Option Value and the Diffusion of Fuel Efficient Vehicles

Erin Baker*

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*Correspondence Address: Erin Baker, 220 Elab, University of Massachusetts, Amherst, MA 01003; edbaker@ecs.umass.edu; 413-545-0670

Abstract

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 vehicle. We show that, a priori, applying an option value framework is as likely to lead to slow diffusion of inefficient vehicles as to slow diffusion of efficient vehicles. This casts some doubt on the idea that an option value framework is the primary driver of the slow diffusion of energy efficient technologies.
Keywords: Energy Efficiency, option value, uncertainty

1 Introduction

It was pointed out in a widely cited paper by Hassett and Metcalf [4] 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 this 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 [3] 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* to invest in an energy conservation technology, rather than *which* technology to choose. This note addresses the question of what happens to the option value effect when the salient choice is which technology to buy.[1]

Specifically, we consider how uncertainty and irreversibility would impact a consumer's decision about *when* to buy *which* new vehicle. We show that, a priori, applying an option value framework is as likely to lead to slow diffusion of inefficient vehicles as to slow diffusion of efficient vehicles. During periods when gasoline prices are low or decreasing, we would expect option value pricing to lead to a perceived gas guzzlers gap, rather than an energy efficiency gap. We develop an extremely simple model of vehicle 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 a gas 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 bring us back to the idea that there are behavioral errors that may need to be addressed by non-traditional policies. More empirical work is needed to carefully test whether an option-value framework is appropriate.

2 A Model of vehicle choice

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

$$V^j(p) = a_j - b_j p \tag{1}$$

where a_j represents the non-monetary value of the car (size, power, color, etc.) (in dollars); b_j represents the efficiency of the car (in gallons/mile * miles driven); and p is the price per gallon of gasoline. Assume that the current gasoline price, p_0, is known, but that the future cost 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 or low as in Figure 1.We assume for simplicity that p_0 is the mean of the distribution ($p_0 = \pi^H p_H + \pi^L p_L$). We assume that a new vehicle will be infinitely lived.

[1] Some recent papers that cite [4], but involve a decision between technologies include [6][8][9][10][11]

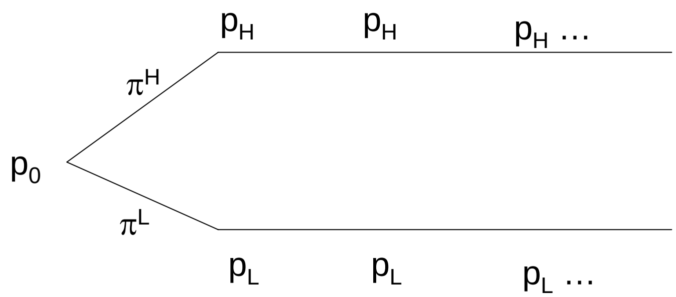

Figure 1: Price Dynamics

Consider a consumer that currently owns a vehicle with low non-monetary value and poor fuel efficiency. The consumer is choosing between two new vehicles, an SUV ($j = S$) that has high non-monetary value, poor fuel efficiency, and higher capital cost; and a compact car ($j = C$) with lower non-monetary value, good fuel efficiency, and lower capital cost. Specifically, $a_S, b_S, k_S > a_C, b_C, k_C$ respectively, where k_j represents the capital cost of car j. Assume that the expected Net Present Value (NPV) of each of the new vehicles is higher than the current vehicle; and that the SUV has the highest NPV when the price is certain to go down, while the compact has the highest NPV when the price is certain to go up. If the consumer uses a simple expected NPV rule, he or she would choose the new vehicle that had the highest expected NPV as follows:

$$\max_{j=S,C} \sum_t \delta^t V^j(p_0) - k_j \tag{2}$$

where δ is the discount factor $= 1/(1+r)$. 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 SUV; if $p_0 > p^*$, she buys the compact.[2]

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

$$V^0(p_0) + \delta \left\{ \pi^H \left(\sum_t \delta^t V^C(p_H) - k_C \right) + \pi^L \left(\sum_t \delta^t V^S(p_L) - k_S \right) \right\} \tag{3}$$

The first term is related to the cost of waiting one period – the consumer will spend one more period with the current low-value vehicle and lose one period of the value of the new vehicle. The second term is related to the value of waiting. If the consumer waits, she will get to buy the vehicle that maximizes her value given the realized price. The overall optimal decision will compare the value of buying a car 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 SUV now; if $\underline{p} < p_0 < \bar{p}$ the consumer will wait; and if $p_0 > \bar{p}$ the

[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 cars of equivalent non-monetary value, with one having higher capital cost and better efficiency.

consumer will buy the compact now.[3] Clearly $\underline{p} \leq p^* \leq \bar{p}$: if it is optimal to buy the SUV now in the NPV problem, it will never be optimal to buy the compact 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 an SUV. If an analyst were assuming an NPV framework, what would he observe? First, if the analyst knew the consumers interest rate, then he would clearly perceive a gas guzzlers gap – the consumer would fail to buy the SUV even though it had a higher NPV than the current vehicle. Second, consider the case where the analyst does not know the consumers interest 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 vehicle rather than purchase the SUV or the compact, and would miscalculate the consumers discount rate as being much higher than it actually is. That is, he would mistakenly observe:

$$\sum_t \tilde{\delta}_S^t V^0(p_0) \geq \sum_t \tilde{\delta}_S^t V^S(p_0) - k_S \tag{4}$$

and/or

$$\sum_t \tilde{\delta}_C^t V^0(p_0) \geq \sum_t \tilde{\delta}_C^t V^C(p_0) - k_C \tag{5}$$

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

This is quite a simple model, but the basic result – that there will be a range of prices in which a gas guzzlers gap would be perceived – is robust. For example, consider how the perceived "gaps" change with changes in the relative energy efficiency of the vehicles. Define the gas guzzlers gap (GG gap) as the distance between $\underline{p}$ and p^*. This is the range of prices in which a consumer would buy the SUV 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 SUV gets more efficient and decrease as the compact gets more efficient, and thus each trigger price decreases as the relative efficiency of the compact car increases (i.e. as $b_S - b_C$ increases). The size of the gaps between the trigger prices, however, are non-monotonic in $b_S - b_C$. When the difference between b_S and b_C is small, then the consumer will always prefer the SUV, leading $\underline{p} = p^* = \bar{p} = p_L$. On the other hand, when the difference between b_S and b_C 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_S and b_C, 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 a GG gap and an EE gap. So, again, there is no particular reason we would expect to see only an EE gap.

What role would policies aimed at subsidizing relatively efficient vehicles play? Consider a policy that subsidized the cost of the compact car based on how relatively efficient is was (i.e. $k_S - k_C = f(b_s - b_c)$, $f' > 0$). It is easy to see that the previous pattern would hold: both gaps

[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.

	Current $j = 0$	Compact $j = C$	SUV $j = S$
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

Table 1: Parameter Values

would be zero for very small and very large differences in relative efficiency, and would be positive over some range of relative efficiency. Such a policy would tend to compact the range of relative efficiencies over which gaps existed, but would not change the structure of the problem.

2.1 Numerical Example

In this section we illustrate with a simple numerical example. 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 $p_H = \$5/gal$ or $p_L = \$1/gal$. 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.

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	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	Com	Com	Com	Com	Com	Com	Com	Com	Com

Table 2: Numerical Example

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.

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 vehicles. This was the argument in Hassett and Metcalf for energy conservation measures; and it has been cited widely as a possible explanation for an

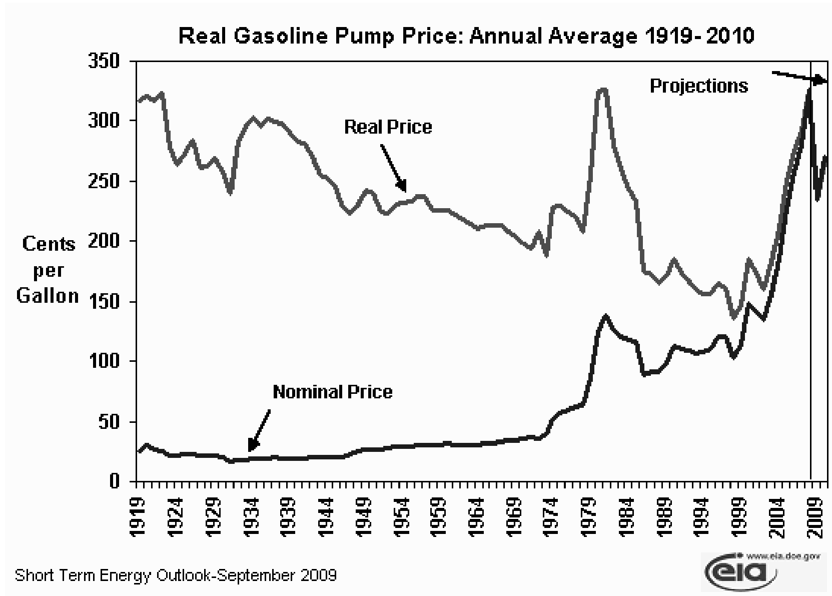

Figure 2: Real Gasoline Prices, reprinted from EIA

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 gas guzzler gap as to a perceived energy efficiency gap. We now compare this model to the evidence to see how it fares as an explanation.

First, consider Figure 2, a reprint of the EIAs chart showing the real price of gasoline between 1919 and 2010. 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 rising or high, and a perceived gas guzzler gap in years when the gasoline price is falling or low. Thus, we should see an energy efficiency gap in 1974 - 1982 and in 1999 - 2009; we should see a gas guzzler gap between 1982 - 1999. 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 ([1][5][7]) 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" [1], 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 [2]. 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, 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 consumer's perception of riskiness in the gas market).

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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