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Why Is Energy Efficiency Such a Hard Sell?

Bongkyun Kim

Graduate Research Assistant

Howard H. Baker Jr. Center for Public Policy and the Department of Economics
University of Tennessee

Charles Sims, PhD

Faculty Fellow, Howard H. Baker Jr. Center for Public Policy
Assistant Professor, Department of Economics
University of Tennessee

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Abstract

The “energy efficiency gap” refers to consumers forgoing energy efficiency investments that yield a positive return. This report reviews the explanations for the energy efficiency gap and revisits one particular explanation - the role of uncertainty in future energy prices and energy efficiency capital costs. We update the option value analysis of Hassett and Metcalf (1993) by extending fuel oil price data to 2015, and using alternative proxies for energy prices. The results show an increase in the implicit discount rate for a generic energy efficiency investment. However, the magnitude of the implicit discount rate is smaller than observed in many surveys. Moreover, the small increase in the implicit discount rate originated from an increase in the investment’s conventional hurdle rate rather than an increase in the investment’s option value. This suggests that future uncertainty can only explain a portion of the energy efficiency gap. The report concludes by highlighting avenues for future research that will clarify the role of uncertainty in explaining the energy efficiency paradox.

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Graduate Research Assistant

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I. Introduction

There is general consensus that energy efficiency technology¹ is one of the most efficient ways to mitigate global warming (Jaffe and Stavins, 1994; Geller et al., 2006; McKinsey & Company, 2009; Ramos et al., 2015; Ameli and Brandt, 2015). For example, according to International Energy Agency projections, cumulative CO₂ reduction from the adoption of energy efficiency technology is the largest in all sectors except the power sector (IEA, 2015)². Economists point out that energy efficiency technology adoption is likely too low since the carbon-reduction benefits these technologies confer are a public good - no one can be excluded from the benefits generated by others carbon-reduction efforts. However, many energy efficient technologies are also cost effective for households and firms even if these CO₂ reduction benefits are not considered. Studies have shown that the net present value of switching from old, energy-intensive devices to new, energy-efficient devices is positive (Sovacool and Hirsh, 2009). Since expected future savings, discounted by the market interest rate, are greater than the initial purchasing cost, these investments would appear to provide a higher rate of return to homeowners and firms than could be earned elsewhere in the economy. For example, even though individual households can save more than 15% of annual energy expenditures by investing in a home energy audit (Fuller et al., 2011), participation rates for these programs in the U.S. is only 1-5% (Lee, 2010; Neme et al., 2011; Palmer et al., 2013).

That consumers forgo energy efficient investments that yield a positive net present value is called the “energy efficiency gap” or “energy paradox” (Jaffe and Stavins, 1994). The gap or paradox reflects the idea that consumers should adopt energy efficient products if they yield a rate of return that is higher than could be earned with other investments. However, the implicit discount rate (the rate of return needed to drive the net present value of the investment to zero) for observed energy efficiency investments can be much higher than any reasonable risk adjusted discount rate. Table 1 presents the implicit discount rate from nineteen energy efficiency studies ranging from heating systems and room air conditioners to freezers and automobiles. In many

¹ Energy efficiency is the ability to use less energy to produce the same amount of useful work or services whereas energy conservation means simply using less energy (Reliable, Affordable, and Environmentally Sound Energy for America’s Future, 2001).

² Other methods include renewables, carbon capture and sequestration (CCS), fuel switching, and nuclear. The largest cumulative CO₂ reduction in the power sector is from renewables.

cases, energy efficiency investments were not made until these investments yielded a 100% return.

There are many theories explaining why the energy efficiency gap exists, and these explanations are generally divided into three categories (Gillingham and Palmer, 2014; Gerarden et al., 2015); “*Consumer behavior*”, “*Market failure*”, and “*Model and measurement error*.” Proponents of consumer behavior and market failure argue the energy efficiency gap exists due to inefficient distortion in markets or irrational characteristics of human behavior. The measurement error explanation suggests that this seemingly paradoxical result arises from incomplete modeling. If all relevant costs were included and the individual decision process is correctly modeled, traditional neo-classical economic theory can explain the low rate of diffusion.

One cost that is missing in most investigations of the energy efficiency paradox is the opportunity cost of investing now versus investing later. Traditional net present value tests for the energy efficiency paradox assume investments in new windows and appliances are of a “now or never” variety. But households and firms can delay these investments to gather more information about electricity prices in the future, the total cost of the investment, or the actual realized energy savings from these new technologies. Since the costs associated with new windows and appliances cannot be fully recouped if electricity prices or realized energy savings are lower than expected, there is an option value to delaying these investments that could potentially explain the energy efficiency paradox. Hassett and Metcalf (1993) use real options analysis (ROA) to show how this option value can partially explain the energy efficiency paradox. However, the role of option values in explaining the energy efficiency paradox remains unresolved. Sanstad, Blumstein, and Stoft (1995) point out that this option value cannot fully explain the high observed implicit discount rates for many energy efficiency investments. Moreover, Baker (2012) shows real options does not apply when there are multiple choices with different efficiencies.

This report provides a brief review of the three main explanations for the energy efficiency gap and revisits the option value explanation.³ In the next two sections, we address two important questions. First, does the energy efficiency gap really exist? If it exists, then energy efficiency programs can be justified based on economic efficiency arguments. If it does not exist, then we have to justify energy efficiency policies based on climate change motivations or distributional considerations. Second, what causes the gap? The answer to this question helps evaluate different public policies intended to correct the energy efficiency gap. In section IV, we update the Hassett and Metcalf study by including data from 1982-2015 and consider other proxies for the price of energy. Section V concludes.

II. What causes the energy efficiency gap?

Current research explaining the energy efficiency gap focuses on non-standard consumer behavior. The main arguments in this category are *rational inattentiveness* (Sallee 2014; Grant

³ There are several other papers reviewing previous literatures explaining the gap. See Gillingham and Palmer (2014), Gerarden et al., (2015), Ameli and Brabdt (2015), Ramos et al., (2015). In particular, Gillingham and Palmer, (2014) focus on behavioral aspect, and Ramos et al., (2015) focus on role of information in explaining the gap.

2015; Davis and Metcalf 2016), *loss aversion* (Greene et al., 2013; Yueming et al., 2014; Urs et al., 2015), and *myopia* or *limited rationality* (Busse et al., 2013; Allcott and Wozny 2014; Sallee et al., 2016).

Acquiring additional information is costly. For example, time and cognitive effort is needed to determine the energy savings from purchasing new energy efficient goods. If the benefit of acquiring the information is small relative to the costs, consumers will choose to forgo valuable information and make the decision under incomplete information. Davis and Metcalf (2016) conduct an online stated-choice experiment to measure the potential welfare benefits from “Energy Guide” labels tailored to each household’s state of residence. They find that state-specific labels lead to more investment in high-usage, high-price states and less investment in low-usage, low-price states. However, both groups invested about the same amount overall. This suggests that better information does not correct the energy efficient paradox.

Consumers also would not be willing to adopt energy efficiency technology if they are loss averse. With uncertainty in the future price of energy, benefits from investment in energy efficient goods are not always consistent with consumers’ expected benefit. When consumers exhibit loss aversion, they put a much larger weight on an expected loss from the investment than from an expected gain. If the majority of consumers are loss averse, the diffusion rate for energy efficient technologies can be slowed. Based on a survey of 1,000 U.S. households in 2004, 2011, 2012 and 2013, Greene et al. (2013) show that households undervalue future fuel savings relative to their expected value. Mean calculated payback periods are about 3 years, which are shorter than the risk neutral payback periods which are 8-5 years.

If consumers are myopic about future energy price, willingness to pay for purchasing energy efficient technology cannot reflect the change in the price. For example, if consumers anticipate that the price of gasoline will not go up in the future, their willingness to pay for an energy efficient car would also decrease meaning they are less likely to buy an energy efficient car. Using data from auto dealerships and wholesale auctions during 1999-2008, Allcott and Wozny (2014) shows that vehicle prices move as if consumers are indifferent between \$1.00 in discounted future gas cost and \$0.76 in vehicle purchase price suggesting evidence of undervaluation of future fuel costs.

The main arguments in the market failure category are *asymmetric information* (Houde 2014; Allcott and Taubinsky 2015; Palmer and Walls 2015; Allcott and Sweeney 2015), and *principal-agent problem* (Gillingham et al., 2012). Note that in the non-standard consumer behavior framework, consumers do not take into account information on energy efficiency technology even if they have full information because the benefit of acquiring the information is small relative to the costs. In the market failure framework, however, the information that might affect the adoption rate is not perfectly distributed among consumers due to a structural problem in the market. If sellers do not efficiently deliver the information on energy efficiency to consumers in the market, adoption rates of energy efficiency goods can be low. In fact, asymmetric information in the market is closely related with non-standard consumer behavior. There are several field experiments that examine whether providing new information can change consumers’ purchasing behavior. For example, Allcott and Taubinsky (2015) use a

field experiment through a home improvement retailer to test whether information provision about compact florescent lightbulbs (CFL) increases its demand. The treatment group received information on cost effectiveness of CFLs relative to incandescent lightbulbs whereas the control group didn't receive this information. The treatment effect, however, did not have a statistically significant effect on CFL market share.

When the person who invests in the energy efficient technology is not the same as the one who receives the benefit of the investment, there is less incentive to invest because the investor does not experience the benefits. Studying residential energy consumption in California, Gillingham et al., (2012) shows that overconsumption of energy is caused by split incentives where either the landlord pays the energy bill and cannot influence the tenant's energy consumption or the tenant cannot perfectly observe the prior choice of insulation by the landlord. In their empirical results, households that pay for heating are 16 percent more likely to change the heat setting at night. Residents are more likely to insulate the dwelling in owner occupied dwellings where the resident pays for energy use.

III. Is the energy efficiency gap really paradoxical?

Most of the early evidence of an energy efficiency gap was based on engineering estimates that compared the present discounted value of future energy savings to the upfront cost of energy-efficient products (equipment purchases and installation). However, this approach ignores two important aspects of the energy efficiency investment: 1) hidden costs other than equipment and installation and 2) the uncertainty in future energy savings. This calls into question the actual size of the energy efficiency paradox or whether it really exists at all.

The first reason the energy efficiency gap may be lower than suggested or nonexistent is hidden costs. This suggests that engineering estimates of the benefits from adoption of energy efficiency technology tend to overestimate the actual energy savings. In many cases, the costs and benefits of energy efficiency technology are calculated under the assumption of perfect installation. For example, imperfectly installed energy efficient windows may require additional costs to correct the problem in the future or may reduce the efficiency gains the windows provide. Also the cost of adopting the new technology extends beyond the actual purchase price. For example, unexpected costs may be associated with retrofitting a home to incorporate the new technology. Therefore, adopting new energy efficiency technology may not be a cost saving investment if all of these costs are accounted for. Using data from the US Department of Energy's Industrial Assessment Centers (IAC) program, Anderson and Newell (2004) find that 9.8% of the reasons small and medium-sized manufacturers reject an energy audit is due to hidden cost.

Another important reason is uncertainty in critical aspects of the investment (Anderson and Newell 2004). There is a lot of randomness in the energy price. This price uncertainty creates uncertainty in the future stream of energy savings generated from the purchase of a more energy efficient technology. When this energy efficient technology requires sunk costs, future uncertainty in the benefits from an energy efficiency investment creates an incentive to delay these investments until the expected net present value of the investment is positive – potentially

by a large amount. For example, Figure 1 shows gasoline prices in the U.S. from 1993-2015. Although the price shows an overall upward trend until 2008, there are many shocks in the price. Moreover, after 2005, this uncertainty in gasoline price becomes much more severe. This inability to predict future gasoline prices creates uncertainty in the future stream of fuel savings generated from the purchase of a more fuel efficient automobile. Since the purchase price of an automobile cannot be fully recouped, consumers will choose to delay these investments until the expected discounted value of future fuel savings exceeds the automobile's purchase price. There is also considerable uncertainty in the gains in miles per gallon from these vehicles since consumers cannot perfectly predict their driving routes or habitats. In settings where sunk costs must be incurred to secure an unpredictable stream of energy efficiency savings, investment in energy efficiency technology is risky and cannot be undone if the benefits of the new technology are lower than anticipated. This provides an incentive to delay the investment. How long the investment should be delayed beyond the point where the expected net present value is positive (or alternatively how much the expected rate of return needs to exceed the minimum required rate of return) is usually determined through real options analysis.



Figure 1: Weekly Retail Gasoline Prices, 1993-2015. Source: Gasoline and Diesel Fuel Update, Environmental Protection Agency (<http://www.eia.gov/petroleum/gasdiesel/>)

Hassett and Metcalf (1993) use real options analysis to incorporate the effect of energy price uncertainty on the decision to invest in energy conservation technologies. This approach yields a critical energy price threshold where investment in energy conservation would maximize the expected discounted value of lifetime energy costs. This investment rule can be rewritten to show that an investor that seeks to maximize the discounted value of lifetime energy costs should actually delay the investment until the discounted value of energy savings exceeds the cost of the investment by a hurdle rate. When energy prices are fairly certain, the hurdle rate is close to 1 and the standard net present value rule is a good approximation for the optimal investment rule. But when energy prices are very uncertain, the hurdle rate is much larger than 1 and the standard net present value rule will be biased in favor of energy efficiency investments. Using data on energy

prices and the price of energy conservation capital in the U.S. from 1955-1981 and a hypothetical distribution of energy savings, they simulate the cumulative investment in energy efficiency technologies over time. Their results show that without uncertainty in energy prices and capital, 99% of households make conservation improvements within 20 years. When households consider the uncertainty in energy prices, investment is optimally made when the expected discounted energy savings exceeds the cost of the investment by approximately four times. This leads to less than 5% of households investing after 20 years.

However, the ability of uncertainty and the option value to fully explain the energy efficiency paradox remains an open question. Sanstad, Blumstein and Stoft (1995) point out that the option value analysis of Hassett and Metcalf (1993) could only explain implicit discount rates of 7-20%. This remains far lower than the implicit discount rates in Table 1. They conclude that the option value does generate behavior that is consistent with the energy efficiency paradox but cannot fully explain the magnitude of the paradox. Subsequent work by Baker (2012) highlights that the real options explanation only pertains to energy efficiency investments where the pertinent decision is whether or when to invest in energy efficiency. When the pertinent decision is which product to choose, the option value plays a much smaller role in explaining the slow diffusion of energy efficient technologies.

Table 1. Required rate of return implied by energy efficient investments

Study	Investment type	Implicit discount rate
Goett (1978)	Space heating system and fuel type	36%
Hausman (1979)	Room air conditioners	29%
Cole and Fuller (1980)	Refrigerators	61-108%
	Thermal shell measures	26%
Gately (1980)	Refrigerators	45-300%
Goett and McFadden (1982)	Water heating fuel type	67%
Meier and Whittier (1983)	Refrigerators	34-58%
Goett (1984)	Cooking and water heating fuel type	36%
Berkovec, Hausman and Rust (1983)	Space heating system and fuel type	25%
Arthur D Little (1984)	Thermal shell measures	32%
Hartman and Doane (1986)	Thermal shell, window and door, water heating, space heating	0-400%
Ruderman (1987)	Gas central space heater	56%
„	Oil central space heater	127%
„	Room air conditioner	19%
„	Central air conditioner	18%
„	Electric water heater	816%
„	Gas water heater	166%
„	Refrigerators	78%
„	Freezer	270%

Hwang et al. (1994)	Refrigerators	69%
„	Freezer	91%
„	Water heating fuel type	84%
„	Dishwasher	111%
„	Clothes washer	391%
Dreyfus and Viscusi (1995)	Automobile	11-17%
Revelt and Train (1998)	Refrigerators	39-46%
Mau et al. (2008)	Hybrid electric car	21-49%
Min et al. (2014)	Light bulbs	100-560%
Houde (2014)	Refrigerators	21-62%
Newell and Siikamaki (2015)	Water heater	19%

The model of Hassett and Metcalf (1993) has been extended in several directions. Ansar and Sparks (2009) incorporate the investor’s anticipation of future technological advances. They find that the combination of the option value and deterministic increase in benefits that come from technological advances in the energy efficient product can explain the implicit discount rates observed in the literature. Bauner and Crago (2015) revisit the Hassett and Metcalf model for investments in rooftop solar systems. Using photovoltaic (PV) panels data from Massachusetts, they find the discounted value of benefits from solar PV needs to exceed installation costs by 60% for investment to occur.

IV. The effect of uncertainty on energy efficiency investments

Here we briefly review the real options approach used by Hassett and Metcalf (1992). Assume that a representative household must choose when to make an irreversible investment in energy conservation to minimize the lifetime cost of energy use. Let $p(t)$ and $k(t)$ denote the price of energy and the investment cost, respectively, and assume that they are uncertain across time, t . Then the objective function for household’s cost minimization problem is

$$E_0 \left\{ \int_0^T p(t) e^{-rt} dt + \int_T^\infty (1-\delta) p(t) e^{-rt} dt + k(T) e^{-rT} \right\} \quad (1)$$

where r is the discount rate, and δ is the savings in energy costs from the energy conservation investment. The first part of equation (1) is the stream of energy costs before the energy conservation investment. The second part is the stream of energy costs after the investment, and the last part is cost of the energy conservation investment. The value of expected energy saving depends on changes in $p(t)$ and $k(t)$ that vary across time. Assume that the price of energy and the price of conservation capital follow a geometric Brownian motion (GBM) process,

$$dp = \mu_p p dt + \sigma_p p dz_p \quad (2)$$

$$dk = \mu_k k dt + \sigma_k k dz_k \quad (3)$$

where dz_p (dz_k) is a standardized Brownian motion process whose change has mean zero and unit variance. The change in $p(t)$ ($k(t)$) over time, t , has mean $\mu_p t$ ($\mu_k t$) and variance $\sigma_p^2 t$ ($\sigma_k^2 t$). The correlation between z_p and z_k is denoted by ρ . Let $X=p/k$. Applying Ito’s Lemma to determine the

stochastic motion of X yields,

$$dX = X_p dp + X_k dk + .5 \left\{ X_{pp} (dp)^2 + X_{kk} (dk)^2 + 2X_{pk} (dp)(dk) \right\} \quad (4)$$

where subscripts indicate partial derivatives of X . Substituting (2) and (3) into (4), and rearranging we have⁴

$$dX = \left(\mu_p - \mu_k + \sigma_k^2 - \rho \sigma_p \sigma_k \right) X dt + \sigma_p X dz_p - \sigma_k X dz_k \quad (5)$$

Equation (5) shows that the ratio $X=p/k$ follows a GBM process with trend equal to $(\mu_p - \mu_k + \sigma_k^2 - \rho \sigma_p \sigma_k)$ and variance equal to $(\sigma_p^2 + \sigma_k^2 - 2\rho \sigma_p \sigma_k)$. Let $\alpha = (\mu_p - \mu_k + \sigma_k^2 - \rho \sigma_p \sigma_k)$ and $\sigma^2 = (\sigma_p^2 + \sigma_k^2 - 2\rho \sigma_p \sigma_k)$.

The investment is only made if p/k (X) equals or exceeds a trigger level, X^* . The value of this optimally timed investment is $V^*(p, k; X^*)$. Once the investment has been made ($p/k \geq X^*$), we can write the value of the investment as the discounted energy savings from the energy

conservation investment over an infinite time horizon net the cost of the investment: $\frac{\delta p}{(r - \mu_p)} - k$. Note that energy savings are discounted by the hurdle rate $r - \mu_p$ which accounts for the expected change in energy prices. If energy prices are expected to rise in the future, an individual will discount future energy savings at a rate lower than r . When the investment has not yet been made ($p/k < X^*$) the only value of the energy investment is the option value, $V(p, k)$. Thus, we can write:

$$V^*(p, k; X^*) = \begin{cases} V(p, k) & \text{if } \frac{p}{k} < X^* \\ \frac{\delta p}{(r - \mu_p)} - k & \text{if } \frac{p}{k} \geq X^* \end{cases} \quad (6)$$

The option value must satisfy the following Bellman equation

$$rV(p, k) dt = E[dV(p, k)] \quad (7)$$

which suggests that one will only retain the option to make the energy efficiency investment if the required return equals the expected return from retaining the investment option (Dixit and Pindyck, 1994). Homogeneity of degree 1 in prices allows us to rewrite the value of the investment in terms of p/k and k ,

$$V(p, k) = kV\left(\frac{p}{k}\right) \quad (8)$$

Applying Ito's Lemma to dV , we obtain

$$dV = kV'dX + .5KV''(dX)^2 + Vdk \quad (9)$$

⁴Note that dt goes to zero as it becomes infinitesimally small, and $dz_i dz_j = dt$ if $i=j$ and 0 otherwise.

Substituting (9) into (7), dividing by dt , and letting dt go to zero, we have the following differential equation

$$(r - \mu_k)V = \alpha XV' + .5\sigma^2 X^2 V'' \quad (10)$$

with boundary condition $V(0)$. This boundary condition requires the option to invest in energy efficiency be 0 if energy prices ever reach 0. A general solution for (10) is given by $V = AX^b$

where $b = \frac{.5\sigma^2 - \alpha + \sqrt{(.5\sigma^2 - \alpha)^2 + 2(r - \mu_k)\sigma^2}}{\sigma^2} > 1$ and A is an unknown constant that must be

determined. We can use value matching and smooth pasting conditions to solve for A and the critical price ratio X^* (Dixit and Pindyck, 1994). The value matching condition indicates that the option value should equal the expected energy savings (net of investments costs) when an investment is optimally made. The smooth pasting condition requires that the value matching condition hold at the margin at X^* .

Incorporating these conditions yields

$$X^* = \frac{b}{b-1} \frac{r - \mu_p}{\delta} \quad (11)$$

An investment in energy efficiency should be delayed until $X(t) \geq X^*$. This condition can be rearranged to compare the expected present value of energy savings and the cost of the energy investment:

$$\frac{\delta p^*}{r - \mu_p} = \frac{b}{b-1} k \quad (12)$$

As σ approaches 0, the term $\frac{b}{b-1}$ approaches one and the optimal investment rule collapses to the traditional discounted cash flow rule – invest in energy efficiency when the discounted value of energy savings equals the cost of the investment. But as the uncertainty in future prices increases,

so too does the term $\frac{b}{b-1}$. Thus, when future uncertainty in energy prices is considered by households, it will be optimal to delay an energy efficiency investment until the expected present value of energy savings exceeds the cost of the energy conservation investment. The larger the uncertainty in future energy prices and the cost of the energy efficiency investment, the more the discounted energy savings must exceed the cost of the investment. Note that the implicit

discount rate from equation (12) is $\frac{(r - \mu_p)b}{b-1}$ which will be larger than the traditional discount rate r .

This condition can be rearranged once again to identify a critical energy price threshold that optimally triggers investment

$$p^* = \frac{b}{b-1} \frac{(r - \mu_p)}{\delta} k \quad (13)$$

As expected, a more costly energy efficiency investment (larger value for k) and greater uncertainty in future prices (larger value for b) will tend to delay energy efficiency investments (larger value for p^*).

V. Revisiting the role of uncertainty

While the analysis above indicates that price uncertainty will tend to delay energy efficiency investments, it does not tell us if the delay is consistent with the delay in energy efficiency investments found in surveys. More specifically, can energy price and energy efficiency investment uncertainty generate an implicit discount rate that is consistent with the implicit discount rates in Table 1? As Sanstad, Blumstein and Stoft (1995) point out, the answer is no based on Hassett and Metcalf original analysis.

Here we revisit this result by updating the Hassett and Metcalf analysis in two ways. First, we include data from 1982 to 2015 in the analysis. As shown in Figure 2, this period was characterized by more volatile prices for energy and energy conservation capital. This suggests that an energy efficiency option value may play a larger role in explaining the energy efficiency paradox than indicated from previous findings. Second, we consider other proxies for energy prices. Hassett and Metcalf use fuel oil prices as a proxy for energy prices. However, fuel oil is generally only used to heat homes in the northeastern part of the United States. Thus fuel oil can be expected to be a poor proxy for energy prices in most of the country. Even in the northeast, use of fuel oil to heat homes is on the decline. We consider two other readily available proxies for household energy prices: electricity and household energy. The datasets for electricity and household energy price come from the Bureau of Labor Statistics (BLS) Consumer Price Index (CPI).⁵ CPI is a measure of the relative average changes over time in the prices paid by urban consumers for goods and services to those of base period prices which are set as 100. In our analysis, base periods are 1982-1984, and electricity and household energy price are not seasonally adjusted. As shown in Figure 3, these energy prices are more stable than fuel oil suggesting that an option value will play a smaller role in explaining the energy efficiency paradox outside the northeastern part of the U.S.

⁵ <http://data.bls.gov/cgi-bin/dsrv?cu>

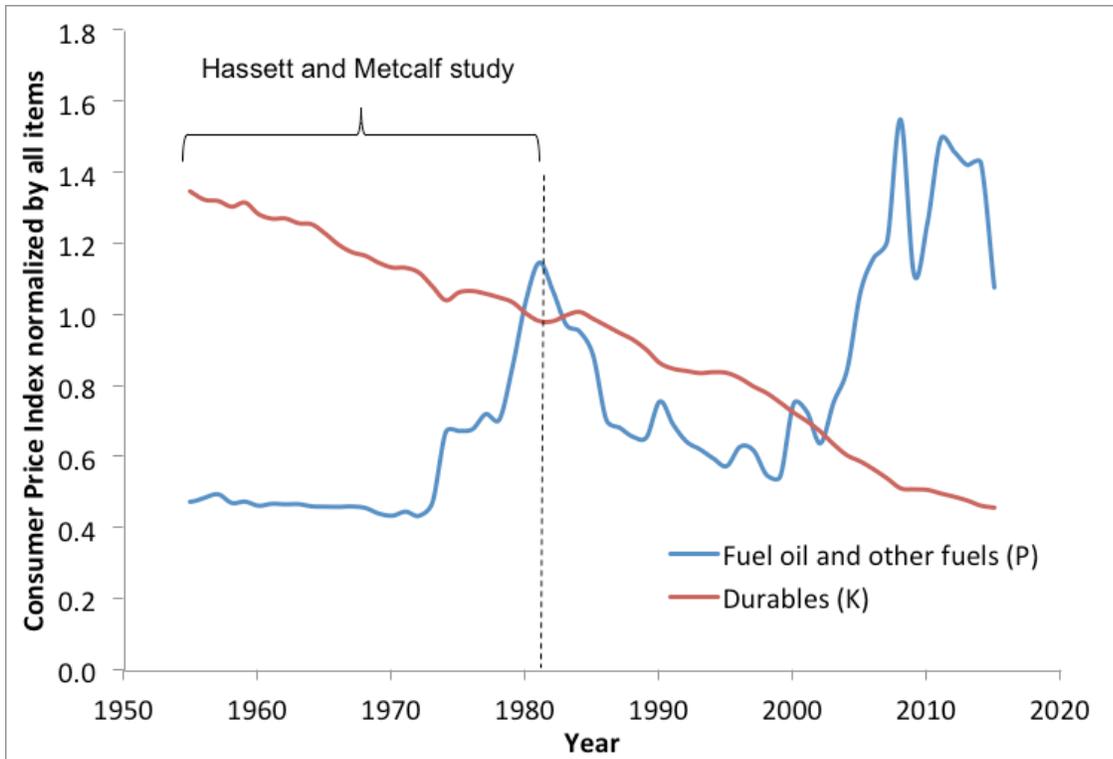


Figure 2. Energy price and energy conservation investment cost data used by Hassett and Metcalf. Consumer price indices for fuel oil and durables are normalized by dividing by the consumer price index for all items.

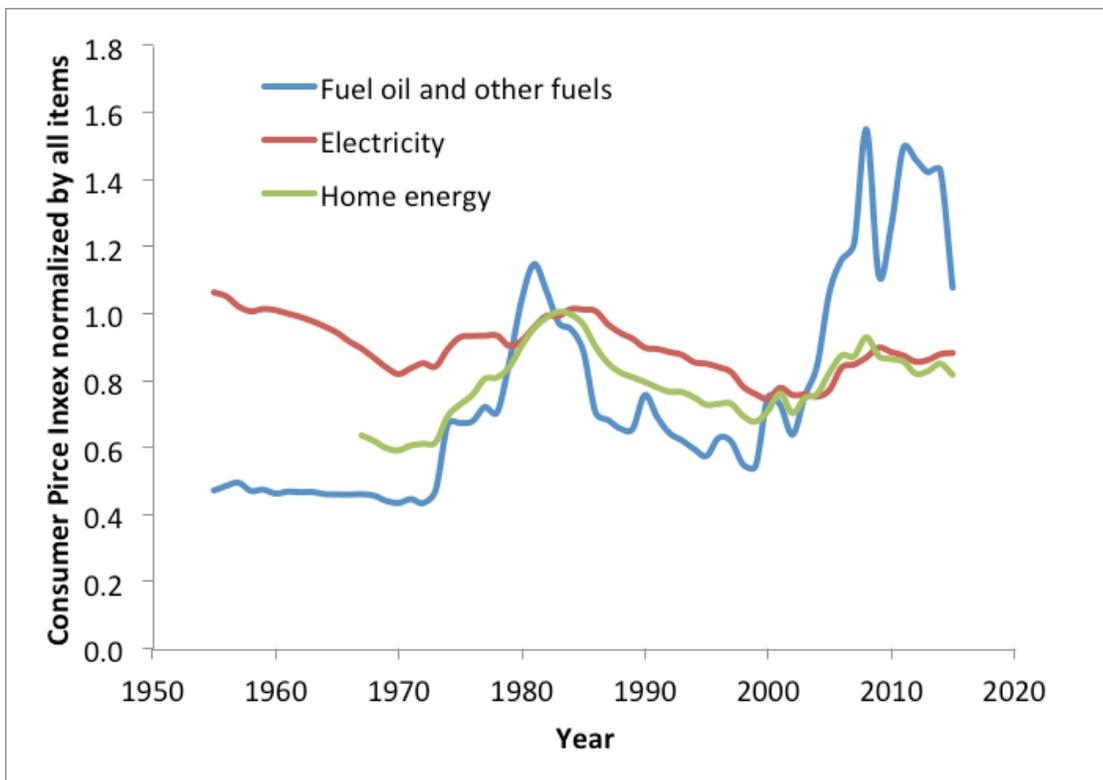


Figure 3. Alternative proxies for energy price trends and volatilities

Our results are presented in Table 2. The shaded rows provide the results from Hassett and Metcalf’s study and serve as a benchmark. We can see that the implicit discount rate increases slightly when data from 1982 to 2015 are included and alternative proxies for energy price measurement are used in the analysis. For example, with a 5% consumer discount rate, the implicit discount rate of Hassett and Metcalf’s study is 6.8% whereas it is 8.3%, 7.0%, and 7.3% when data are extended to 2015, electricity is used, and household energy is used, respectively. This pushes the implicit discount rate slightly closer to the implicit discount rates observed in Table 1. However, the increase in the implicit discount rate is due to a larger conventional hurdle rate ($r-\mu_p$) rather than a larger option value multiplier ($b/b-1$). In fact, the option value multiplier is smaller than Hassett and Metcalf’s results. This suggests that the option value is playing an even smaller role in explaining the high implicit discount rates when these alternative proxies for energy price are used.

Table 2. Consumer discount rates, option value multipliers and hurdle rates

	Drift rate for X (α)	Variance parameter for X (σ)	Consumer discount rate (r)	Conventional hurdle rate ($r-\mu_p$)	Option value multiplier ($b/(b-1)$)	Implicit discount rate ($b(r-\mu_p)/(b-1)$)
Hassett and Metcalf results (fuel oil from 1955-1981)	0.046	0.089	0.05	0.016	4.279	0.068
			0.1	0.066	1.838	0.121
			0.15	0.116	1.503	0.174
			0.2	0.166	1.369	0.227
Fuel oil from 1955-2015	0.032	0.129	0.05	0.036	2.279	0.083
			0.1	0.086	1.618	0.140
			0.15	0.136	1.433	0.195
			0.2	0.186	1.343	0.250
Electricity from 1955-2015	0.015	0.031	0.05	0.053	1.316	0.070
			0.1	0.103	1.175	0.121
			0.15	0.153	1.125	0.172
			0.2	0.203	1.099	0.223
Household energy from 1967-2015	0.025	0.050	0.05	0.045	1.625	0.073
			0.1	0.095	1.316	0.125
			0.15	0.1448	1.2186	0.1765
			0.2	0.1948	1.1707	0.2281

Mathematically, as shown at Figure 4, this is because b is a decreasing function of drift rate (α) and variance parameter (σ), and option value multiplier ($b/b-1$) is decreasing function of b .⁶ Smaller values for α and σ lead to larger values for b , and this results in a smaller option value multiplier. Note that the value of σ implied by the extended 1955-2015 data is actually larger than σ from Hassett and Metcalf’s study. However, the value of α is also smaller in the extended dataset. As shown in Figure 4, because the magnitude of the effect of α is significantly larger

⁶ Figure 4 comes from fuel oil price from 1955-2015 case by chaining value of α and σ while holding other parameters constant.

than the effect of σ , the option value multiplier decreases due to the decrease in α . Intuitively, consumers are more hesitant to invest in energy efficient technologies from 1981-2015 because energy prices are increasing more slowly and not because energy prices were more volatile in this period.

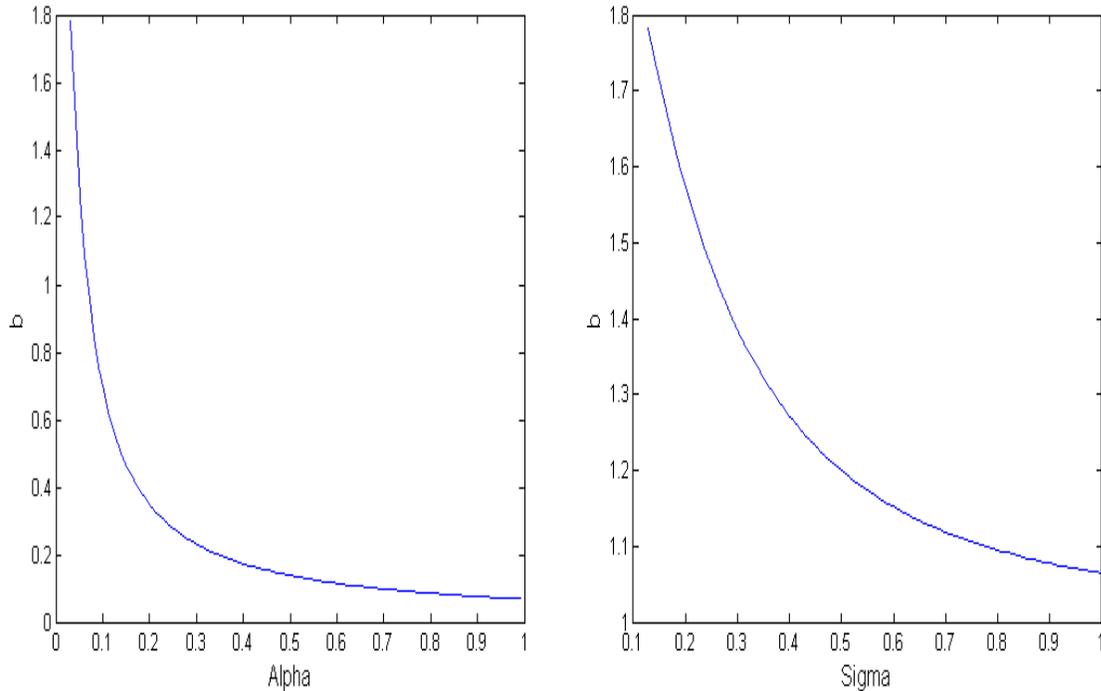


Figure 4. Relation between b and drift rate (α) and variance parameter (σ).

More importantly, in spite of the increase in the implicit discount rate from extending the dataset or using alternative proxies for energy price measurement, the implicit discount rate in Table 2 is still far smaller than the implicit discount rates suggested in Table 1. Hence, as Sanstad, Blumstein and Stoft (1995) point out, real option analysis cannot fully explain the magnitude of the energy efficiency paradox even when we extend the dataset to account for more volatile energy prices, or use alternative proxies for energy price.

VI. Conclusion

In this report, we provide evidence that an energy efficiency option value cannot fully explain the energy efficiency paradox. Using the most recent fuel oil price data and electricity and household energy as alternative proxies for energy price, we find an increase in the implicit discount rate for a generic energy efficiency investment. But the magnitude is still too small to explain the large implicit discount rates documented in many surveys. More importantly, the small increase in the implicit discount rate is from an increase in the investment's conventional hurdle rate rather than an increase in the investment's option value. This suggests that an option value is playing an even smaller role in explaining the energy efficiency gap than suggested by Hassett and Metcalf (1993).

Our analysis only considers the two sources of uncertainty considered in Hassett and Metcalf's study: uncertainty in future energy prices and uncertainty in future energy efficient capital costs. However, there are other sources of uncertainty that influence the decision to invest in energy efficiency technologies. For example, in our model, we assume that savings in energy costs from the energy conservation investment (δ) are constant over time. In reality, the future savings from an energy efficiency investment are highly uncertain. Car buyers cannot perfectly predict energy saving from purchasing a more fuel efficient automobile due to an inability to predict future driving patterns. Homeowners cannot perfectly predict energy savings from more efficient windows or better insulation due to an inability to predict future weather outcomes. Future research should consider whether additional sources of uncertainty make an option value a more convincing explanation for the energy efficiency paradox.

References

- Allcott, Hunt, and Dmitry Taubinsky. "Evaluating behaviorally motivated policy: experimental evidence from the lightbulb market." *The American Economic Review* 105.8 (2015): 2501-2538.
- Allcott, Hunt, and Nathan Wozny. "Gasoline prices, fuel economy, and the energy paradox." *Review of Economics and Statistics* 96.5 (2014): 779-795.
- Allcott, Hunt and Richard L. Sweeney. "The Role of Sales Agents in Information Disclosure: Evidence from a Field Experiment." *Management Science* (2015), forthcoming.
- Ameli, N. and N. Brandt. "What Impedes Household Investment in Energy Efficiency and Renewable Energy?", *OECD Economics Department Working Papers*, No. 1222 (2015), OECD Publishing, Paris.
- Anderson, Soren T., and Richard G. Newell. "Information programs for technology adoption: the case of energy-efficiency audits." *Resource and Energy Economics* 26.1 (2004): 27-50.
- Ansar, Jasmin, and Roger Sparks. "The experience curve, option value, and the energy paradox." *Energy Policy* 37.3 (2009): 1012-1020.
- Arthur, D. "Little Inc., 1984. Measuring the Impact of Residential Conservation Programs: An Econometric Analysis of Utility Data. Volume III, Final Report for RP1587." *Electric Power Research Institute*.
- Baker, Erin. "Option value and the diffusion of energy efficient products." *Energy Journal* 33.4 (2012): 49-59.
- Bauner, Christoph, and Christine L. Crago. "Adoption of residential solar power under uncertainty: Implications for renewable energy incentives." *Energy Policy* 86 (2015): 27-35.

- Berkovec, Jim, Jerry A. Hausman, and John Rust. *Heating system and appliance choice*. Massachusetts Institute of Technology, Department of Economics, 1983.
- Busse, Meghan R., Christopher R. Knittel, and Florian Zettelmeyer. "Are Consumers Myopic? Evidence from New and Used Car Purchases." *American Economic Review*, 103.1 (2013): 220-56.
- Cheney, Dick. "Reliable, Affordable, and Environmentally Sound Energy for America's Future." *Report of the National Energy Policy Development Group, Washington* (2001): 137-145.
- Cole, H., and R. Fuller. "Residential energy decision making: an overview with emphasis on individual discount rates and responsiveness to household income and prices." *Hittman Associates report, Columbia, MD* (1980).
- Davis, L. W. & Metcalf, G. E. "Does Better Information Lead to Better Choices? Evidence from Energy-Efficiency Labels." *Journal of the Association of Environmental and Resource Economists*, 3 (2016), 589-625.
- Dixit, Avinash K., and Robert S. Pindyck. *Investment under uncertainty*. Princeton University Press, 1994.
- Dreyfus, Mark K., and W. Kip Viscusi. "Rates of time preference and consumer valuations of automobile safety and fuel efficiency." *Journal of Law and Economics* (1995): 79-105.
- Fischbacher, Urs, Simeon Schudy, and Sabrina Teyssier. Heterogeneous preferences and investments in energy saving measures. No. 2015-11. Munich Discussion Paper, (2015).
- Fuller, Merrian C. "Driving Demand for Home Energy Improvements: Motivating residential customers to invest in comprehensive upgrades that eliminate energy waste, avoid high utility bills, and spur the economy." *Lawrence Berkeley National Laboratory* (2011).
- Gately, Dermot. "Individual discount rates and the purchase and utilization of energy-using durables: Comment." *Bell Journal of Economics* 11.1 (1980): 373-374.
- Geller, Howard, et al. "Policies for increasing energy efficiency: Thirty years of experience in OECD countries." *Energy Policy* 34.5 (2006): 556-573.
- Gerarden, Todd, Richard G. Newell, and Robert N. Stavins. "Deconstructing the Energy-Efficiency Gap: Conceptual Frameworks and Evidence." *The American Economic Review* 105.5 (2015): 183-186.
- Gillingham, Kenneth, Matthew Harding, and David Rapson. "Split incentives in residential energy consumption." *Energy Journal* 33.2 (2012): 37-62.

- Gillingham, Kenneth, and Karen Palmer. "Bridging the energy efficiency gap: policy insights from economic theory and empirical evidence." *Review of Environmental Economics and Policy* (2014): ret021.
- Goett, Andrew Alexander. *Appliance fuel choice: An application of discrete multivariate analysis*. University Microfilms, 1978.
- Goett, Andrew, and D. McFadden. "Residential end-use energy planning system (REEPS)." *NASA STI/Recon Technical Report N 83* (1982): 13619.
- Goett, Andrew. "Household appliance choice: Revision of REEPS behavioral models." *Electric Power Research Institute report no. EA-3409* (1984).
- Greene, David L., David H. Evans, and John Hiestand. "Survey evidence on the willingness of US consumers to pay for automotive fuel economy." *Energy Policy* 61 (2013): 1539-1550.
- Hartman, Raymond S., and Michael J. Doane. "Household discount rates revisited." *The Energy Journal* 7.1 (1986): 139-148.
- Hassett, Kevin A., and Gilbert E. Metcalf. "Energy Tax Credits and Residential Conservation Investment." *Working Paper 4020, National Bureau of Economic Research*. (1992).
- Hassett, Kevin A., and Gilbert E. Metcalf. "Energy conservation investment: Do consumers discount the future correctly?" *Energy Policy* 21.6 (1993): 710-716.
- Hausman, Jerry A. "Individual discount rates and the purchase and utilization of energy-using durables." *The Bell Journal of Economics* (1979): 33-54.
- Houde, Sébastien. *How consumers respond to environmental certification and the value of energy information*. No. w20019. National Bureau of Economic Research, (2014).
- Hwang, Roland J., et al. "Residential appliance data, assumptions and methodology for end-use forecasting with EPRI-REEPS 2.1." *Lawrence Berkeley Laboratory, University of California, Tech. Rep* (1994).
- International Energy Agency (IEA). "Energy Technology Perspectives 2015: Mobilising Innovation to Accelerate Climate Action." (2015).
- Jacobsen, Grant D. "Do energy prices influence investment in energy efficiency? Evidence from energy star appliances." *Journal of Environmental Economics and Management* 74 (2015): 94-106.
- Jaffe, Adam B., and Robert N. Stavins. "The energy paradox and the diffusion of conservation technology." *Resource and Energy Economics* 16.2 (1994): 91-122.

- Lee, David. "Better Buildings 2.0 Presentation." *Denver, CO: Building America Residential Energy Efficiency Meeting*. (2010).
- Mau, Paulus, et al. "The 'neighbor effect': Simulating dynamics in consumer preferences for new vehicle technologies." *Ecological Economics* 68.1 (2008): 504-516.
- McKinsey & Company. "Pathways to a Low-Carbon Economy Version 2 of the Global Greenhouse Gas Abatement Cost Curve." (2009).
- Meier, Alan K., and Jack Whittier. "Consumer discount rates implied by purchases of energy-efficient refrigerators." *Energy* 8.12 (1983): 957-962.
- Neme, Chris, Meg Gottstein, and Blair Hamilton. "Residential efficiency retrofits: a roadmap for the future." *Montpelier: Regulatory Assistance Program* (2011).
- Newell, Richard G., and Juha Siikamäki. "Individual Time Preferences and Energy Efficiency." *The American Economic Review* 105.5 (2015): 196-200.
- Min, Jihoon, et al. "Labeling energy cost on light bulbs lowers implicit discount rates." *Ecological Economics* 97 (2014): 42-50.
- Palmer, Karen, et al. "Assessing the energy-efficiency information gap: results from a survey of home energy auditors." *Energy Efficiency* 6.2 (2013): 271-292.
- Palmer, Karen L., and Margaret Walls. "Does Information Provision Shrink the Energy Efficiency Gap? A Cross-City Comparison of Commercial Building Benchmarking and Disclosure Laws." *Resources for the Future Discussion Paper* (2015): 15-12.
- Qiu, Yueming, Gregory Colson, and Carola Grebitus. "Risk preferences and purchase of energy-efficient technologies in the residential sector." *Ecological Economics* 107 (2014): 216-229.
- Ramos, Ana, et al. "The role of information for energy efficiency in the residential sector." *Energy Economics* 52 (2015): S17-S29.
- Revelt, David, and Kenneth Train. "Mixed logit with repeated choices: households' choices of appliance efficiency level." *Review of Economics and Statistics* 80.4 (1998): 647-657.
- Ruderman, Henry, Mark D. Levine, and James E. McMahon. "The behavior of the market for energy efficiency in residential appliances including heating and cooling equipment." *The Energy Journal* 8.1 (1987): 101-124.
- Sallee, James M. "Rational Inattention and Energy Efficiency" *Journal of Law and Economics*, 57.3, (2014): 781-820.

Sallee, James M., Sarah West, and Wei Fan. *Do Consumers Recognize the Value of Fuel Economy? Evidence from Used Car Prices and Gasoline Price Fluctuations*. *Journal of Public Economics* 134, (2016): 61-73.

Sanstad, Alan H., Carl Blumstein, and Steven E. Stoff. "How high are option values in energy-efficiency investments?" *Energy Policy* 23.9 (1995): 739-743.

Sovacool, Benjamin K., and Richard F. Hirsh. "Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition." *Energy Policy* 37.3 (2009): 1095-1103.