Option Value and the Diffusion of Energy Efficient Products

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In a widely cited series of papers, Hassett and Metcalf argue that the slow diffusion of energy saving technology may be due to a high option value to waiting. While the authors clarify that this is relevant for yes/no decisions (such as whether to add insulation to a home), this argument has been widely cited even in investment decisions that involve a choice over multiple appliances or vehicles. In this note we consider how uncertainty and irreversibility would impact a consumer's decision about when to buy which new product. We show that, a priori, applying an option value framework is as likely to lead to slow diffusion of inefficient products as to slow diffusion of efficient products. This casts some doubt on the idea that an option value framework is the primary driver of the slow diffusion of energy efficient technologies.

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1. INTRODUCTION

It was pointed out in a widely cited paper by Hassett and Metcalf (1993) that uncertainty in future energy prices combined with the irreversibility of investments into conservation technologies leads to an option value for waiting to install energy conservation technologies, leading to slower than expected diffusion. The implication of that paper is that there appears to be an energy efficiency gap if we analyze the evidence based on an assumption of Net Present Value decision making; but the gap disappears if we believe that consumers are using an option value framework.

In the NBER paper (Hassett and Metcalf, 1992) on which that paper was based, they were explicit about the kind of technologies their model applied to: "Typical conservation investments include ceiling and wall insulation, storm doors and windows and caulking." A key assumption that is never quite made explicit is that the important decision faced by the consumer is *whether* or *when*

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to invest in an energy conservation technology, rather than *which* technology to choose. Yet, a number of papers cite Hassett and Metcalf (1993), but involve a decision *between* technologies (Naughten, 2003; Schleich and Gruber, 2008; Ching-Shin et al., 2010; Sovacool and Hirsh, 2009; Strachan and Dowlatabadi, 2002). This note addresses the question of what happens to the option value effect when the salient choice is which technology to buy.

Specifically, we consider how uncertainty and irreversibility would impact a consumer's decision about *when* to buy *which* new product, where the product might be a new vehicle, a new appliance, or a light bulb. We show that, a priori, applying an option value framework is as likely to lead to slow diffusion of inefficient products as to slow diffusion of efficient products. During periods when energy prices are low or decreasing, we would expect option value pricing to lead to a perceived "energy guzzlers" gap, rather than an energy efficiency gap. We develop an extremely simple model of product choice to build the intuition of the result, and illustrate it with a simple numerical example.

These results imply that we would expect to see an energy guzzlers gap in the data, if decision makers are really using an option value framework. To the degree that we don't see such a gap, it casts doubt on the idea that decision makers are making extremely rational decisions based on an option value framework. This would lead back to the idea that there are behavioral issues, such as hyperbolic discounting or heuristic decision-making, that may need to be addressed by non-traditional policies (Gillingham et al., 2009; Turrentine and Kurani, 2007). More empirical work is needed to carefully test whether an option-value framework is appropriate.

2. A MODEL OF PRODUCT CHOICE

We assume that the consumer chooses a product based on multiple criteria that can be combined in a willingness to pay measure. Let the one period value of product j be

$$V^j(p) = a_j - b_j p \quad (1)$$

where a_j represents the non-monetary value of the product (size, power, color, etc.) (in dollars); b_j represents the efficiency of the product (measured as the total energy expended to perform the appropriate service over one period¹); and p is the price per unit of energy. Assume that the current price, p_0 , is known, but that the future price is uncertain. We keep our model very simple and assume that the future price will be realized in the next period, will remain at that level forever, and that it will either be high p_H , or low p_L as in Figure 1.

We assume for simplicity that p_0 is the mean of the distribution: $p_0 = \pi^H p_H + \pi^L p_L$, where π^H , π^L are the probability of a high or low price, respectively. We assume that a new product will be infinitely lived.

1. For example, for a vehicle this would be the gallons/mile * miles driven.

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Figure 1: Price Dynamics

Consider a consumer that currently owns a product with low non-monetary value and poor energy efficiency. The consumer is choosing between two new products, a “Premium” product (PP; $j = R$) that has high non-monetary value, poor energy efficiency, and higher capital cost (such as an SUV); and an “Efficient” product (EP, $j = F$) with lower non-monetary value, good energy efficiency, and lower capital cost (such as a compact car). Specifically, $a_R, b_R, k_R > a_F, b_F, k_F$ respectively, where k_j represents the capital cost of product j . Assume that the expected Net Present Value (NPV) of each of the new products is higher than the current product; and that the PP has the highest NPV when the price is p_L , while the EP has the highest NPV when the price is p_H . If the consumer uses a simple expected NPV rule, he or she would choose the new product that had the highest expected NPV as follows:

$$\max_{j=R,F} \sum_t \delta^t V^j(p_0) - k_j \quad (2)$$

where $\delta = 1/(1+r)$ is the discount factor based on discount rate r . The NPV of buying car j now is linear and decreasing in p_0 . Thus, there will be a switching price p^* , such that if $p_0 < p^*$ the consumer will buy the PP; if $p_0 > p^*$, she buys the EP.²

If, however, the consumer waits for one period her value will be:

$$V^0(p_0) + \delta \left\{ \pi^H \left(\sum_t \delta^t V^F(p_H) - k_F \right) + \pi^L \left(\sum_t \delta^t V^R(p_L) - k_R \right) \right\} \quad (3)$$

The first term is related to the cost of waiting one period—the consumer will spend one more period with the current low-value product and lose one period

2. There will be such a switching price as long as there is a trade-off among any of the attributes (non-monetary, operating cost, or capital cost). So, for example, we could model two products of equivalent non-monetary value, with one having higher capital cost and better efficiency.

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of the value of the new product. The second term is related to the value of waiting. If the consumer waits, she will get to buy the product that maximizes her value given the realized price. The overall optimal decision will compare the value of buying a product now in equation (2) with the value if waiting in equation (3).

If we assume that the high and low prices are fixed (and therefore $\pi^H = \frac{p_0 - p_L}{p_H - p_L}$), then the value if waiting (3) is linear and decreasing in p_0 . Therefore, there will be two switching prices in this problem, $\underline{p}$ and $\bar{p}$: if $p_0 < \underline{p}$ the consumer will buy the PP now; if $\underline{p} < p_0 < \bar{p}$ the consumer will wait; and if $p_0 > \bar{p}$ the consumer will buy the EP now.³ Clearly $\underline{p} \leq p^* \leq \bar{p}$: if it is optimal to buy the PP now in the NPV problem, it will never be optimal to buy the EP now in the overall decision problem.

This means that in the range where $\underline{p} < p_0 < p^*$, applying an option value framework would lead the consumer to wait rather than buy a PP. If an analyst were assuming an NPV framework, what would he observe? First, if the analyst knew the consumer's discount rate, then he would clearly perceive an energy guzzlers gap—the consumer would fail to buy the PP even though it had a higher NPV than the current product. Second, consider the case where the analyst does not know the consumer's discount rate, but attempts to infer it based on the purchase decision. In this case, the analyst would observe the consumer choosing to keep the current product rather than purchase the PP or the EP, and would miscalculate the consumers discount rate as being much higher than it actually is. That is, he would mistakenly observe:

$$\sum_t \tilde{\delta}_R^t V^0(p_0) \geq \sum_t \tilde{\delta}_R^t V^R(p_0) - k_R \quad (4)$$

and/or

$$\sum_t \tilde{\delta}_F^t V^0(p_0) \geq \sum_t \tilde{\delta}_F^t V^F(p_0) - k_F \quad (5)$$

where $\tilde{\delta}_R$ and $\tilde{\delta}_F$ are the discount factors required to justify keeping the old car (in an NPV framework). These would reflect discount rates $\tilde{r}_R$ and $\tilde{r}_F$ that are in fact higher than the consumers actual discount rate. For a wide range of parameter values $\tilde{r}_R$ would be greater than $\tilde{r}_F$: the perceived energy guzzlers gap would be larger than the perceived energy efficiency gap.

This is a quite simple model, but the basic result—that there will be a range of prices in which an energy guzzlers gap would be perceived—is robust. For example, consider how the perceived “gaps” change with changes in the relative energy efficiency of the products. Define the energy guzzlers gap (EG

3. Note that it is possible that $\underline{p} < p_L$ and/or $\bar{p} > p_H$. In these cases it will never happen that $p_0 < \underline{p}$ or $p_0 > \bar{p}$ respectively.

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Table 1: Parameter Values

	Current $j = 0$	Compact $j = F$	SUV $j = R$
a_j (non-monetary value)	2000	4000	6000
b_j (efficiency)	750 (20 mpg)	500 (30 mpg)	1000 (15 mpg)
k_j (capital cost)	—	18,000	25,000

gap) as the distance between $\underline{p}$ and p^* . This is the range of prices in which a consumer would buy the PP in an NPV world, but would wait in an option value world. Similarly, we can define the energy efficiency gap (EE gap) as the distance between p^* and $\bar{p}$. Finally, define the hysteresis range as the distance between $\underline{p}$ and $\bar{p}$: the range over which the consumer would wait rather than buy now.

It is clear that each of the trigger prices, $\underline{p}$, p^* , $\bar{p}$ will increase as the PP gets more efficient and decrease as the EP gets more efficient, and thus each trigger price decreases as the relative efficiency of the EP increases (i.e. as $b_R - b_F$ increases). The size of the gaps between the trigger prices, however, are non-monotonic in $b_R - b_F$. When the difference between b_R and b_F is small, then the consumer will always prefer the PP, leading $\underline{p} = p^* = \bar{p} = p_L$. On the other hand, when the difference between b_R and b_F is very large, the consumer will always prefer the compact, leading $\underline{p} = p^* = \bar{p} = p_H$. Thus, as we increase the difference between b_R and b_F , the size of each of the ranges will first increase and then decrease. Moreover, for a wide range of relative energy efficiencies, there will be both an EG gap and an EE gap. So, again, there is no particular reason we would expect to see only an EE gap.

2.1 Numerical Example

In this section we illustrate with a simple numerical example, using vehicles as the example product. We use the model in (1), with the parameter values given in Table 1. We assume the consumer drives 15,000 miles per year and has a discount rate of 5%. Starting in the 2nd period, gasoline will either be $p_H = \$5/\text{gal}$ or $p_L = \$1/\text{gal}$.

Using these parameter values we have calculated the optimal choice under different values of p_0 (or equivalently, π^H). Table 2 shows the results. The first two rows show the values of p_0 and π^H . The next two rows show the value of buying an SUV or a compact car now (in thousands). The fifth row shows the value if waiting. The optimal choice shows which of the three alternatives has the highest value. The last row shows what the consumer would do if she were making her decision solely based on expected NPV. We have highlighted this row to show where the NPV decision differs from the optimal choice. This is where we would get a perceived gap. For $1.6 \leq p_0 \leq 3.2$ there would be a perceived gas guzzler gap; for $3.4 \leq p_0 \leq 4.4$ there would be a perceived energy efficiency gap.

Table 2: Numerical Example

p0		1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	5
pi H		0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1	1
SUV now		75	71	67	63	59	55	51	47	43	39	35	31	27	23	19	15	11	7	3	-1	-5
Com now		52	50	48	46	44	42	40	38	36	34	32	30	28	26	24	22	20	18	16	14	12
Wait		73	70	66	63	60	57	54	51	47	44	41	38	35	32	29	25	22	19	16	13	10
Optimal	SUV	SUV	SUV	SUV	wait	wait	wait	wait	wait	wait	wait	wait	wait	wait	wait	wait	wait	wait	wait	Com	Com	Com
NPV only	SUV	SUV	SUV	SUV	SUV	SUV	SUV	SUV	SUV	SUV	SUV	SUV	SUV	Com	Com	Com	Com	Com	Com	Com	Com	Com

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We are not arguing that these are particularly realistic numbers. The example is simply to illustrate the point that, a priori, an option value framework will not necessarily lead to an energy efficiency gap.

2.2 Extensions and Other Applications

The model can be extended in a number of directions, but the essential insight remains. For example, in the simple price dynamics above, the expected value of the future price is equal to the current price. While this assumption is commonly used in the real options literature, it may not be the best representation of the actual price dynamics. Consider an alternate assumption, such as reversion to the mean. We can model extreme mean reversion in this simple model by having the expected future price independent of the current price. In this case, the current price would have very little impact on decisions. The expected future price would drive decisions in much the same way as the model above: if prices are expected to be low, the Premium product would be optimal now; if prices are expected to be high the Efficient product would be optimal now; if expected price is somewhere in the middle, it would be optimal to wait. Similarly, if there were a heterogeneity of beliefs about future prices among buyers, we would see those who expected prices to be low to buy PPs, those who expected prices to be high to buy EPs, and those whose beliefs fall in the middle to wait.

In this simple model, the consumer is expected to keep the new product forever, thus the investment is entirely irreversible. With some products, such as vehicles, however, reselling the product is not uncommon. Specifically, a consumer could sell a car if the gas price moved in a direction that made it unfavorable. Nevertheless, for new cars at least, quite a bit of the value of the car is lost upon the initial sale, due largely to asymmetric information (See Akerlof, 1970). Moreover, evidence has shown that prices of used SUVs go down as the gas price goes up, and the opposite is true for compact cars. Thus, the amount of the investment that is sunk is exacerbated by a change in gas price.

The possibility of leasing, however, would invalidate the model. If it was possible to lease a product for a short time period at a reasonable cost, then it would provide great option value. In any market where leasing is seen as a viable option for the consumer, then the option value framework is not valid (and would therefore not explain “gaps” in either direction).

Uncertainty about prices are not the only incentive to wait to buy a new product. People may wait to invest in a current technology if they believe that the technology will soon be improved (Kornish, 2001; Ulu and Smith, 2009). However, there is no strong reason to think that this would lead to an EE gap rather than a PP gap.

We have provided a specific example of a choice between new vehicles. This model, however, can apply to other areas as well. Most obviously, it applies to consumer decisions to buy appliances such as refrigerators or washing machines. This can also be applied to more efficient lighting alternatives or energy generation alternatives as well.

3. DISCUSSION

The key question we are interested in is whether the option value model can provide an explanation for the perceived energy efficiency gap in products where the salient decision is *which* rather than *when*. This was the argument in Hassett and Metcalf for energy conservation measures; and it has been cited widely as a possible explanation for an energy efficiency gap even in cases where there is clearly a choice being made between technologies. As we have argued above, *a priori*, the option value model is as likely to lead to perceived energy guzzler gap as to a perceived energy efficiency gap.

Note that if consumers are using an option value framework, then they are sensitive to volatility, even if they are risk neutral. The more uncertainty there is about future prices, the more likely the consumer will wait (see e.g. Dixit and Pynkyck, 1994). Mathematically, this happens because the second period decision induces a non-linearity. In fact, non-linearities induced by second stage decisions often swamp non-linearities introduced by risk aversion.⁴ Our model can be contrasted with some of the recent work on multiple irreversibilities (Baker, 2009; Gollier et al., 2000; Kolstad, 1996ab) as well as with the classic real-options literature. The first body of work has shown that in the climate change context there are two, opposing, irreversibilities—on the one hand, irreversible environmental damages may occur by not acting; on the other hand, early action removes the option to not act. In our model, there is only one irreversibility—early action removes later choice. In the second body of work, the classic choice is between acting and not acting: not acting leaves open the option to act in the future, while acting usually brings in near term benefits. Our model builds on this by having two clearly differentiated alternatives when acting. If we buy a Premium Product, such as an SUV, now, then we are in bad shape if the price goes up; if we buy an Efficient Product, such as a compact car now, we are in bad shape if the price goes down; if we wait, we lose the benefit of a nice new car now.

We now compare this model to the evidence on vehicle purchase to see how it fares as an explanation. If (1) gas guzzlers have higher non-monetary utility than efficient cars and (2) consumers are applying an option value framework, then we would expect to see a perceived energy efficiency gap during years when the gasoline price is high, but there is uncertainty about the future price, and a perceived gas guzzler gap in years when the gasoline price is low, but uncertain. Consider Figure 2, a reprint of the EIA's chart showing the real price of gasoline between 1919 and 2010. We see high prices during the periods 1979–1986 and in 2004–2009. If consumers were concerned about uncertain prices, then we

4. See for example Gollier et al. (2000), who found that it takes a very high level of prudence to reverse the non-linearity induced by a second stage decision in a climate change problem. More generally, the inclusion of risk aversion in real option problems *can* impact the results, but there is no clear pattern as to whether it makes it more or less likely that decision makers will wait (Chronopoulos et al., 2011; Hugonniera and Morellec, 2007).

*Option Value and the Diffusion of Energy Efficient Products / 57***Figure 2: Real Gasoline Prices**

EIA Short-Term Energy Outlook, February 2012

Source: Reprinted from EIA.

would expect to see an energy efficiency gap. On the other hand, we see sustained low prices during the period between 1982–1999. Thus, using an NPV framework, we would expect to see high sales of SUVs. But, if consumers were using an option value framework, we might see a gas guzzler gap during this period (depending on consumers' expectations and uncertainty). If, however, there is a true energy efficiency gap (not a perceived gap that can be explained by the option value model) then we would fail to see a gas guzzler gap in the 80's and 90's.

A number of recent papers (Allcott and Wozny, 2011; Langer and Miller, 2008; Sallee and West, 2008) have estimated the relationship between the price of gasoline and the price and/or demand for new vehicles as a function of their operating costs. The period of this data has ranged from about 2003 to 2006 or 2008. The conclusions vary significantly, but seem to indicate that over this period consumers have shown a “revealed willingness to trade off a dollar in discounted future gasoline costs for less than a dollar in purchase price” (Allcott and Wozny, 2011), with the trade-off ranging between 2% and 25%. This is consistent with the option value model, but since it only tests a period in which we would expect to see an energy efficiency gap, it is not sufficient.

The only paper that we could find that used data in the period between 1982–1999 was Dreyfus and Vicusi (1995). They use a hedonic pricing model to estimate the discount rate and the trade-off mentioned above in the year 1988. They find a discount rate somewhere in the range of 11%–17%, which they argue is very near the market interest rate for buying a used vehicle; and a willingness to pay for a decrease in operating costs of 35%. But, given the low price of gasoline in 1988 the option value model would depress the price of gas guzzlers

more than efficient cars. Thus, it would imply that 35% is an overestimate—that consumers actually value less than 35% of a savings on operating costs. Which brings us back to a real energy efficiency gap rather than a perceived gap caused by an option value framework.

More empirical work is needed to determine whether an option value framework may explain the perceived energy efficiency gap found in the recent papers. First, it is important to test periods in which gasoline prices are low (but uncertain), and determine whether the price and/or demand for SUVs and other gas guzzlers respond in a way consistent with an option value framework. Second, an option value framework implies that consumers are sensitive to the volatility of gasoline prices, thus it would be useful to regress buying decisions against the volatility of gas prices (or some other variable that would represent consumers' perceptions of riskiness in the gas market). Moreover, even if the perceived EE gap cannot be explained by an option value framework, there may be other rational explanations. For example, Bento et al. (2011) have shown that ignoring consumer heterogeneity in preferences can cause a perceived EE gap when using discrete choice modeling.

In conclusion, applying an option value decision model may not explain the energy efficiency gap in vehicles or other contexts where the salient decision is which technology to invest in. While the Hassett-Metcalf paper makes an intuitive case for yes/no decisions, the outcome in decisions over multiple technologies is not as clear.

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