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Innovation under the ENERGY STAR Program

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Abstract

Innovation under the ENERGY STAR Program Yeong Jae Kim School of Public Policy Georgia Institute of Technology Year of Enrollment: 2011 Expected Final Date: 2017 Email: Ykim445@gatech.edu What is the role of voluntary environmental policies on innovation of firms? The impact of voluntary environmental policy on innovation is ambiguous because of two opposite effects: signaling and innovation effects. First, the signaling effect of voluntary environmental policy hinders innovation of firms because a firm send a signal to government and it anticipates loose environmental policies in the future, so it is less likely to innovate. Second, even though a voluntary environmental policy is less stringent than a mandatory environmental policy, a firm may find ways to improve the energy efficiency of their products or use less energy to make products. Depending the size of two effects, a firm participating in the voluntary environmental program may or not lead to technological innovation. The objective of this paper is to investigate net effects of ENERGY STAR on household appliance firms' innovative behavior using patent data. Numerous researchers have paid attention to the consumer side of ENERGY STAR, but relatively few studies have been conducted regarding the manufacturers side of product innovation. Particularly, product innovation in the household appliance industry is relatively understudied. Taylor, Fujita, and Dale (2012) conducted a pilot study on the dynamics of innovation and energy efficiency policies. They provides the general relationship between the rate and direction of technological change of household appliance industry. The results highlighted in their paper focuses on several leading firms, Maytag, Electrolux, Whirlpool, and General Electric, because they have dominated household appliance market. However, the limitation arises from the neglect of the other firms related to patenting behaviors of firms. In this paper, I would like to fill the gap. In this paper, I relax their assumption by including more number of houshold appliance firms to examine patenting behavior of firms with regard to domestic or foreign ENERGY STAR participating firms in 1997 using difference-in-difference estimation method. This paper contributes to an understanding of whether voluntary environmental policy in general and particularly ENERGY STAR spur or deter environmental innovation of firms. To test this hypothesis, I collected patent data from 1985 to 2004 to analyze firms' innovation behaviors related to the energy efficiency of refrigerators; I gathered the data from the United States Patent and Trademark Office database. I found weak evidence of the impact of ENERGY STAR on participating firms' patents. However, I found no evidence that the impact on innovation differed for foreign and domestic inventors. I also found no evidence of a mandatory environmental policy on innovation, which suggests that voluntary policies may be crowding out mandatory ones.

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Innovation under the ENERGY STAR Program

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Abstract

The objective of this paper is to examine the impact of the voluntary environmental policy on technological innovation in household appliance firms. The key hypothesis is that firms participating in the ENERGY STAR program were more likely to innovate in response to the 1997 ENERGY STAR criteria update than firms that did not participate. Since participation in the voluntary environmental policy is not random, I should find time-varying instrument variables and account for unobserved heterogeneity. To test this hypothesis, I collected NBER patent data from 1990 to 2003 to analyze firms' innovation behaviors related to the energy efficiency of household appliances and matched with COMPUSTAT to include firm-level financial information. Using Fixed effect Poisson and Poisson instrument variable estimator, I found a statistically significant evidence of the impact of ENERGY STAR on participating firms' patents.

Keywords: Voluntary Environmental Program, Innovation, Patents

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1. Introduction

What role do voluntary environmental policies play in determining firms' innovation? The impact that such policies have on innovation is ambiguous because of two opposing effects: signaling and innovation. The signaling effect of a voluntary environmental policy hinders innovation because firms send signals to the government that they anticipate loose environmental policies in the future; they are thus less likely to innovate. Second, even though a voluntary environmental policy is less stringent than a mandatory environmental policy, firms may find ways to improve the energy efficiency of their products or use less energy to make those products. Depending on the relative sizes of the two effects, participating in the voluntary environmental program may or not lead to technological innovation. It is empirically challenging tease out these two effects.

The objective of this paper is to investigate the net effects that ENERGY STAR participation had on household appliance firms' innovation behaviors. I examine why firms participate in ENERGY STAR program, and who is actively innovating once a firm is participating in ENERGY STAR. This program can be complementary or substitutionary to mandatory energy-efficiency mandates that create incentives for firms to make innovations in energy efficiency.

My first motivation to write this paper is that product innovation in the household appliance industry has been relatively understudied. Numerous researchers have paid attention to the consumer side of ENERGY STAR, but relatively few studies have been conducted regarding the manufacturer side of product innovation. Taylor, Fujita, and Dale (2012) conducted a pilot study on the dynamics of innovation and energy efficiency policies. They provided the general relationship between the rate and direction of technological change in the household appliance industry. Their paper focused on several leading firms (Maytag, Electrolux, Whirlpool, and General Electric) because those firms have dominated the household appliance market. However, a limitation arises due to the authors' neglect of other firms' patenting behaviors. In this paper, I would like to fill that gap.

The second purpose of this paper is to provide evidence of the relationship between voluntary environmental programs and technological innovation. There is a body of literature which examines the relationship between energy policy and innovation. Researchers are mainly investigating the impact of environmental regulations on innovation and technology. Building on Jaffe and Palmer (1997), scholars have taken advantage of the econometric technique to estimate the impacts of various factors on energy innovation (Altwies & Nemet, 2013; Jaffe, Newell, & Stavins, 2002). Particularly, most of the literature relies on R&D expenditures or patent data to assess this relationship. Jaffe and Palmer's (1997) seminal study investigates the relationship between total R&D expenditures (or the number of patent applications) and pollution abatement costs. Subsequently, numerous studies have found a positive relationship with environmental regulation (Arimura, Hibiki, & Katayama, 2008; Brunnermeier & Cohen, 2003; Lanoie et al., 2011; Popp, 2003, 2006b). One study emphasizes the negative relationship between environmental regulation and innovation; for example, the increased age of capital in U.S. electric utilities in the 1970s (Nelson, Tietenberg, & Donihue, 1993). However, it is not considered to be properly designed as a regulation that would encourage innovation.

However, there is not much evidence to test whether voluntary environmental policy deters or spurs technological innovation. In general, findings on the effectiveness of voluntary environmental programs are mixed. Innes and Sam (2008) find the effectiveness of the 33/50 program[2] only last the first year of the program. Carrión-Flores, Innes, and Sam (2013) even argue that the 33/50 program deters future innovation. However, it is possible for firms to learn better technological options by participating in voluntary environmental programs. Contary to other voluntary environmental programs, ENERGY STAR program is generally considered to be a stringent program, and it appears to be an effective voluntary program (Fischer & Lyon, 2014). After becoming an ENERGY STAR partner[3], a firm agrees to measure and track energy usage, implement energy performance strategies, and further educate staff and the public about its achievement. It could be the case that ENERGY STAR may spur the innovation of ENERGY STAR partners. Since the ENERGY STAR program expanded to include refrigerators in 1997, numerous firms have started to become ENERGY STAR partners, which may positively affect the patenting behavior of household appliance firms, especially ENERGY STAR participating firms.

Previous literature[4] emphasized that the decision to participate in a voluntary program is random and there is no systematic difference between the treatment group and control group (Khanna & Damon, 1999). If I use a traditional difference-in-differences estimation method to tease out the impact of the ENERGY STAR on innovation, endogenous problems could arise. To avoid this, Pizer, Morgenstern, and Shih (2008) used a difference-in-differences estimation and propensity score matching technique where there is no selection bias on unobserved characteristics. This method allows for overcoming observed differences between participants and non-participants.

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[2] The 33/50 program was the EPA's first effort to reduce pollution by regulated firms initiated in 1991.
[3] https://www.energystar.gov/buildings/about-us/become-energy-star-partner
[4] For reviews of this literature, see Lyon and Maxwell (2002) and Morgenstern and Pizer (2007).

Due to there being a relatively small number of firms[5], I employ a two-stage estimation approach instead of using difference-in-difference and propensity score matching techniques. In a nutshell, I find a suggestive evidence of the impact of ENERGY STAR program on household appliance technological innovation. Unlike other no-significant results of the effectiveness of the other programs in the previous literature, it is attributed to the minimum energy efficiency standard which may kick unqualified products out of the market and push technology frontiers. The rest of the paper is organized as follows. First, I provide the historical background of energy policy related to household appliances. Second, I describe the theoretical argument and literature review. Third, I estimate and discuss the results of the impact of ENERGY STAR on innovation using a two-stage model: a participating equation and patenting equation. Finally, I discuss the implications and then conclude.

2. Background

The energy crisis in the 1970s led to the implementation of energy efficiency standards. States such as California, Massachusetts, and New York led the way. For example, California passed legislation to create energy efficiency standards for refrigerators in 1978 (ACEEE, 2014). The California Energy Commission subsequently updated these standards in 1980 and 1987. As a consequence, the annual energy consumption of refrigerators in the state gradually decreased. However, states had different types of regulations, and companies did not want to comply with various regulations. Therefore, companies called for a unified federal standard (Lester & Hart, 2012). California's success provided the impetus for the implementation of federal energy efficiency standards. In 1987, President Reagan signed national legislation to finalize the federal

[5] I identify firms using patent data. Someone might argue that using NAICS codes would be more appropriate to identify relevant firms, but it raises the issue of low matching ratios among patent data, NAICS codes, and COMPUSTAT. So I use NBER patent data to discern relevant firms.

standards for products. Following that, the Department of Energy updated the federal standards for refrigerators in 1990, 1993, 2001, and 2014.

The Federal Trade Commission required companies to add Energy Guide labels on their household appliances to inform consumers of the estimated annual operating costs of those products. These estimates were based on the national average price of electricity. Federal standards varied depending on the configuration and the size of the refrigerator.

The federal energy efficiency standards spurred firms' product innovations because firms had to satisfy the requirements. Levine, Koomey, McMahon, Sanstad, and Hirst (1995) showed that the net benefit of the federal minimum energy efficiency standards enacted in 1994 was about $45 billion. Companies challenged themselves to develop technologies with greater energy efficiency—including better insulation, more efficient compressors, and improved heat exchangers. For these reasons, experts have viewed these regulatory policies as some of the most successful energy efficiency policies (Brown, 2001).

To promote the diffusion of energy-efficient products and assist companies that were investing in such products, ENERGY STAR was created in 1992. ENERGY STAR is a voluntary program that provides information about energy-efficient technologies to consumers and companies; the program thereby corrects the informational asymmetry between firms and consumers. Sellers with highly energy-efficient products are asked to indicate the quality of their products to consumers through this program. Thus, informed consumers can select these highly energy-efficient products instead of less efficient products by looking for the ENERGY STAR logo on a product's label. This program is successful in reducing energy consumption and greenhouse gas emissions (Sanchez, Brown, Webber, & Homan, 2008).

ENERGY STAR includes household and commercial appliances, including air conditioners, heat pumps, and refrigerators. Several revisions have been made to the ENERGY STAR criteria for refrigerators since 1992. On January 1, 2003, all refrigerators and freezers greater than 7.75 cubic feet in volume were required to be 10% more energy efficient than the minimum federal standard to be ENERGY STAR certified. Products less than 7.75 cubic feet in volume had to be at least 20% above the federal minimum standard to receive the certification. In 2004, the criteria for full-sized refrigerators rose to 15% in 2004 and to 20% more in 2008. The latter version of the standard (version 4.1), remained in effect until September 15, 2014, [6] when the new ENERGY STAR criteria for residential refrigerators took effect. Table 1 summarizes energy policies that may positively affect the patenting behavior of household appliance firms.

Table 1. Energy policies that may impact innovation of household appliance firms[7]

Year	Event
1990	First federal refrigerator efficiency standards enacted
1992	Energy Policy Act signed; EPA ENERGY STAR program is created
1993	Federal refrigerator standards are updated; Super-Efficient Refrigerator Program(SERP) Golden Carrot strategy announced
1997	EPA/DOE Energy Star program expanded to include refrigerators
2001	Federal refrigerator efficiency standards are updated
2007	Energy Independence and Security Act of 2007 (EISA) signed; requires DOE final rule on 2014 refrigerators by end of 2010

In the household appliance market, firms strategically compete to maximize profits and increase market share. Increasing the number of households with energy-efficient products will, over time, reduce overall household energy consumption. As a result, households will spend less

[6] http://www.energystar.gov/index.cfm?c=refrig.pr_crit_refrigerators
7 Source: Department of Energy, 2010; Deumling, 2009; Taylor, 1995

on energy, allowing them to spend more on other goods and services. From the firms' viewpoint, they will incur upfront costs to improve the energy efficiency of their products and thus lose short-term profits. However, firms can increase their long-term profits by selling a greater volume. Economic theory indicates that a firm strategically determines the price of its products to maximize profits. Houde (2014) used product-level transactional data from the U.S. refrigerator market to demonstrate that firms clustered their performance around the certification requirement and thereby maximized their profits. Houde (2014) conducted a welfare analysis of ENERGY STAR, but he did not address the relationship between environmental policy and innovation which is underexplored.

The economic theory indicates a club members share a common value and enjoy benefits after joining voluntary programs excluding non-club members (Buchanan, 1965; Kotchen, 2012). Once a firm participates in the program, a firm decides whether it continuously introduce ENERGY STAR products or shirks rules on ENERGY STAR depends on enforcement and monitoring mechanism (Prakash & Potoski, 2006) and firms' resources (Hart, 1995).

Since the United States is a big market, both domestic and foreign firms have an incentive to innovate. First, firms must meet the minimum federal standards dictated by the National Appliance Energy Conservation Act (NAECA) to sell their products in the United States. Additionally, firms have incentives to participate in voluntary environmental regulations in order to send signals to both consumers and the government. Firms hope to expect selling more products by sending a green signal to consumers. This is called the signaling effect. Firms may hope to expect to escape more stringent regulation from the government by sending earlier signals. Or a firm may have an incentive to innovate in order to satisfy the threshold of voluntary standards or even more. Here we expect to see a differential impact of the policy on domestic or foreign firm innovation.

3. Methods

3.1. Model specifications

Building on Brouhle, Graham, and Harrington (2013)'s model specification, I construct a two-stage model to estimate the impact of ENERGY STAR on innovation. Ideally, I should account for unobserved heterogeneity, find time-varying instruments, and use a fixed effect Poisson estimator.

First, I construct a firm participation equation. If a firm expects a net benefit, a firm would participate in the ENERGY STAR program. This equation determines factors that affect a firm participation in the ENERGY STAR program. Similar to Brouhle, Graham, and Harrington (2013)'s model, I model a firm's net benefit of participation in the ENERGY STAR as follows:

$$D_{i,t}^{*}= \beta_1 X_{1i,t} + \varepsilon_{i,t} \qquad (1)$$

where $X_{1i,t}$ is a vector of independent variables for I firm and t year. β is a vector of parameters I estimate, and $\varepsilon_{i,t}$ is residuals. Table 2 shows a list of dependent and independent variables. Since we cannot measure net benefits of participating, we proxy this with a binary participation decision.

$$D_{i,t}=1 \text{ if } D_{i,t}^{*}>0 \qquad (2)$$

$$=0 \text{ otherwise}$$

It reduces to the form and I estimate it using a logit model.

$$D_{i,t}= F(\beta_1 X_{1i,t}) + u_{i,t} \qquad (3)$$

A firm-level patenting equation is as follow:

$$Y_{i,t} = \alpha D_{i,t} + \beta_2 X_{2i,t} + \varepsilon_{2i,t} \quad (4)$$

Where $Y_{i,t}$ is energy-related household appliance patents by a firm i and year t, $D_{i,t}$ is a participation in the ENERGY STAR program, $X_{2i,t}$ is a vector of exogenous variables, $\varepsilon_{2i,t}$ is random errors. Since a dependent variable is the number of patents, I employ a Poisson model and use a generalized method of moments (GMM) estimator. In order to overcome the potential endogenous problem in equation (4), I follow two approaches addressed in Brouhle et al., (2013). The first approach is to control for unobserved time invariant effect by using fixed effect panel model estimation. This overcomes the potential unobserved heterogeneous effects across firms. For example, "green" managers, engineers, or lawyers may affect both the decision to participate in the ENERGY STAR program and the patenting equation. Early participants in ENERGY STAR partners and late participants in ENERGY STAR partners may behave differently.

The second approach is to control for an unobserved time variant effect by using an instrumental variable. A participation in the Green Light program, which was a precedent of the ENERGY STAR program, may affect the decision to participate in the ENERGY STAR program but not energy related household appliance patents. Since the purpose of the Green Light program is to encourage firms or organizations to install energy-efficient technologies, the motivation for a firm to develop innovative technology is weak. It was later integrated into ENERGY STAR.[8] The identification of year of participating in Green Light program comes from the Green Light program reports from 1992[9] to 1996. Each year, a report introduces a new

[8] https://www.energystar.gov/index.cfm?c=about.ab_milestones

[9] https://nepis.epa.gov/Exe/ZyNET.exe/91012HSE.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1991+Thru+1994&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C91thru94%5CTxt%5C00000027%5C91012HSE.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

member. A sample of the report's front page is attached in Appendix 2. I manually identify a list of firms and year of participation.[10] The rationale for the valid instrumental variable is that Green Light program is not to encourage energy-related household appliance patents directly, but through participation in the ENERGY STAR program. I also test the validity of the instrument variable in the patenting equation.

Table 2. A list of variables

Variables	**Obs**	**Mean**	**Std. Dev.**	**Participation equation**	**Patenting equation**
Dependent variables					
ENERGY STAR	345	0.17	0.38	X	
No. of patents (by year and firm)	345	3.13	5.04		X
Independent variables					
Green Light Program	345	0.24	0.43	X	
ROA-Return on Assets=net income/total assets	343	5.16	7.05		X
DTA-debt to assets	343	0.15	0.09		X
Employee: three-year moving average	309	4.01	1.83	X	X
Capital intensity: log of the average of a firm's past three-years capital expenditure	320	6.12	2.29	X	X
R&D intensity: log of the average of a firm's past three-years R&D expenditure	312	5.66	2.31	X	X
Beverage and Tobacco Product Manufacturing	345	0.04	0.20		X
Chemical Manufacturing	345	0.23	0.42		X
Machinery Manufacturing	345	0.08	0.27		X
Computer and Electronic Product Manufacturing	345	0.22	0.42		X
Electrical Equipment, Appliance, and Component Manufacturing	345	0.20	0.40		X
Transportation Equipment Manufacturing	345	0.14	0.35		X
Miscellaneous Manufacturing	345	0.01	0.12		X
Others	345	0.07	0.25		X
Germany	345	0.05	0.21		X
Italy	345	0.03	0.16		X
Japan	345	0.24	0.43		X
South Korea	345	0.03	0.18		X

[10] Green light participating firms in 1992: 501 KK TOSHIBA, AMANA REFRIGERATION INC, CARRIER CORORATION, COCA COLA BOTTLING WORKS CO, GEN ELECTRIC CO, MAYTAG CO, and WHIRLPOOL CORP

United Kingdom	345	0.05	0.22	X
New Zealand	345	0.01	0.12	X
Switzerland	345	0.04	0.20	X
United States	345	0.54	0.50	X

* The North American Industry Classification System (NAICS) 2002

*I also use one-year and two-year lags to check the robustness of the models.

3.2. Construction of data

Patent counts are frequently used as a measure of innovation. Of course, not all firms decide to patent their innovations (Cohen, Nelson, & Walsh, 2000), and thus patent counts are not a perfect measure of energy innovation output.[11] However, they are generally considered one of the best energy innovation outputs.

Previously, Taylor, Fujita, Dale, and McMahon (2012) identified energy-efficient patents related to refrigerator using U.S. Patent Classification (USPC) and four major players including mergers and acquisitions: General Electric, Whirlpool, Electrolux, and Maytag. They identified 64 energy-related patents for refrigerators between 1976 and January 17, 2011, out of a total of 1,060 refrigerator patents. There are two possible caveats to this search method. It may omit relevant patents filed by small firms, and therefore I consider their results to be an under representation of the entire scope of refrigeration innovation. More broadly, to better define energy-efficient technological developments in household appliances, I also refer to the recent two level keywords search methods (Barbieri & Palma, 2016).

In this paper, I combine two papers' method which has a broader scope than the four major manufacturers.[12] I collected the patent data to analyze firm innovation behaviors related to

[11] A discussion of the relationship between patent data and energy innovation output is well documented in Popp (2005)'s paper.

[12] Barbieri and Palma (2016)

1. first-level keywords: (((energysav$ OR energy efficien$ OR energy conservation OR high efficien$ OR low energy OR low-energy OR low electricity consumption OR energy reduction OR energy economis$ OR energy

refrigerator energy efficiency gathered from the CASSIS[13] (USPTO) and matched with NBER patent database[14] (Hall, Jaffe, & Trajtenberg, 2001) using patent number. Additionally, I match patent data with COMPUSTAT's financial information using a Global Company Key (GVKEY).[15] I can identify firms using NAICS codes, but one concern is that I may not obtain enough control variables.

I matched the retrieved patents to the ENERGY STAR partner list. [16] I assumed that the ENERGY STAR partner list is the most up-to-date proxy for ENERGY STAR participating firms. One caveat of this database is that I could not distinguish the participating year of the firm, so I manaully found the year of firm participation, which is shown in Table 6.

It is not a complete list of ENERGY STAR participants over the course of the years because a firm can go in and out of the ENERGY STAR program. For simplicity of analysis, I ruled out this possibility. I assume that ENERGY STAR partner does not withdraw its membership because a firm can maintain its membership as long it has at least one eligible product. If a household appliance does not satisfy ENERGY STAR requirements, a certification body (CB) reports to the Environmental Protection Agency (EPA) and shars with other CBs through an internal account which is not publicly available on the ENERGY STAR website. It is

economiz$ OR energy performanc$ OR less electric energy OR less electricity OR less energy OR energy use manage$ OR energy AND use control$ OR energy manage$) AND (residen$ OR hous$ OR domestic OR hom$ OR dwellin$ OR famil$)).TIAB.)-->399

2. second-level keywords: (refrigerator OR refrigerators OR fridge OR fridges OR washingmachine$ OR dishwash$).TIAB. -> 5344

Taylor, Fujita, and Dale (2013)

3. ((energy AND efficiency) OR (appliance) OR (household) OR (refrigerator) OR (cooler)) AND (62/$)).CCLS. ---->3220

[13] CASSIS is a stand-alone machine that includes US Patent and Trademark Office database (Utility patents: Jan, 1969 to Apr, 2010).

[14] https://sites.google.com/site/patentdataproject/Home/downloads

[15] GVJEY is a unique six-digit number key assigned to each company in COMPUSTAT database.

[16] http://www.energystar.gov/index.cfm?fuseaction=ESTAR_PARTNER_LIST.showProductSearch&s_code=ALL&partner_type_id=MANUFACTURER&cntry_code=ALL&award_search=N

therefore not possible to obtain a list of disqualifed or delisted ENERGY STAR products and firms. Once again, even though one product may be disqualifed over the course of years, it does not necessarily mean that a firm discontinues its ENERGY STAR partnership. In addition, I also found Green Light participating firms[17] from the Environment Protection Agency (EPA)'s Green Lights Annual Reports.

I dropped any firm that had less than 5 patents from the sample. This resulted in 1,311 patents, including 444 patents by ENERGY STAR participating firms and 867 patents by non-ENERGY STAR participating firms. Figure 1 illustrates the number of energy-related and non-energy-related household appliance patent applications.

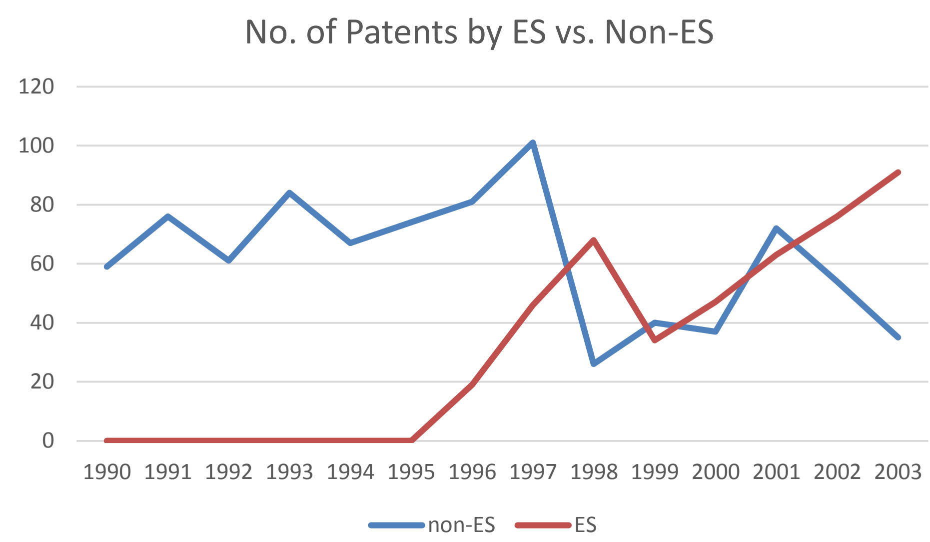

Figure 1. Number of patents by ENERGY STAR/non-ENERGY STAR firms

To identify where R&D occurred, I used the location information of the assignee. Figure 2 shows the number of patent applications by the assignee's country of origin. United States

[17] Green Light participating firms: 501 KK Toshiba, Amana Refrigeration Inc, Carrier Corporation, Coca Cola Botting Works Co, Gen Electric Co, Maytag Co, and Whirlpool Corp.

inventors accounted for about 56% of total patent applications. South Korean inventors accounted for 22%, followed by Japanese inventors.

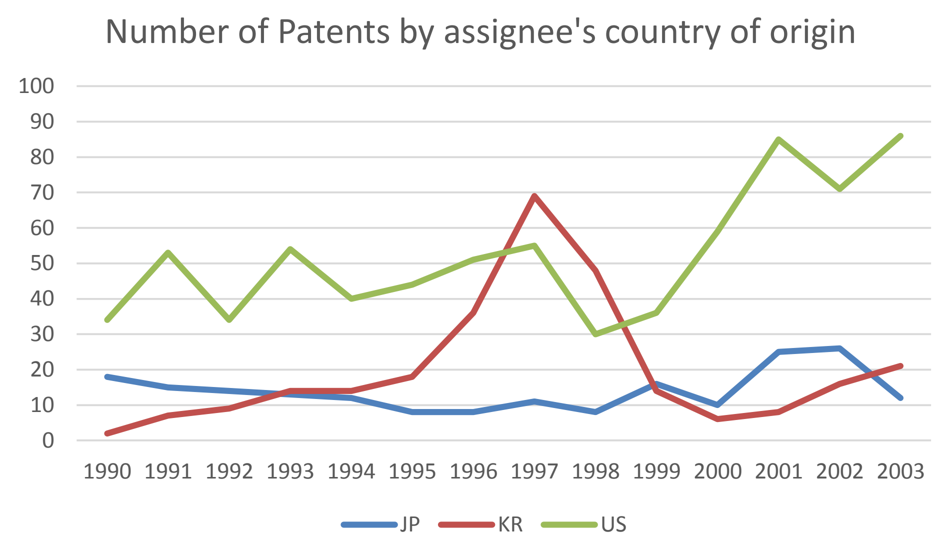

Figure 2. Number of patents by assignee's country of origin

Table 2 shows variables used in both participation equation and patenting equation. Once again, I use the number of patents by a firm each year. In the ENERGY STAR participation equation, an instrumental variable is Green Light[18], which is a binary variable that indicates whether a firm participated in the Green Light program.

In a participation equation, DeCanio and Watkins (1998) addressed several factors which affect the decision of firms to participate in the Green Light program: large firms, higher earnings/share and higher price/earnings. Therefore, I include in the model the number of employees and firm financial information: Return on Assets and Debt to Assets. Koehler (2007) pointed out several factors influencing participation in voluntary environmental program: final

[18] Howarth, R. B., Haddad, B. M., and Paton (2004) showed that over 2,300 organizations participated in the Green Light program and they achieved about 40 percent energy reduction.

goods producers, consumer pressure, and higher advertising expenditures per unit sales. Several other variables can be included, but I do not include them in models because most ENERGY STAR partners are final goods producers as well. It is also not easy to obtain entire advertising expenditures for companies over the course of years.

In a patenting equation, firm-level financial information is included in my model to measure firm profitability and uncertainty. Return on Assets, which is net income divided by total assets, is a measure of resource availability of a firm (Russo & Fouts, 1997). Debt to assets is a measure of financial risk (Arora & Cason, 1995). Much previous literature emphasized the significance of a firm’s technical capacity, i.e., capital intensity or R&D intensity, on maximizing energy efficiency of firms (Matisoff, 2010; Stafford, 2012). Since capital intensive firms are more likely to file patent applications (Carrión-Flores & Innes, 2010), I include capital-intensity, which is measured by the log of the average of a firm's capital expenditure for the past three years. I also include R&D intensity which is measured by the log of the average of a firm's past three years’ R&D expenditure. I relax this assumption later to check the robustness of the models.

Finally, I have several control variables. I include a three year moving average of the number of employees to control for the size of a firm. Industries can have different incentives to file patent applications, and Lange (2009) argues for the importance of industries examining voluntary environmental programs, so I include a NAICS industry code dummy variable. Environmental innovation is spurred by the anticipated regulation of energy efficiency policy as well, so I include a year fixed effect.

4. Main Estimation Results

In the participation equation, within variation of being an ENERGY STAR partner is greater than between variation[19] of being an ENERGY STAR partner, so the standard error of the fixed effects coefficients is tolerant enough to be used in the patenting equation. To estimate a binary participation decision, a logit model can be consistently estimated with fixed effects, and is preferred to a probit model in panel data structure. In order to check the validity of the instrument variable, i.e., Green Light Program participation, I conduct an F-test on the instrument to see if the instrument is jointly significant in the endogenous variable (Cameron & Trivedi, 2010).[20]

In the patenting equation, one could use a two-stage estimation method to estimate the effect of ENERGY STAR by including the ENERGY STAR hat from the participation equation. However, the standard error would be incorrect. Using the IV estimation command (ivpoisson gmm) in STATA, the standard error is already corrected (Windmeijer & Silva, 1997). Several papers also use the GMM estimator to estimate the fixed-effects Poisson model for panel data (Blundell, Griffith, & Windmeijer, 2002; Wooldridge, 1999; Wooldridge, 2010).

Table 3 shows the participation equation results. First, a participation in the Green Light program is a significant predictor of participation in the ENERGY STAR program across six different specifications. Consistent with the previous literature, a larger firm is more likely to participate in the ENERGY STAR program. This is in part because a big firm does not have to

[19] The between variation of being ENERGY STAR partner is 0.24 which is less than the within variation 0.30.

[20] Conditional estimator is always safe when $T < 20$ a unconditional estimator has a negligible amount of bias for $16 \leq T < 20$. The bias in the unconditional estimator grows as T decreases (Couṕ, 2005). Since T=14, I use conditional logit fixed effect. The "conditional logit" (clogit) estimation should be preferred because it allows for clustered by industry-robust standard errors. In this case, the Chi2 statistics is 109.05.

pay a huge amount of transaction costs to fill out documents in order to be an ENERGY STAR partner.

Table 3. Logit models: motivation for participation in the ENERGY STAR program.

VARIABLES	(1) Logit	(2) Logit	(3) Logit	(4) Probit	(5) Probit	(6) Probit
Green Light Program	2.293***	4.704***	2.405***	2.709***	1.395***	3.352***
	(0.446)	(0.997)	(0.594)	(0.495)	(0.256)	(0.677)
Return on Assets	-0.0604*	0.128*	-0.0464	0.0679**	-0.0368*	0.0387**
	(0.0336)	(0.0653)	(0.0339)	(0.0334)	(0.0193)	(0.0180)
Debt to Assets	4.139*	-5.910**	2.894	-3.527**	2.565**	5.235***
	(2.192)	(2.895)	(2.181)	(1.546)	(1.177)	(1.588)
Log (3-year moving average of number of employees)	1.400***	2.660***	0.903**	1.455***	0.805***	-0.316
	(0.491)	(0.796)	(0.411)	(0.374)	(0.250)	(0.206)
Log (3-year moving average of capital expenditure)	-0.279	2.098***	-0.215	1.161***	-0.175	-0.582***
	(0.272)	(0.712)	(0.270)	(0.354)	(0.142)	(0.196)
Log (3-year moving average of R&D expenditure)	-1.036***	-4.062***	-0.668*	-2.257***	-0.589***	0.380***
	(0.392)	(0.852)	(0.379)	(0.430)	(0.192)	(0.140)
YEAR FE	YES	YES	YES	YES	YES	NO
INDSUTRY FE	NO	YES	NO	YES	NO	NO
FIRM FE	NO	NO	YES	NO	NO	YES
Constant	-20.62***	-25.37***	-34.59***	-8.392***	-5.950***	-2.197***
	(1.319)	(3.238)	(1.355)	(1.532)	(0.496)	(0.520)
Observations	309	264	309	160	187	309

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4 shows the result of the patenting equation. To obtain the consistent estimator, the price we have to pay is larger standard errors in Column (3) and (4). The key finding is that ENERGY STAR partners are more likely to innovate than non-ENERGY STAR partners. The surprising results are that none of other variables are significant. I expect to see a positive sign in the effect of the number of employees and R&D expenditure.

Table 4. GMM Poisson models: patenting equations

VARIABLES	(1) Poisson FE	(2) Poisson FE	(3) Poisson IV	(4) Poisson IV
ENERGY STAR	-0.101	-0.101	2.007**	3.468***
	(0.246)	(0.299)	(0.960)	(1.022)
Return on Assets	-0.0142	-0.0142	-0.00305	0.00307
	(0.0133)	(0.0161)	(0.0404)	(0.0151)
Debt to Assets	-4.391***	-4.391**	2.612	3.333**
	(1.373)	(1.864)	(2.499)	(1.499)
Log (3-year moving average of number of employees)	-0.472	-0.472	-0.0584	-0.121
	(0.748)	(0.895)	(0.194)	(0.180)
Log (3-year moving average of capital expenditure)	0.221*	0.221	0.149	0.182
	(0.124)	(0.190)	(0.151)	(0.159)
Log (3-year moving average of R&D expenditure)	0.224	0.224	-0.0152	0.127
	(0.167)	(0.175)	(0.296)	(0.184)
YEAR FE	YES	YES	NO	NO
FIRM FE	YES	YES	NO	NO
Observations	304	304	309	309

(1) Robust standard errors in parentheses
(2) Bootstrap standard errors in parentheses
(3) Std. Err. adjusted for 8 clusters in industry
(4) Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

As a robustness check, I replace the three-year moving average of covariates by one-year or two-year lags: the number of employees, the average of capital expenditure, and the average of R&D expenditure. Both cases are consistent with the main model estimation results. Since three of our control variables are highly multicollinearities, I remove two of them and check the robustness of our findings. The main findings are robust after including each of them.

5. Further Estimation Results

Table 5 shows an estimation result of an instrument variable poisson with a country and Energy Star interaction term. This interaction term indicates a differential impact between U.S. and non-U.S. companies in response to the policy update. I could not find any evidence of a differential impact of domestic or foreign firms on innovation. This could be expected because ENERGY STAR is a flagship voluntary energy efficiency program in the United States, so foreign ENERGY STAR firms have also been affected by the ENERGY STAR criteria update. Therefore, there is no particular reason to believe that U.S. firms are more likely to innovate than non-US firms in response to the policy change.

Table 5. A differential impact of domestic and foreign firms

VARIABLES	(1) Poisson IV	(2) Poisson IV	(3) Poisson IV
Inter_ES_US	23.50	35.43	32.39
	(15.53)	(39.16)	(29.73)
ENERGY STAR	-25.58	-41.94	-38.11
	(16.97)	(45.45)	(34.12)
Return on Assets	-0.0323	-0.0295	0.0147
	(0.0464)	(0.0873)	(0.0507)
Debt to Assets	-1.435	-17.31	-15.15
	(3.621)	(19.11)	(14.64)
Log (3-year moving average of number of employees)	0.628		
	(0.558)		
Log (3-year moving average of capital expenditure)	0.167		
	(0.429)		
Log (3-year moving average of R&D expenditure)	-0.656*		
	(0.370)		
Log (One-year lag of average of number of employees)		2.525	
		(1.708)	
Log (One-year lag of capital expenditure)		-3.818	
		(3.233)	
Log (One-year lag of R&D expenditure)		1.602	
		(1.904)	
Log (Two-year lag of average of number of			3.238*

employees)			
			(1.764)
Log (Two-year lag of capital expenditure)			-3.194
			(2.144)
Log (Two-year lag of R&D expenditure)			0.550
			(0.902)
Constant	0.281	6.751	6.544
	(1.110)	(5.772)	(4.037)
YEAR FE	YES	YES	YES
FIRM FE	YES	YES	YES
Observations	309	282	281

Exponential mean model with endogenous regressors
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6 shows an estimation result on the interaction term between the mandatory policy change in 2001 and ENERGY STAR partners in order to tease out the differential effect of ENERGY STAR and non-ENERGY STAR firms. When it came to the mandatory policy change, I found no evidence supporting an impact on ENERGY STAR partner firms of the federal refrigerator efficiency standards update in 200. The standards update in 2001 did not give ENERGY STAR participating companies more incentive to invent energy-efficient technologies. However, the energy efficiency standard update in 2001 gives an incentive to innovate non-ENERGY STAR firms, which is the main purpose of the mandatory policy. One possible explanation is the crowding effects between mandatory environmental policy and voluntary environmental policy associated with ENERGY STAR partners. It is plausible that increases in energy patents in response to the voluntary environmental policy led to a lesser incentive to further develop energy-efficient technologies because ENERGY STAR firms are already meet the mandatory policy criteria. Therefore, the effectiveness of the voluntary program may crowd out the effectiveness of the mandatory program.

Table 6. Interaction between ENERGY STAR and Mandatory Policy

VARIABLES	(1) Poisson IV	(2) Poisson IV	(3) Poisson IV
ENERGY STAR*Mandatory	-4.598**	-2.874**	-2.891**
	(1.796)	(1.271)	(1.186)
Mandatory	-0.330	-0.328	-0.455
	(0.408)	(0.452)	(0.455)
ENERGY STAR	5.501***	3.547**	3.399**
	(1.911)	(1.529)	(1.458)
Return on Assets	0.00964	0.00717	0.0116
	(0.0150)	(0.0157)	(0.0166)
Debt to Assets	3.275**	2.932	2.301
	(1.609)	(2.356)	(2.393)
Log (3-year moving average of number of employees)	-0.138		
	(0.179)		
Log (3-year moving average of capital expenditure)	0.196		
	(0.164)		
Log (3-year moving average of R&D expenditure)	0.142		
	(0.192)		
Log (One-year lag of average of number of employees)		0.0719	
		(0.264)	
Log (One-year lag of capital expenditure)		-0.174	
		(0.388)	
Log (One-year lag of R&D expenditure)		0.255	
		(0.261)	
Log (Two-year lag of average of number of employees)			0.346
			(0.283)
Log (Two-year lag of capital expenditure)			-0.273
			(0.372)
Log (Two-year lag of R&D expenditure)			0.120
			(0.235)
YEAR FE	YES	YES	YES
FIRM FE	YES	YES	YES
Constant	-0.288	-0.0851	0.549
	(0.441)	(0.923)	(0.902)
Observations	309	282	281

Exponential mean model with endogenous regressors
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5. Conclusions

This paper contributes to an understanding of whether voluntary environmental policy in general—and ENERGY STAR in particular—spur or detract from firms' environmental innovation. I found a result suggestive of the impact of ENERGY STAR on household appliance firm's innovation. It shows that ENERGY STAR firms more actively participated in energy-related household appliance patents in response to the ENERGY STAR criteria update in 1997. The results show strong evidence that an ENERGY STAR criteria change can spur innovation in household appliance firms that participate in ENERGY STAR. There is no differential impact between U.S. firms and non-U.S. firms. It also shows the potential evidence of the crowding-out effect on innovation of a mandatory environmental policy and a voluntary environmental policy.

From the firms' collective viewpoint, they will incur up-front costs to improve the energy efficiency of their products and thus lose short-term profits. A new energy-efficient technology could be worth billions of dollars, but companies must bear a considerable amount of upfront costs that may lead to uncertain future benefits. Due to the nature of energy efficiency investments, firms are reluctant to invest in R&D to improve energy-efficient technologies. As a result, energy-efficient technologies will be underfunded. Therefore, government interventions play a significant role in guaranteeing a steady supply of energy-efficient technologies in the market. According to Porter (1991), environmental regulation can be an incentive for technological innovation.

The identification of energy-related household appliance patents in this paper was broader than Taylor, Fujita, Dale, and McMahon's (2012) list of patents, which was very conservative. I suggest that Taylor et al.'s (2012) identified patents (64 patents between 1976 and

2011) were the lower bound, and this study's identified energy-related refrigerator patents (2,530 patents between 1985 and 2004) are the upper bound.

Similarly with Graham, Brouhle, and Ramirez (2014)'s paper, it would be necessary to conduct patent weighted citation analysis in order to measure information flow from the ENERGY STAR participants to non-participants. Previous literature argues for a free-ride effect from voluntary environmental policy participants to non-participants. Building on the Jaffe, Trajtenberg, and Henderson (1993)'s seminal paper, this is an area of future research.

Another remaining question is whether technological innovation spurs a tightening of the mandatory energy efficiency policy from 2001. It is plausible that firms participating in ENERGY STAR are already satisfing the minimum energy efficiency requirement of the mandatory policy in 2001 so that ENERGY STAR firms may lobby to the government to strengthen the minimum criteria. ENERGY STAR firms want to further enjoy the first mover advantage. Compared to non-ENERGY STAR firms, future work is required to test a reverse causality between voluntary and mandatory environmental policy and technological innovation.

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Table 5. A list of firm names (Participants vs. Non-participants)

Types	Company names
ENERGY STAR Partner	501 HITACHI LTD
	AB ELECTROLUX
	AMANA REFRIGERATION INC
	ECOLAB
	FISHER & PAYKEL APPLIANCES LTD
	GEN ELECTRIC CO
	MAYTAG CO
	SAMSUNG ELECTRONICS CO LTD
	UNITED TECHNOLOGIES CORP
	WHIRLPOOL CORP
Non-ENERGY STAR Partner	501 HONDA GIKEN KOGYO KK
	501 KK TOSHIBA
	501 SHARP KK
	ATSUSHITA ELECTRIC IND CO LTD
	BASE CORP
	BOSCH & SIEMENS HAUSGERAETE GMBH
	CHUBU ELECTRIC CO INC MITSUBISHI DENK..
	CHURCH & DWIGHT
	COCA COLA BOTTLING WORKS CO
	COGATE PALMOLIVE CO
	ELTEK SPA
	HAC
	HELIX TECH
	ILEVER HOME & PERSONAL CARE USA A DIV..
	INTEE CORP
	ISTEON GLOBAL TECH INC
	PROCTER & GAMBLE CO
	RACKITT BENCKISER NV
	SANGO ELECTRIC CO LTD

Table 6. Number of Patents by ENERGY STAR participants vs. non-ENERGY STAR participants

	Assignee/country									
Year patent applied for	CA	DE	IT	JP	KR	NL	NZ	SE	US	Total
1990	0	1	0	18	2	0	0	4	34	59
1991	0	0	0	15	7	0	0	1	53	76
1992	0	0	0	14	9	0	1	3	34	61
1993	0	1	0	13	14	0	0	2	54	84
1994	0	0	0	12	14	0	0	1	40	67
1995	0	0	0	8	18	0	3	1	44	74
1996	0	1	0	8	36	0	0	1	51	97
1997	1	6	0	11	69	0	3	1	55	146
1998	5	0	0	8	48	0	1	2	30	94
1999	6	1	0	16	14	0	0	1	36	74
2000	2	0	2	10	6	0	5	0	59	84
2001	5	5	3	25	8	2	1	1	85	135
2002	3	6	1	26	16	6	0	1	71	130
2003	1	6	0	12	21	0	0	0	86	126
Total	23	27	6	196	282	8	14	19	732	1,307

*CA(Canada), DE(Germany), IT(Italy), JP(Japan), KR(South Korea), NL(Netherlands), NZ(New Zealand), SE(Sweden), US(United States)

Table 7. Summary Statistics (Participants vs. Non-participants)

	ES=1			ES=0		
	Obs	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**
No. of patents	128.00	**5.24**	6.77	217.00	**1.88**	3.06
ROA-Return on Assets=net income/total assets	60.00	**4.61**	4.69	283.00	**5.28**	7.46
DTA-debt to assets	60.00	**0.19**	0.08	283.00	**0.15**	0.09
Employee	52.00	**4.20**	1.53	257.00	**3.97**	1.88
Capital intensity	59.00	**6.24**	2.09	261.00	**6.09**	2.34
R&D intensity	52.00	**5.41**	1.95	260.00	**5.70**	2.38
Beverage and Tobacco Product Manufacturing	128.00	**0.00**	0.00	217.00	**0.06**	0.25
Chemical Manufacturing	128.00	**0.11**	0.31	217.00	**0.30**	0.46
Machinery Manufacturing	128.00	**0.00**	0.00	217.00	**0.13**	0.34
Computer and Electronic Product Manufacturing	128.00	**0.30**	0.46	217.00	**0.17**	0.38
Electrical Equipment, Appliance, and Component Manufacturing	128.00	**0.33**	0.47	217.00	**0.13**	0.34
Transportation Equipment Manufacturing	128.00	**0.11**	0.31	217.00	**0.16**	0.36
Miscellaneous Manufacturing	128.00	**0.04**	0.19	217.00	**0.00**	0.00
Others	128.00	**0.11**	0.31	217.00	**0.05**	0.21
Germany	128.00	**0.00**	0.00	217.00	**0.07**	0.26
Italy	128.00	**0.00**	0.00	217.00	**0.04**	0.20
Japan	128.00	**0.11**	0.31	217.00	**0.32**	0.47
South Korea	128.00	**0.09**	0.28	217.00	**0.00**	0.00
United Kingdom	128.00	**0.00**	0.00	217.00	**0.08**	0.28
New Zealand	128.00	**0.04**	0.19	217.00	**0.00**	0.00
Switzerland	128.00	**0.11**	0.31	217.00	**0.00**	0.00
United States	128.00	**0.66**	0.48	217.00	**0.48**	0.50

Table 8. Correlation Matrix

	greenlight	roa	dta	Avgemp3yearexp	Avgcapx3yearexp	Avgxrd3yearexp
greenlight	1					
roa	-0.0047	1				
dta	0.0528	-0.302	1			
avgemp3yearexp	0.1388	-0.326	0.22	1		
avgcapx3yearexp	0.1291	-0.201	0.1457	0.8457	1	
avgxrd3yearexp	0.0121	-0.27	0.0662	0.8613	0.9116	1

Appendix 1. ENERGY STAR participating firms

Name	year of participation	Source
SAMSUNG ELECTRONICS CO LTD	1996	http://news.samsung.com/us/2015/04/06/samsung-electronics-wins-two-2015-energy-star-partner-of-the-year-awards-for-sustained-excellence-and-climate-communications/
CARRIER CORORATION	1997	http://dms.hvacpartners.com/docs/1009/Public/02/58MXA-11PD.pdf
GEN ELECTRIC CO	1997	https://www.energystar.gov/ia/partners/prod_development/revisions/downloads/clotheswash/GE_CW_Comments4.15.05.pdf?5442-a1e8
MAYTAG CO	1997	https://www.energystar.gov/ia/partners/prod_development/revisions/downloads/clotheswash/Maytag.pdf?5442-a1e8
AB ELECTROLUX	1998	http://ieeexplore.ieee.org/document/645988/
AMANA REFRIGERATIO N INC	1998	https://www.whirlpool.com/digitalassets/MLPDF/Use%20and%20Care%20Guide%20-%2020070003.pdf
DAEWOO ELECTRONICS CO LTD	1998	http://heinonline.org/HOL/LandingPage?handle=hein.journals/lwpra24&div=42&id=&page=
ELECTROLUX HOME PROD INC	1998	http://ieeexplore.ieee.org/document/645988/
WHIRLPOOL CORP	1998	https://www.energystar.gov/index.cfm?fuseaction=pt_awards.showAwardDetails&esa_id=384
WHIRLPOOL EURO BV	1998	https://www.energystar.gov/index.cfm?fuseaction=pt_awards.showAwardDetails&esa_id=384
WHIRLPOOL INT BV	1998	https://www.energystar.gov/index.cfm?fuseaction=pt_awards.showAwardDetails&esa_id=384
501 HITACHI LTD	1999	http://tv.manualsonline.com/manuals/mfg/hitachi/42hdt79_55hdt79_42hdx99_55hdx99_1_2.html
ECOLAB	1999	ftp://ftp.cs.huji.ac.il/cs/adir/mirror/LDP/HOWTO/pdf/Ecology-HOWTO.pdf
FISHER & PAYKEL APPLIANCES LTD	1999	http://link.springer.com/chapter/10.1007/978-3-642-60020-3_14#page-1
BOSCH & SIEMENS HAUSGERAETE GMBH	2007	http://www.bosch-home.com/us/press-releases-detail.html?pressrelease=epa-recognizes-bosch-home-appliances-with-2014-energy-star%C2%AE-partner-of-the-year-sustained-excellence-award~13147

Appendix 2. A sample of Green Lights Report