.7
	3	2 +Recycle Exhaust	768.3	374.8
	4	2 +Microwave	1028.8	295.0
	5	2 +Heat Pump	1311.9	139.4
Compact Electric Dryer (120V)				
	0	Baseline	634.2	499.2
	1	Automatic Termination	670.5	439.4
1994 Std Level	2	1 +Insulation	700.4	430.3
	3	2 +Recycle Exhaust	836.3	405.2
	4	2 +Microwave	1096.8	318.4
	5	2 +Heat Pump	1379.9	150.7
Standard Gas Dryer (120V)				
	0	Baseline	770.1	4.32
	1	Automatic Termination	806.4	3.80
1994 Std Level	2	1 +Insulation	836.3	3.73
	3	2 +Recycle Exhaust	972.2	3.50

Note: Energy use assume each cycle can load 7 pounds of clothes (3 pounds for compact dryer)

APPENDIX D: RETAILERS PROVIDING DATA TO NPD GROUP

Table D1. Retailer List used by NPD Group

BJs Wholesale Club	Navy Exchange
Bloomingdales	Nebraska Furniture Mart
Boscovs	Pamida
Circuit City	PC Richart & Sons
Dillard's	Queen City Appliance
Fortuno	RC Willey
Fred Meyer	REX Stores
Gottschalks	Sears
HH Gregg	Shopko
Home Depot	Target
JC Penney	Ultimate Electronics
Meijer	Vanns
Menards	

APPENDIX E: *CONSUMER REPORTS* PRODUCT REVIEWS OVER TIME

These tables list the years *Consumer Reports* rated (a) room ACs; (b) refrigerators (c) dishwashers; (d) clothes washers; and (e) clothes dryers. They also provide the variables the magazine used for evaluation in each year (with the exception of 2003, the one year that we are currently missing data from *Consumer Reports*).

Table E1. Room Air Conditioners

	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'04	'05	'10	'11	'12
Price	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Overall Score					√	√	√	√	√	√	√	√	√	√	√	√	√	√
Btu/hr	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
EE Ratio	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Comfort	√	√	√	√	√	√	√	√	√		√	√	√	√	√	√	√	√
Brownout	√	√	√		√	√	√	√							√	√	√	√
Noise	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Ease of Use											√	√	√	√	√	√	√	√
Weight (lb)	√	√	√	√				√		√								
Temperature Uniformity	√	√	√	√	√	√												
Direction Control	√	√	√	√	√	√												
Flow Control				√	√	√	√	√										
Convenience						√												
Moisture Removal (pt/hr)	√	√	√	√	√	√				√								
Thermostat sensitivity										√								

Table E2. Refrigerator/Freezers

	'87	'88	'89	'91	'92	'94	'96	'98	'99	'00	'01	'02	'04	'05	'06	'07	'08	'09	'10	'11	'12
Price	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Overall Score						√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Energy Cost	√	√	√	√	√	√	√	√	√	√	√	√						√	√	√	√
kWh/yr	√	√	√	√	√						√										
Temp Performance							√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
EE								√	√	√	√	√	√	√	√	√	√	√	√	√	√
Noise	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Ease of Use	√	√	√	√	√	√	√	√	√	√	√	√							√	√	√
Claimed Volume							√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Usable Volume							√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Ref Volume	√	√	√	√	√	√															
Freezer Volume	√	√	√	√	√	√															
Temp Balance	√	√	√	√	√	√															
Temp Uniformity	√	√	√	√	√	√															
Temp Compensation	√	√	√	√	√	√															
Meat-Keeping	√	√	√	√	√	√															
Reserve Capacity	√	√	√	√	√	√															
Crisper Humidity	√	√	√	√	√	√															
Ice-Making	√	√	√	√	√	√															
Initial Settings					√																

Table E3. Dishwashers

	'83	'87	'90	'93	'95	'97	'98	'00	'01	'02	'04	'05	'06	'07	'08	'09	'10	'11	'12
Price	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Overall Score				√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Washing	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
EE	√	√	√	√			√	√	√	√	√	√	√	√	√	√	√	√	√
Noise	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Ease of Use							√	√	√	√	√	√	√	√	√	√	√	√	√
Loading							√	√	√	√	√	√	√	√	√				
Cycle Time (min)	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Water Use (gal)	√	√	√	√	√	√	√	√	√										
Energy Cost					√	√													
Heated Drying	√																		
Brand Frequency of Repair Record	√																		

Table E4. Clothes Washers

	'89	'91	'92	'93	'95	'96	'97	'99	'00	'01	'02	'04	'05	'06	'07	'08	'09	'10	'11	'12
Price	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Overall Score					√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Washing				√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
EE		√	√			√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
WE	√	√	√	√	√		√	√	√	√	√	√			√	√	√	√	√	√
Capacity	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Gentleness					√							√	√	√	√	√	√	√	√	√
Noise	√	√	√	√				√	√	√	√	√	√	√	√	√	√	√	√	√
Vibration																	√	√	√	√
Ease of Use			√																	
Service Access		√	√	√	√															
Cycle Time (min)								√	√		√	√	√	√	√	√	√	√	√	√
Sand Disposal			√																	
Energy Cost				√	√															
Water Use (gal)				√		√	√	√												
Control				√	√															
Spin				√																
Unbalanced Load	√	√	√	√																
Water Extraction	√	√																		
Linting	√	√	√																	

Table E5. Clothes Dryers

	'89	'92	'93	'95	'98	'99	'00	'01	'02	'04	'05	'06	'07	'08	'10	'11	'12
Price	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Overall Score				√	√	√	√	√	√	√	√	√	√	√	√	√	√
Drying	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Capacity	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√

Convenience		√	√	√	√	√		√							√	√	√
Noise			√	√	√	√	√	√	√	√	√	√	√	√	√	√	√

APPENDIX F: CODING CLOTHES WASHER FEATURES

Table F1. Clothes Washer Manual Feature Variables and Feature Names

Feature Variable	Feature Name in Manuals
Add-a-garment option	add a garment garment + Add Clothes
Advanced clean action	cascade wash vanes RollerJets™ RollerJets™ & Forced Water Circulation Eco Active™ Wash Archie Paddles Bosch Exclusive Paddles GentlePower™ Agitator HydroWave™ Wash System HydroWash™ system Ultra Handwash–America's Gentlest Agitation™, GentlePower™ Agitator cascading wash vanes WAVEFORCE™ XTRA ROLL ACTION™ agitator XTRA ROLL ACTION™ PLUS agitator SURE CARE® agitator SURGILATOR®, Clothes Mover agitator LoadSensor™ Agitator The CALYPSO® Wash Motion Impeller Hydro Plate Wash System Washplate curved four-vane agitator Pulsator Boomerang pulsator pulsator, cascading water fall, pendulum wash, omni directional flow
Electronic controls	electronic electromechanical LED display LCD display digital graphic display electronic push button LCD screen touch screen rotary electronic LED display, electronic push button LED display, One-Touch electronic controls

	One-Touch electronic controls LCD display, Touch-2-Open ™ Cycle Selector electronic, display with load size indicator Cleantouch ™ control panel basic electronic Flexible Electronic Controls color LCD display color LCD touch screen, eco monitor Eco Monitor LED display, Eco Monitor digital display Upfront Electronic Control Panel with Dial-A-Cycle™ Computer Trac ® controls
Mechanical controls	mechanical mechanical push button mechanical, LED Readout
Programmable controls	my cycle custom PGM favorite
Cycle status end signal	YES/ NO
Cycle status estimated time	YES/ NO
Cycle status lights	YES/ NO
Delay start option	YES/ NO
Automatic machine diagnosis	SMARTDIAGNOSIS™ fault indicators,pc indicator
Bleach dispenser	YES/ NO
Detergent dispenser	YES/ NO
Fabric softener dispenser	YES/ NO
Direct inject dispenser	water circulation water circulation and steam nozzles catalyst ® clean action direct inject deep clean cleaning action Special Cleaning Action with Sensi-Care™ Wash System powerspray powerfoam ™
Other dispenser features	Smart Dispense ™ Touch-2-Open (TM) dispenser with Luxury-Glide (TM) SmartBleach ™ timed beach dispenser Detergent Advantage System Dispenser Efficient Detergent System with Anti-Escape Value Oxi/Color-safe Bleach Dispenser Efficient Detergent System with Anti-Escape Valve

	Precision Dispense Optimal Dispense (with cartridge)
Demand Response ready	DR ready
Fluff option	FANFRESH™ Fresh Hold® TumbleFresh™ Fresh Spin™ FRESH CARE
Internal heater	internal heater
Water level selector	Auto Probably Auto Not available YES - 3 Water levels YES - 4 Water levels YES - 5 Water levels YES - Two water levels YES - 2 Water levels YES - Infinite YES - Based on cycle selection
Water level sensor	Automatic Water Level SENSOR LEVEL CONTROL (SLC) Probably Automatic Water Level Automatic Water Level - Optional Not available Water Fill Optimization Hydrowater ™ SENSOTRONIC ® Technology ActiveClean™ Technology, EcoSmart™ Technology Adaptive Fill Water Level Economical Intelligent Wash System 6th Sense ™ Technology IntelliFill™ Water Level Control H2Low™ wash system ECO MONITOR
Water-saving option Advanced motor	ActiveWater™ direct drive inverter motor direct drive motor two speed motor high speed motor adaptive variable speed motor dependable drive® orbital transmission precision endurance drive
NSF certification	YES/ NO

Extra rinse option	Extra Rinse Super Rinse 2nd Rinse Option Rinse Plus Alergy Rinse Second Rinse Power Rinse™ 2nd Rinse Option (auto) Rinse Time Selector
Remote laundry monitoring	remote monitor ready remote laundry monitor
High heat	Deep Clean Sanitize XXTRA SANITARY Sanitize Sanitize Cycle with Super Hot Water Deep Clean
Silver ion	SilverCare ™ Sanitization
Steam	Add steam Option SteamWash™ System, SteamFresh™ Cycle, Sanitary Cycle with Added Steam Option Steam Assist Steam Deep steam high-efficiency steam cycles, SteamFresh ™ high-efficiency steam cycles Deep Clean with Steam Steam Clean Deep Steam TrueSteam™ Technology, SteamFresh™ Cycle
Washer cleaning cycle	Cycle with 8 cups of bleach Tub clean BasketClean cycle PureCycle™ Cycle with AFFRESH™ with steam Clean washer cycle Clean washer cycle with steam Cycle with AFFRESH™
Balance adjustment	SPINSENSE™ Out of Balance Recovery Automatic Recovery Option Automatic Balance System Unbalanced load detection system Unbalanced Spin Load Compensator Dynamic off-balance detection

	Dynamic Balance Sensing Balance Display
Reduced noise	Whisper Quiet LoDecibel™ Quiet Operation Quiet Performance Quiet Performance, AVS™ Anti-Vibration System VRT ™ (Vibration Reduction Technology) Quiet-By-Design™, Deluxe Quiet Plus Insulation Package Hush Quiet Plus Insulation Package Deluxe Noise Reduction Package Quiet Pump Quiet-By-Design™ Standard Noise Package Low Noise Speed Control System TrueBalance™ Anti-Vibration System Quiet Operation QUIET WASH™ Plus System Quiet Option SilentTech ™ package for quiet performance LoDecibel™ Quiet Operation, TrueBalance™ Anti-Vibration System
Smooth suspension	Auto Balance Suspension System Suspension System 6-Point suspension system Smooth Balance™ Suspension System TRIPOD SUSPENSION Serenity ™ load management system
Soil level selector	YES
Soil level sensor	SENSOTRONIC® Technology Economical Intelligent Wash System 6th SENSE™ Technology Fabric Sense™ Fabric Select
Max Extract option	Max Extract option Max Extract™ option
Spin speed option	Manual Selector Not available Manual Selector (Custom Care) Auto Auto - with fabric selection (Fabric Sense™ System) Auto - with cycle selection (manual override) Auto - with cycle selection Auto - with fabric selection (Fabric Select)

	Auto - with cycle selection (with override Auto - with cycle selection (with override)
Spin time option	Not available Extended Spin Option Spin Time Selector
Temperature "nudge" option	Energy Saver eco Cold Not available Energy saving wash eWash ECO E EcoAction® eco friendly option Care Control Temperature Management all cold rinses ECOBOOST™
Temperature selector	YES/ NO Only with program selection
Temperature sensor	AutoTemp ATC Automatic Temperature Control Not available PerfecTemp SensorWash SENSOTRONIC® ActiveClean™ Tech, EcoSmart™ Tech PerfecTemp Plus Economical Intelligent Wash System TEMP-ASSURE ACCUWASH™ SENSORSURE™ ATC SENSORSURE™ ATC, thermal optimizer Assured Water Temp Option thermal optimizer Temperature Sensor Precision Temperature Control
Quick wash option	quick wash option fast wash rapid wash Speed Wash
Max extract tub	super plus extraction™ basket extraction tub™
Other tub features	diamond drum™ permatuf ii™ basket

	white porcelain basket durasmooth™ white porcelain basket
Stainless steel tub	ss drum neverust™ ss drum ss tub ss basket commercial quality ss drum
Tilted tub	tilted drum tiltub™
Woolmark certification	YES/ NO

Table F2: Notes on Clothes Washer Features obtained from User Manuals

Category	Feature	Description
Certifications	NSF certification	Indication that the model is NSF Certified to Sanitize and Reduce Allergens
	Woolmark certification	Indication of whether the model is "Woolmark" certified
Detergent and Dispenser	HE detergent	Indication of whether the manual recommends/requires "he" detergent
	Detergent dispenser	Has an automatic detergent dispenser
	Bleach dispenser	Has an automatic bleach dispenser
	Fabric softener dispenser	Has an automatic fabric softener dispenser
	Direct inject dispenser	Specifics on dispenser's direct-inject/ pressurized water dispersion features
	Other dispenser features	Other dispenser-related features/technologies
Controls	Electronic controls	Specifics on Electronic Controls
	Mechanical controls	Specifics on Mechanical Controls
	Programmable controls	User-specified programming option
Temperature	Temperature selector	Specifics on whether temperature variation can be selected manually
	Temperature sensor	Specifics on automatic temperature sensor/optimization/precision
	Temperature "nudge" option	Specifics on an option to reduce energy use by "nudging" temperatures down.
Water level/wash size	Water level sensor	Specifics on water level/load sensor/automation
	Water level selector	Specifics on whether water level/load size can be manually adjusted
	Water-saving option	Specifics on water-saving options
Spin	Spin time option	Option to adjust spin duration manually
	Spin speed option	Option to adjust spin speed manually
	Max Extract option	Has a "Max Extract" fast spin option
Cycle Status	Cycle status end signal	Has end of cycle signal
	Cycle status lights	Has cycle status lights
	Cycle status estimated time	Has estimated wash time display
Soil level/wash length	Soil level selector	Soil level can be selected manually (if separate from the cycle selection itself)
	Soil level sensor	Specifics on soil level sensors/wash length automation
	Quick wash option	Has quick/speed wash option
Rinse	Extra rinse option	Specifics on Extra Rinse option
Suspension/ balance/noise	Smooth suspension	Specifics on suspension features
	Balance adjustment	Specifics on balance adjustment features
	Reduced noise	Specifics on noise reduction features

Sanitization	Washer cleaning cycle	Specifics on washer cleaning/sanitization cycles/technologies
	High heat	Laundry sanitization based on high temperatures
	Steam	Laundry sanitization based on steam
	Silver ion	Laundry sanitization based on silver ion technology
Tub/drum	Stainless steel tub	Stainless steel tub/basket
	Other tub features	Other specific tub/basket features
	Max extract tub	Specifics on tub designed for maximum moisture extraction
	Tilted tub	Tilted tub
Motor/ internal heater/other advanced features	Advanced motor	Specifics on advanced motor technologies (direct drive, etc.)
	Automatic machine diagnosis	Specific washer machine problem diagnosis technologies
	DR ready	Demand Response Technologies
	Remote laundry monitoring	Remote Laundry Monitoring capabilities
	Advanced clean action	Specifics on cleaning action/agitation/wash vane technologies
	Internal heater	Internal heater/heating element/booster heater
Other Options	Delay start option	Delay start of laundry option
	Fluff option	Option to periodically rotate/spin a finished load if sits in the washer a long time
	Add-a-garment option	Has an "add a garment" option

APPENDIX G: PRODUCT PRICE-EFFICIENCY RELATIONSHIP

Table G1. Regression Results of Room Air Conditioner Price by Efficiency Level

Dependent Variable: Price ($2013)	(1) Un-weighted	(2) Un-weighted	(3) Sales Weighted	(4) Sales Weighted
El 1	-153.8***		-263.6***	
	(26.62)		(28.49)	
EL 2	-129.0***		-189.8***	
	(30.72)		(29.56)	
tr (linear time trend)	0.0733	-1.351***	-0.0344	-0.854**
	(0.245)	(0.322)	(0.263)	(0.429)
tr x EL 1	-1.012**	0.0540	-0.866**	0.0774
	(0.421)	(0.363)	(0.386)	(0.455)
tr x EL 2	-0.244	-0.346	-0.538	-0.212
	(0.439)	(0.431)	(0.472)	(0.507)
Constant	494.2***	435.3***	475.8***	264.9***
	(16.54)	(7.582)	(20.63)	(8.064)
Model fixed effects	No	Yes	No	Yes
Observations	9,269	9,269	9,269	9,269
R-squared	0.161	0.068	0.322	0.052
Number of Models	794	794	794	794

Standard errors clustered by model in parentheses
Omitted Category: EL 0
* significant at p<0.1; ** significant at p<0.05; *** significant at p<0.01

Table G2. Regression Results of Refrigerator Price by Efficiency Level

Dependent Variable: Price ($2013)	(1) Un-weighted	(2) Un-weighted	(3) Sales Weighted	(4) Sales Weighted
El 1	146.9		259.2**	
	(147.2)		(128.7)	
EL 2	-187.9		-310.5**	
	(191.9)		(150.0)	
tr (linear time trend)	-2.220	-6.595***	-0.970	-4.188***
	(1.946)	(0.479)	(1.537)	(0.662)
tr x EL 1	1.942	-1.473***	3.643*	-3.187***
	(2.068)	(0.492)	(1.877)	(0.815)
tr x EL 2	4.671*	-0.231	7.719***	-0.968
	(2.573)	(0.670)	(2.036)	(1.259)
Constant	1,435***	2,001***	591.9***	1,215***
	(138.3)	(19.64)	(107.1)	(33.98)
Model fixed effects	No	Yes	No	Yes
Observations	95,790	95,790	95,790	95,790
R-squared	0.006	0.098	0.092	0.192
Number of Models	5,732	5,732	5,732	5,732

Standard errors clustered by model in parentheses
Omitted Category: EL 0
* significant at p<0.1; ** significant at p<0.05; *** significant at p<0.01

Table G3. Regression Results on Dishwasher Price by Efficiency Level

Dependent Variable: Price ($2013)	(1) Un-weighted	(2) Un-weighted	(3) Sales Weighted	(4) Sales Weighted
El 1	312.6***		345.8***	
	(116.9)		(110.3)	
EL 2	423.5***		351.9***	
	(120.9)		(125.3)	
tr (linear time trend)	1.461	-4.132*	9.035**	-3.802**
	(3.312)	(2.139)	(3.872)	(1.870)
tr x EL 1	-3.781	-0.329	-9.552**	0.164
	(3.312)	(2.150)	(3.828)	(1.894)
tr x EL 2	-3.011	-0.555	-8.898**	0.165
	(3.335)	(2.146)	(3.933)	(1.895)
Constant	388.4***	992.1***	113.2	671.9***
	(116.4)	(13.65)	(110.2)	(17.47)
Model fixed effects	No	Yes	No	Yes
Observations	38,026	38,026	38,026	38,026
R-squared	0.023	0.173	0.008	0.302
Number of Models	2,042	2,042	2,042	2,042

Standard errors clustered by model in parentheses

Omitted Category: EL 1 (Below 1994 Standard)

* significant at p<0.1; ** significant at p<0.05; *** significant at p<0.01

Table G4. Regression Results of Clothes Washer Price by Efficiency Level

Dependent Variable: Price ($2013)	(1) Un-weighted	(2) Un-weighted	(3) Sales Weighted	(4) Sales Weighted
EL 1	-6.137		23.37	
	(58.56)		(34.17)	
EL 2	126.2**		184.7***	
	(61.75)		(69.38)	
EL 3	750.1***		816.1***	
	(58.98)		(49.42)	
tr (linear time trend)	0.995	-3.878***	0.609	-5.180***
	(3.402)	(1.228)	(3.014)	(1.613)
tr x EL 1	-1.579	1.423	-2.295	3.212**
	(3.672)	(1.226)	(3.122)	(1.631)
tr x EL 2	-3.538	0.801	-3.197	2.174
	(3.488)	(1.315)	(3.137)	(1.699)
tr x EL 3	-6.581*	-7.711***	-6.891**	-5.570***
	(3.444)	(1.339)	(3.064)	(1.763)
Constant	553.7***	1,339***	397.4***	1,085***
	(37.10)	(23.65)	(22.24)	(26.24)
Model fixed effects	No	Yes	No	Yes
Observations	21,481	21,481	21,481	21,481

R-squared	0.307	0.438	0.524	0.549
Number of Models	1,079	1,079	1,079	1,079

Standard errors clustered by model in parentheses

Omitted Category: EL 0

* significant at p<0.1; ** significant at p<0.05; *** significant at p<0.01

APPENDIX H: BASIC STATISTICS ON QUALITY CHANGES AT TIME OF SALE

Table H1. Change in CR Ratings Pre/Post MEPS Event for Room ACs, Basic Statistics by Product Type

Rating Category	Before 2000 DOE Standard			After 2000 DOE Standard		
	Mean	Ste. Dev.	Obs.	Mean	Ste. Dev.	Obs.
Small Capacity (<7,000 btu/hr)						
Overall Score	70.29	8.33	85	71.26	8.96	164
Comfort Score	4.29	0.89	77	4.93	0.25	164
EE Ratio	9.51	0.70	100	10.40	0.62	164
Number of Models			100			164
Medium Capacity (7,000 to 8,900 btu/hr)						
Overall Score	63.53	11.30	64	69.92	5.87	103
Comfort Score	4.32	0.67	62	4.88	0.40	103
EE Ratio	9.66	0.54	78	10.46	1.03	103
Number of Models			78			103
Large Capacity (≥ 9,000 btu/hr)						
Overall Score	62.00	6.50	26	66.71	8.44	125
Comfort Score	4.15	0.86	40	4.90	0.30	125
EE Ratio	9.62	0.74	42	10.56	0.48	125
Number of Models			42			125

Table H2. Change in CR Ratings Pre/Post MEPS Event for Refrigerators, Basic Statistics by Product Type

Rating Category	Before 1990 Congress Standard			Between 1990 Congress and 1993 DOE Standard			Between 1993 and 2001 DOE Standard			After 2001 DOE Standard		
	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.
Top-Mount Refrigerator												
Overall Score	-	-	0	-	-	0	71.10	8.31	73	65.63	8.47	283
Energy Cost (2013$/yr)	83.50	11.33	100	82.59	6.42	34	65.15	11.02	73	49.66	7.90	164
Capacity (cu.ft.)	15.16	1.14	96	14.52	0.44	34	19.24	2.47	73	19.65	1.66	283
Temperature Performance	3.93	0.42	85	4.20	0.53	34	4.26	0.50	73	3.91	0.78	283
Energy Efficiency Score	-	-	0	-	-	0	3.52	1.03	50	4.69	0.49	283
Number of Models			100			34			73			283
Bottom Freezer Refrigerator												
Overall Score	-	-	0	-	-	0	73.13	6.96	15	72.31	7.32	342
Energy Cost (2013$/yr)	-	-	0	103.00	0.00	2	60.13	5.01	15	67.38	15.60	230
Capacity (cu.ft.)	-	-	0	15.80	0.00	2	19.25	1.94	15	23.42	3.25	342
Temperature Performance	-	-	0	4.33	0.00	2	4.82	0.38	15	4.77	0.52	342
Energy Efficiency Score	-	-	0	-	-	0	3.15	1.07	13	3.86	0.97	342
Number of Models			0			2			15			342
Side-by-Side Refrigerator												
Overall Score	-	-	0	-	-	0	63.70	8.86	74	68.62	29.82	330
Energy Cost (2013$/yr)	109.778	20.146	45	104.00	0.00	2	83.00	13.03	74	68.12	11.67	151

Capacity (cu.ft.)	21.775	0.389	32	15.20	0.00	2	22.60	4.58	67	24.23	2.39	330
Temperature Performance	-	-	0	3.67	0.00	2	3.72	0.80	74	3.97	0.83	330
Energy Efficiency Score	-	-	0	-	-	0	1.91	0.90	53	3.82	0.62	330
Number of Models			45			2			74			330
Built-In Refrigerator												
Overall Score	-	-	0	-	-	0	63.86	4.41	7	67.18	7.72	229
Energy Cost (2013$/yr)	-	-	0	98.00	0	1	90.29	5.99	7	73.43	14.68	111
Capacity (cu.ft.)	-	-	0	14.70	0	1	25.09	0.50	7	23.37	2.42	229
Temperature Performance	-	-	0	4.00	0	1	4.43	0.53	7	4.17	0.83	229
Energy Efficiency Score	-	-	0	-	-	0	1.71	0.95	7	3.55	0.76	229
Number of Models			0			1			7			229

Table H3. Change in CR Ratings Pre/Post MEPS Event for Dishwashers, Basic Statistics for Standard Product Type

Rating Category	**Before 1994 DOE Standard**			**Between 1994 DOE and 2010 Congress Standard**			**After 2010 Congress Standard**		
	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.
Overall Score	64.14	9.65	71	74.26	8.74	745	68.31	10.70	621
Washing Performance	3.85	0.88	217	4.62	0.73	745	4.43	0.68	621
Cycle Time (min.)	80.98	9.40	165	117.02	17.88	618	127.17	15.41	621
Energy Efficiency Score	3.62	0.87	210	3.78	0.67	684	4.31	0.50	621
Number of Models			222			745			621

Table H4. Change in CR Ratings Pre/Post MEPS Event for Clothes Washers, Basic Statistics by Product Type

Rating Category	**Before 1994 DOE Standard**			**Between 1994 and 2004 DOE Standard**			**Between 2004 and 2007 DOE Standard**			**Between 2007 DOE Standard and 2011 Congress Standard**			**After 2011 Congress Standard**		
	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.
Top Loader															
Overall Score	-	-	0	61.57	7.85	232	56.03	7.87	102	57.24	13.96	119	74.18	2.79	22
Capacity Score	3.62	0.86	45	4.02	0.94	179	3.85	0.74	102	4.03	0.97	119	5.00	0.00	22
Cycle Time (mins)	40.00	1.73	3	47.12	6.51	57	47.30	9.19	102	49.20	8.68	119	55.00	11.75	22
Energy Efficiency Score	3.14	0.83	36	2.63	0.71	191	2.66	0.76	102	3.12	0.77	119	4.50	0.51	22
Number of Models			45			232			102			119			55
Front Loader															
Overall Score	-	-	0	76.78	8.66	41	71.10	8.07	52	75.25	4.65	147	81.60	3.36	57
Capacity Score	1.80	0.45	5	3.78	1.11	37	3.90	1.21	52	4.51	0.71	147	5.00	0.00	57
Cycle Time (mins)	72.50	31.82	2	59.38	8.29	24	75.96	19.30	52	77.89	17.98	147	83.77	12.86	57
Energy Efficiency Score	5.00	-	1	4.90	0.31	39	4.31	0.67	52	4.59	0.55	147	4.93	0.26	57
Number of Models			5			41			52			147			57

Table H5. Change in CR Ratings Pre/Post MEPS Event for Clothes Dryers, Basic Statistics by Product Type

Rating Category	Before 1994 DOE Standard			After 1994 DOE Standard		
	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.
Electric Dryer						
Overall Score	-	-	0	71.13	10.16	437
Drying Performance	3.77	0.56	25	4.10	0.78	437
Capacity Score	4.12	0.81	41	4.64	0.58	437
Number of Models			57			437
Gas Dryer						
Overall Score	-	-	0	72.22	10.77	295
Drying Performance	3.94	0.52	12	4.19	0.82	295
Capacity Score	4.25	0.75	12	4.61	0.58	295
Number of Models			36			295

APPENDIX I: DIFFERENCE-IN-MEANS RESULTS REGARDING QUALITY CHANGES AT TIME OF SALE

Table I1: Change in CR Ratings Pre/Post MEPS Event for Room ACs, Difference-in Means Results by Product Type

	Post 2000 - Pre 2000 Standard			
Small Capacity (<7K btu/hr)	**Diff.**	**Percent Diff.**	**t-stat**	
Overall Score	0.968	1.38%	0.847	
Comfort Score	0.647	15.10%	6.290	***
EE Ratio	0.888	9.34%	10.436	***
Med Capacity (7-9K btu/hr)				
Overall Score	6.391	10.06%	4.189	***
Comfort Score	0.561	12.98%	5.958	***
EE Ratio	0.802	8.31%	6.756	***
Large Capacity (9K+ btu/hr)				
Overall Score	4.712	7.60%	3.181	***
Comfort Score	0.754	18.17%	5.420	***
EE Ratio	0.947	9.84%	7.779	***

Table I2: Change in CR Ratings Pre/Post MEPS Event for Refrigerators, Difference-in Means Results by Product Type

	Post 1990 - Pre 1990 Standard				Post 1993 - Pre 1993 Standard				Post 2001 - Pre 2001 Standard			
Bottom Freezer	**Diff.**	**Percent Diff.**	**t-stat**		**Diff.**	**Percent Diff.**	**t-stat**		**Diff.**	**Percent Diff.**	**t-stat**	
Overall Score									-0.823	-1.13%	-0.448	
Energy Cost (2013$/yr)					-42.867	-41.62%	-33.122	***	7.245	12.05%	4.382	***
Capacity (cu.ft.)					3.447	21.81%	6.874	***	4.173	21.68%	7.854	***
Temperature Performance					0.483	11.15%	4.882	***	-0.042	-0.87%	-0.406	
Energy Efficiency Score									0.706	22.38%	2.346	***
Built-In												
Overall Score									3.326	5.21%	1.907	**
Energy Cost (2013$/yr)					-7.714	-7.87%	-3.406	***	-16.853	-18.67%	-6.338	***
Capacity (cu.ft.)					10.386	70.65%	55.167	***	-1.711	-6.82%	-6.923	***
Temperature Performance					0.429	10.71%	2.121	**	-0.254	-5.73%	-1.213	
Energy Efficiency Score									1.840	107.35%	5.070	***
Top-Mount												
Overall Score									-5.470	-7.69%	-4.996	***
Energy Cost (2013$/yr)	-0.912	-1.09%	-0.577		-17.438	-21.11%	-10.279	***	-15.492	-23.78%	-10.836	***
Capacity (cu.ft.)	-0.642	-4.23%	-4.628	***	4.719	32.50%	15.831	***	0.410	2.13%	1.346	*
Temperature Performance	0.267	6.79%	2.632	***	0.061	1.45%	0.564		-0.345	-8.11%	-4.598	***
Energy Efficiency Score									1.173	33.31%	7.856	***
Side-by-Side												
Overall Score									4.915	7.72%	2.537	***
Energy Cost (2013$/yr)	-5.778	-5.26%	-1.924	**	-21.000	-20.19%	-13.864	***	-14.881	-17.93%	-8.323	***
Capacity (cu.ft.)	-6.575	-30.20%	-95.522	***	7.399	48.67%	13.233	***	1.635	7.24%	2.847	***
Temperature Performance					0.053	1.44%	0.567		0.247	6.64%	2.378	***
Energy Efficiency Score									1.909	100.20%	14.825	***

Table I3: Change in CR Ratings Pre/Post MEPS Event for Dishwashers, Difference-in Means Results for Standard Product Type

	Post 1994 - Pre 1994 Standard				Post 2010 - Pre 2010 Standard			
	Diff.	**Percent Diff.**	**t-stat**		**Diff.**	**Percent Diff.**	**t-stat**	
Overall Score	10.120	15.78%	8.509	***	-5.948	-8.01%	-11.104	***
Washing Performance	0.767	19.92%	11.681	***	-0.191	-4.13%	-4.983	***
Cycle Time (min.)	36.035	44.50%	35.113	***	10.146	8.67%	10.695	***
Energy Efficiency Score	0.156	4.32%	2.389	***	0.528	13.98%	16.181	***

Table I4: Change in CR Ratings Pre/Post MEPS Event for Clothes Washers, Difference-in Means Results by Product Type

	Post 1994 - Pre 1994 Standard				Post 2004 - Pre 2004 Standard			
Top Loader	Diff.	Percent Diff.	t-stat		Diff.	Percent Diff.	t-stat	
Overall Score					-5.540	-9.00%	-5.931	***
Washing Performance	1.272	39.12%	2.648	***	-1.355	-29.97%	-17.756	***
Capacity Score	0.400	11.05%	2.739	***	-0.169	-4.21%	-1.676	**
Cycle Time (mins)	7.123	17.81%	5.395	***	0.181	0.38%	0.144	
Energy Efficiency Score	-0.511	-16.27%	-3.451	***	0.029	1.09%	0.313	
Front Loader								
Overall Score					-5.684	-7.40%	-3.237	***
Washing Performance	1.207	34.49%	2.379	**	-1.015	-21.56%	-8.562	***
Capacity Score	1.984	110.21%	7.330	***	0.120	3.17%	0.485	
Cycle Time (mins)	-13.125	-18.10%	-0.582		16.587	27.94%	5.238	***
Energy Efficiency Score	-0.103	-2.05%	-2.084	**	-0.590	-12.04%	-5.592	***

	Post 2007 - Pre 2007 Standard				Post 2011 - Pre 2011 Standard			
Top Loader	Diff.	Percent Diff.	t-stat		Diff.	Percent Diff.	t-stat	
Overall Score	1.206	2.15%	0.805		16.947	29.61%	12.010	***
Washing Performance	0.043	1.37%	0.392		0.835	26.02%	8.404	***
Capacity Score	0.172	4.47%	1.498	*	0.975	24.22%	10.968	***
Cycle Time (mins)	1.898	4.01%	1.569	*	5.798	11.78%	2.206	**
Energy Efficiency Score	0.461	17.34%	4.447	***	1.382	44.34%	10.629	***
Front Loader								
Overall Score	4.156	5.84%	3.512	***	6.345	8.43%	10.803	***
Washing Performance	0.022	0.60%	0.220		0.637	17.14%	7.298	***
Capacity Score	0.606	15.53%	3.417	***	0.490	10.86%	8.414	***
Cycle Time (mins)	1.930	2.54%	0.631		5.881	7.55%	2.604	***
Energy Efficiency Score	0.277	6.44%	2.677	***	0.345	7.52%	6.094	***

Note: While it appears that the average washing performance and energy efficiency score of front-load washers decreased after the 2004 standard, this is actually due to the fact that CR changed its testing method to make it harder for washers to achieve an excellent score. The major change CR incorporated was to test models using the maximum possible load size using the adjustable water level, as this feature had become prevalent in most models by this time. The final score is based on both the testing result from a normal load (8lb) and maximum load (which depends on the washer volume) with a 50/50 weight. An indicator of the effect of the change is seen in the energy efficiency ratings of models like the Maytag MAH7500a, which dropped from a 4-point score in 2002 to a 3-point score for the same model in 2004. Despite the change in testing methodology, the energy efficiency performance and washing performance of both front- and top-load washers have improved over time steadily since then.

Table I5: Change in CR Ratings Pre/Post MEPS Event for Clothes Dryers, Difference-in Means Results by Product Type

	Post 1994 - Pre 1994 Standard			
Electric Dryer	Diff.	Percent Diff.	t-stat	
Overall Score				
Drying Performance	0.335	8.87%	2.841	***
Capacity Score	0.521	12.64%	4.013	***
Gas Dryer				
Overall Score				
Drying Performance	0.251	6.38%	1.585	*
Capacity Score	0.360	8.47%	1.635	*

APPENDIX J: PRODUCT PRICE-DESIGN RELATIONSHIP

Table J1. Room AC Price Trend Differentiated by Product Design

Dependent Variable: Price ($2013)	(1) Un-weighted	(2) Un-weighted	(3) Sales Weighted	(4) Sales Weighted
Built-in	196.7***		266.0***	
	(27.03)		(32.37)	
tr (linear time trend)	-0.360	-1.529***	-0.848***	-0.883***
	(0.246)	(0.159)	(0.304)	(0.145)
tr x Built-in	0.0142	0.417	-0.000402	0.323
	(0.399)	(0.421)	(0.688)	(0.557)
Constant	347.3***	434.6***	250.8***	263.5***
	(15.74)	(7.452)	(17.96)	(8.152)
Model fixed effects	No	Yes	No	Yes
Observations	9,269	9,269	9,269	9,269
R-squared	0.143	0.068	0.174	0.051
Number of Models	794	794	794	794

Standard errors clustered by model in parentheses

Omitted Category: Window

* significant at p<0.1; ** significant at p<0.05; *** significant at p<0.01

Table J2. Dishwasher Price Trend Differentiated by Product Design

Dependent Variable: Price ($2013)	(1) Un-weighted	(2) Un-weighted	(3) Sales Weighted	(4) Sales Weighted
Built-in	320.4***		17.16	
	(32.51)		(41.26)	
Counter-Top	-240.9***		-245.9***	
	(22.35)		(19.52)	
Under Sink	-57.05		2.060	
	(89.97)		(68.12)	
tr (linear time trend)	0.633**	-0.897***	0.316	-1.193***
	(0.292)	(0.270)	(0.310)	(0.306)
tr x Built-in	-1.405***	-4.041***	-0.00703	-2.595***
	(0.443)	(0.338)	(0.558)	(0.441)
tr x Counter-Top	-0.393	0.0948	-0.276	0.381
	(0.399)	(0.272)	(0.330)	(0.309)
tr x Under Sink	1.098	3.472***	-0.307	2.880***
	(1.638)	(0.991)	(1.626)	(1.001)
Constant	421.4***	998.8***	429.8***	675.0***
	(20.28)	(13.20)	(19.30)	(17.57)
Model fixed effects	No	Yes	No	Yes
Observations	37,981	37,981	37,981	37,981
R-squared	0.023	0.185	0.004	0.311
Number of Models		2,038		2,038

Standard errors clustered by model in parentheses

Omitted Category: Portable

* significant at p<0.1; ** significant at p<0.05; *** significant at p<0.01

Table J3. Clothes Dryer Price Trend Differentiated by Product Design

Dependent Variable: Price ($2013)	(1) Un-weighted	(2) Un-weighted	(3) Sales Weighted	(4) Sales Weighted
Gas	24.47		116.7**	
	(27.87)		(57.58)	
tr (linear time trend)	2.388***	-8.159***	1.443***	-5.590***
	(0.273)	(0.402)	(0.527)	(0.492)
tr x Gas	0.440	-1.006	-0.179	-1.066
	(0.397)	(0.611)	(0.781)	(0.715)
Constant	498.8***	1,239***	438.7***	866.2***
	(19.62)	(19.94)	(38.88)	(23.15)
Model fixed effects	No	Yes	No	Yes
Observations	31,373	31,373	31,373	31,373
R-squared	0.073	0.356	0.063	0.347
Number of Models	1,646	1,646	1,646	1,646

Standard errors clustered by model in parentheses
Omitted Category: Electric
* significant at p<0.1; ** significant at p<0.05; *** significant at p<0.01

Appendix K: INFORMATION ON CLOTHES WASHER FEATURES

Table K1: Results of clustering clothes washer features by technical function

Feature Cluster	Features in Cluster	Feature Names (see Appendix F for more detail)
Mechanical	7	“mechanical controls,” “water level selector,” “soil level selector,” “temperature selector,” “spin speed option,” “spin time option,” “extra rinse option”
Convenience	9	“add-a-garment option,” “cycle status end signal,” “cycle status estimated time,” “cycle status lights,” “delay start option,” “bleach dispenser,” “detergent dispenser,” “fabric softener dispenser,” “fluff option”
Digital and automating	9	“electronic controls,” “programmable controls,” “automatic machine diagnosis,” “direct inject dispenser,” “DR ready,” “water level sensor,” “remote laundry monitoring,” “soil level sensor,” “temperature sensor”
Core	7	“advanced clean action,” “internal heater,” “advanced motor,” “balance adjustment,” “reduced noise,” “smooth suspension,” “other dispenser features”
Sanitization-related	5	“NSF certification”, “high heat,” “silver ion,” “steam,” “washer cleaning cycle”
Nudge	4	“water-saving option,” “Max Extract option,” “temperature nudge option,” “quick wash option”
Tub-related	4	“Max Extract tub,” “other tub features,” “stainless steel tub,” “tilted tub”

Figure K1: Evolving share of top-loading and front-loading clothes washers with features in the “mechanical” cluster

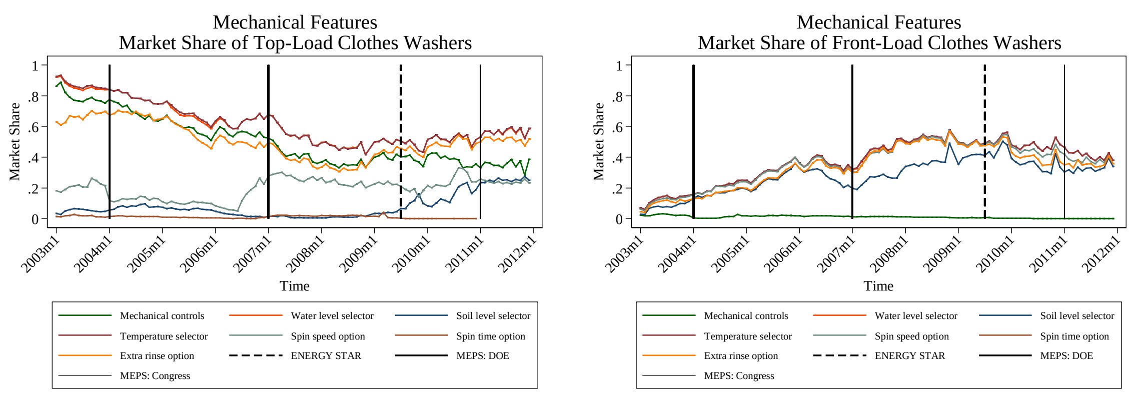

Figure K2: Evolving share of top-loading and front-loading clothes washers with features in the "convenience" cluster

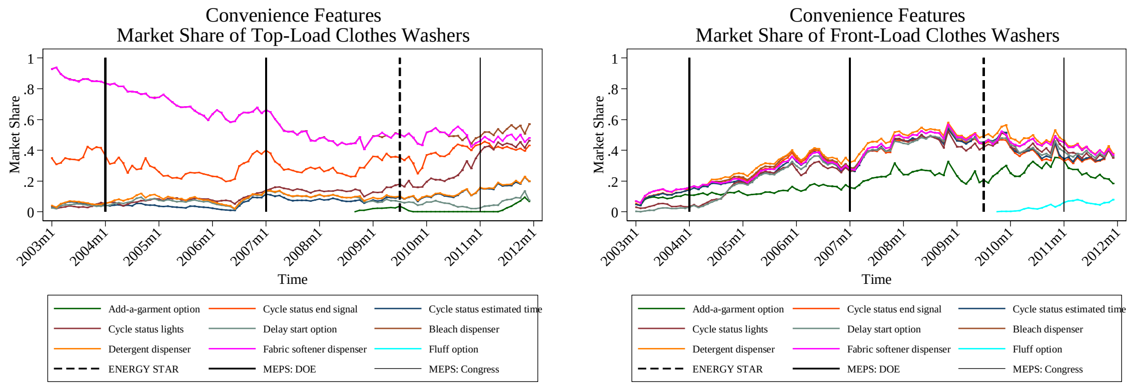

Figure K3: Evolving share of top-loading and front-loading clothes washers with features in the "digital and automating" cluster

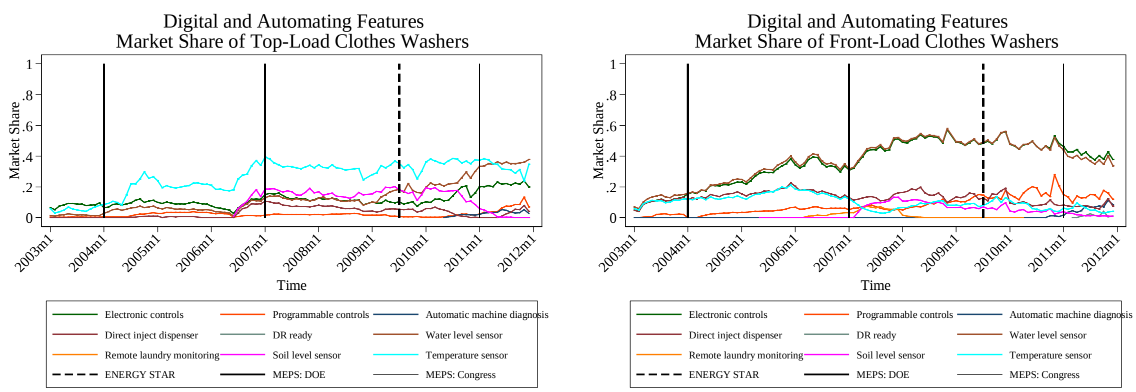

Figure K4: Evolving share of top-loading and front-loading clothes washers with features in the "core" cluster

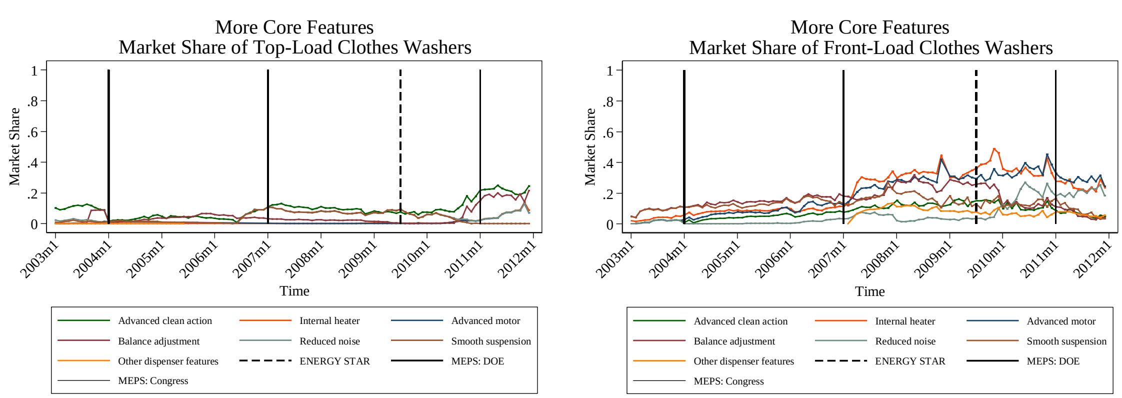

Figure K5: Evolving share of top-loading and front-loading clothes washers with features in the "sanitization-related" cluster

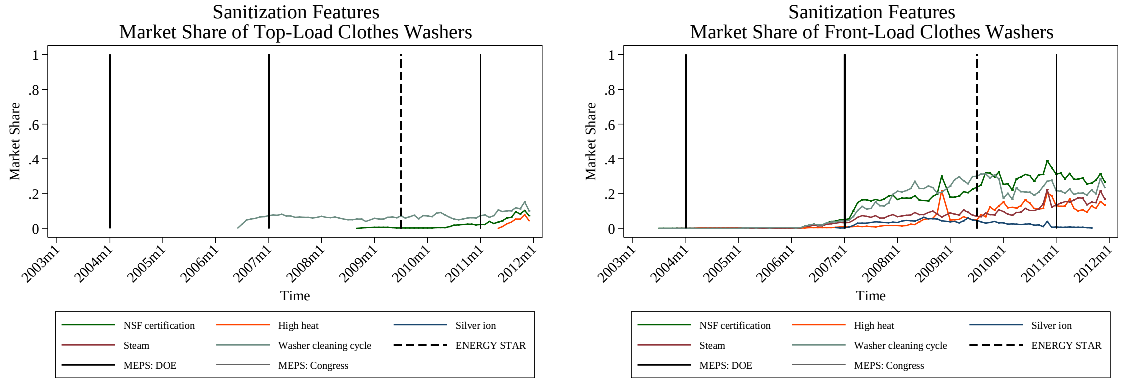

Figure K6: Evolving share of top-loading and front-loading clothes washers with features in the "nudge" cluster

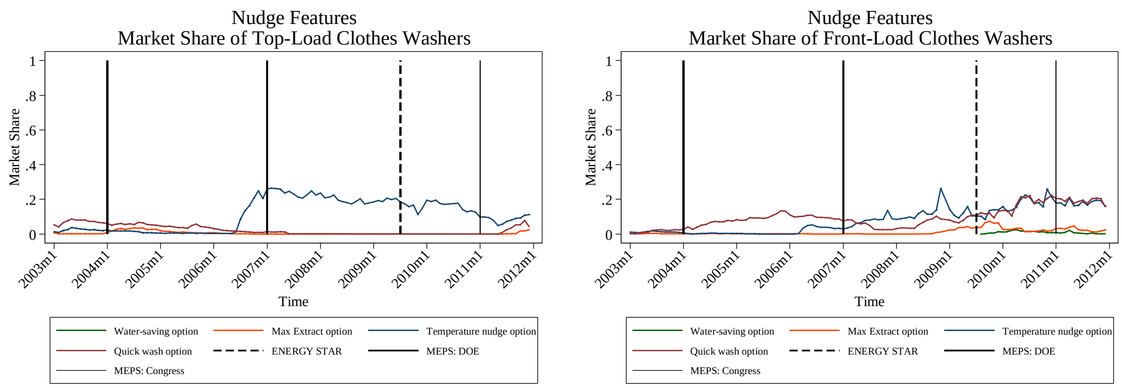

Figure K7: Evolving share of top-loading and front-loading clothes washers with features in the "tub-related" cluster