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Energy Conservation Investment: Do consumers discount the future correctly?

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We argue that the apparently high discount rates attributed to investors making energy conservation investments are not irrational or the result of some market failure. Rather they may result from an investor recognizing that many conservation investments entail substantial sunk costs. In the presence of these costs and uncertainty over future conservation savings, consumers should use a higher hurdle rate for investment than if there were no uncertainty. Simulations suggest that the hurdle rate should be about four times greater than the standard rate. An implication of our model is that tax subsidies for the purchase of conservation capital are likely to be ineffective. We discuss alternative policy approaches which are more likely to increase energy-efficient investment, namely mandatory efficiency standards and energy taxes.

Keywords: Conservation investment; Discounting; Uncertainty

[M]any common conservation measures have after-tax returns on investment that are often double those of stocks, bonds, money market funds, and real estate. However, the level of energy conservation activity is not consistent with these high yields.[1]

As the above quotation suggests, there is considerable concern over the apparent lack of response of investment in conservation and other energy saving capital to changes in prices. This concern reflects a seeming paradox which we term the energy paradox: the seeming anomaly that very attractive investment opportunities in energy-efficient capital, opportunities with high *ex ante* rates of return, are routinely passed over by investors.[2] Closely allied to this belief is the notion that investors do not make investment decisions rationally.[3] We argue in this paper that the energy paradox may not be a paradox at all and what appears to be irrational behaviour on the part of potential investors can in fact be rationalized within a simple economic model. The basic insight is that the future return on this investment (the avoided energy costs) is highly uncertain. Potential investors should delay their investment in some optimal way to avoid the bad realization when energy prices fall and the investment becomes unprofitable on an *ex post* basis. In the next section, we characterize this argument more carefully. We then highlight the implications of our argument for energy conservation policies.

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The energy paradox

We begin by examining the apparent paradox of underinvestment in energy saving capital. Consider an individual who is contemplating making an energy saving investment today. Crucial for evaluating the benefits of the investment is the ability of the individual to forecast uncertain future energy prices. We incorporate uncertainty in our model by assuming that the natural log of the energy price follows a continuous time random walk. This process has the desirable feature that forecast uncertainty increases with forecast horizon, and that we may observe extended periods of low energy costs as well as extended periods of high energy costs. In formal terms, we model P_t as

$$\frac{dP_t}{P_t} = \alpha\, dt + \sigma\, dz \tag{1}$$

where dz is an increment to a Wiener process with mean zero and unit variance. Figure 1 is a representation of such a process. Energy costs are rising exponentially at trend rate α but exhibit substantial randomness around the trend. The parameter σ determines the degree of randomness price exhibits

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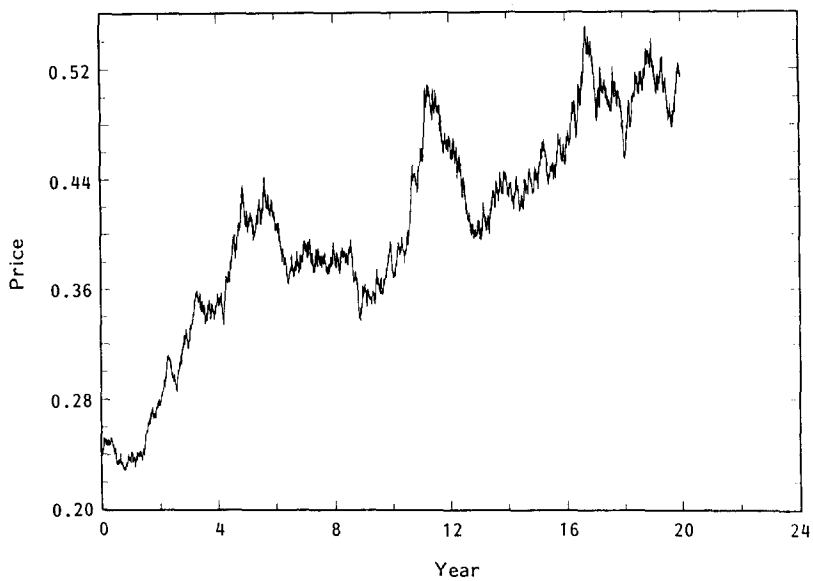

Figure 1. Price: continuous time random walk with drift.

around its trend. We refer to σ as the volatility of the energy price. Below, we discuss appropriate values for α and σ. Assume for the sake of simplicity that the quantity of energy consumed in each period is always one energy unit and that an energy-efficiency investment saves a fraction δ of the energy costs each period. If we invest today and begin receiving the savings δP_t tomorrow, the expected present discounted value of the energy savings (discounted at rate γ from today until infinity) would equal

$$B = \frac{\delta P_t}{\gamma - \alpha} \tag{2}$$

Note that this is *expected* savings and would only equal actual savings if $\sigma = 0$. If the cost of the energy investment is given by C, then the standard cost benefit calculation says to invest if $B > C$ or

$$\delta P_t > (\gamma - \alpha) C \tag{3}$$

that is, if the energy savings exceed the annualized cost of the investment adjusted for the expected growth in energy costs (and hence energy savings). We will refer to the right-hand side of Equation (3) as the hurdle rate for this investment – the minimum savings required before investment becomes profitable. Previous studies have calculated the energy savings associated with various energy saving durable goods, compared them with the cost, and estimated high discount rates (γ) of the order of 20–50% or even higher.[4] Because of these implausibly high discount rates, some have argued that the estimated discount rate is fundamentally mismeasured, as a variety of market imperfections (access to capital, information about the benefits of the investment etc) are subsumed into the discount rate.[5]

While there may in fact be market barriers to investment in energy-efficient capital, we note that the reasoning that led to the benefit–cost rule in Equation (3) is incorrect and that policy inferences drawn from this reasoning may be misguided. Return to the individual contemplating the investment with cost C and benefits equal to a stream of energy savings δP_s, $s > t$. Let P^* be the energy price such that Equation (3) is just satisfied ($B = C$). At P^* the investor should not invest yet. To see this, consider the following two possibilities for the future energy cost (P). First, assume that prices increase in the future so that $P_s > P^*$ for $s > t$. Now the realized energy savings exceed the expected savings and *ex post* the investment was cost effective in the sense that the rate of return exceeded γ. Second, assume that energy costs fall and $P_s < P^*$. Now the actual benefits fall short of the cost, and the investment was a bad one (in the sense of yielding a low rate of return).

How should the potential investor reconcile these different possible outcomes of her investment? She should recognize that once the investment is made, there is no undoing it.[6] If she invests today, she is stuck with the investment, good or bad. However, if she waits one period she can decrease the chance that she will lose money. The random walk assumption means that once energy costs move into the region where $P > P^*$, they are likely to stay in that region longer. Put differently, the probability that prices will fall into the region below P^* drops as P

increases above P^*. The more P grows above P^*, the more likely it is that prices will stay in this region and the more likely that the *ex post* benefit of the investment will exceed the cost. Similarly, if P falls below P^*, it becomes less likely that P will rise into the region where the benefits of the investment will exceed the cost. Thus the investor may wish to wait a period to see what P will do. If energy costs go up a bit, she may wish to wait a bit longer to see whether they will rise again and so decrease the likelihood that energy costs will fall below P^* again.

In effect, the investor holds an option (an option *not* to invest) prior to making the investment. Once she makes the investment, the option is lost since the investment cannot be undone. This option is more valuable the more uncertain future energy costs are. At one extreme, the option is worthless if σ equals 0; you know today whether an investment made today will be profitable *ex post* or not. However, as σ increases, the *ex post* value of the investment can increasingly diverge from its *ex ante* value and waiting to invest becomes increasingly prudent.[7]

Clearly, choosing how long one should wait as P rises above P^* is an optimization problem. In an earlier paper, we solve this problem of minimizing the expected present discounted flow of energy savings net of the cost, and show that the optimal time to invest is when

$$\delta P_t > \Gamma \cdot (\gamma - \alpha) C \tag{4}$$

where Γ is greater than one.[8] When there is very little uncertainty, the investment rule becomes similar to the standard one. As uncertainty increases, however, the required hurdle rate increases dramatically.[9] When uncertainty is very high, the hurdle rate can easily reach seven times the hurdle rate in the absence of uncertainty. Below we present evidence drawn from our earlier work which indicates that the moments of observed price series suggest that the optimal hurdle rate for energy conservation investment should be roughly four to five times the hurdle rate in the absence of uncertainty. What appears to be myopic behaviour (ie high γ) may simply reflect an optimal investment strategy in the face of uncertainty.

Uncertainty and cumulative investment

An understanding of the actual pattern of investment requires some additional modelling: without some form of heterogeneity we will be unable to explain differences in adoption behaviour across individuals. The model described above would predict that once the price series rose sufficiently high to cover the higher hurdle rate, everyone in society should simultaneously invest.

To achieve more realistic diffusion patterns, we appeal to housing heterogeneity: some consumers with very inefficient houses can reap large energy savings from insulation, some cannot, either because of weather, existing insulation or other factors affecting the performance of energy improvement measures. As energy costs increase, investment in energy conservation capital becomes more attractive to people with increasingly lower values of δ. Put differently, the individuals with the largest savings to be gained will be the ones most likely to shift first, followed by households with lower expected energy savings. Using this logic we simulate the adoption of energy improvements as follows. We assume that energy savings has a normal distribution with a mean of 0.2 and a standard deviation of 0.1, numbers meant to be roughly consistent with engineering estimates. We then simulate the price processes which drive the energy investment using different values of σ, the volatility parameter. If individuals behave according to our model, then they will choose to invest when the annual energy savings achieved through investment in alternative energy devices divided by the cost of the investment (think of this as the rate of return of the investment) is greater than $\Gamma \cdot (\gamma - \alpha)$.

To see graphically how this works, consider Figure 2, which plots a hypothetical distribution of energy savings (δ_i) for the USA. As noted above, if total energy expenditure were US$1000 before improvement and an individual calculated her personal δ to be 0.5, then the post improvement expenditure would be US$500. As the price of energy increases, the return to investment increases. At first, individuals with large savings (high δ) invest, and later individuals with lower savings invest. If energy costs grow high enough, eventually 100% of the population will invest.

We show one possible cumulative investment pattern in Figure 3 for a model in which there is no future price uncertainty ($\sigma = 0$). In this model, energy costs are rising exponentially at a rate of 4.6% per year and the real discount rate is 0.05. Our estimates of α and σ (see below) were estimated using aggregate US energy price data for the years 1955–81. The derivation of these estimates of α and σ is explained more fully in our previous paper.[10] We used the time period 1955–81 as we were interested in explaining the low use of the federal conservation tax credit in the early years of the programme before energy prices fell. We set the initial price of energy so that at time 0, 25% of the population has invested

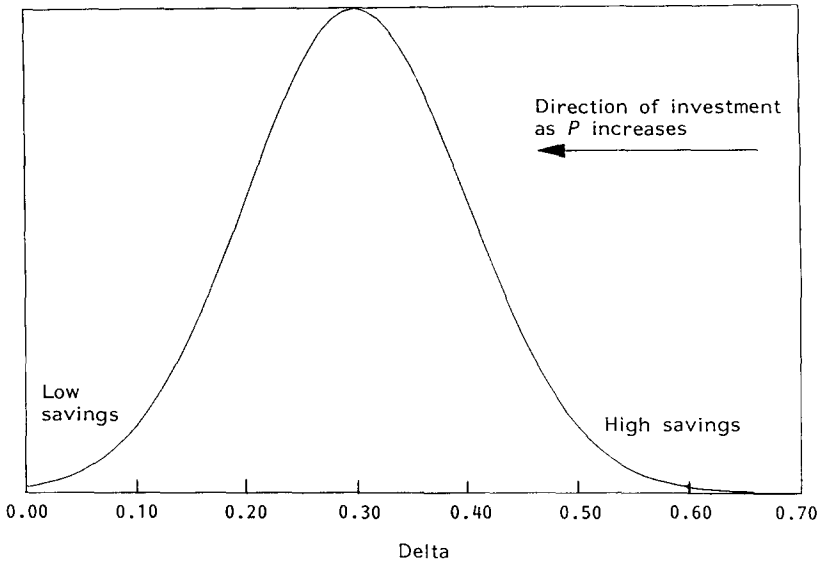

Figure 2. Potential energy savings distribution.

in the energy saving capital. What is striking from Figure 3 is the rapid growth in investment with 40% of the population investing after four years and nearly everyone investing after 20 years.

This simulation approach can be used to evaluate the effectiveness of policies to encourage additional investment. Figure 4 allows for a 15% tax credit for the purchase of energy saving capital in year 1. As expected, investment rises sharply in year 1 – roughly 20% – with complete investment by the population in about 15 years. This experiment suggests that the US residential energy conservation tax credit which was in place from 1978 to 1985 should have had a substantial impact on investment at the residential level.[11]

Figure 5 now allows for the possibility of uncertainty over future energy costs. Our estimate of σ is 0.093. Based on our estimates of α and σ and a real discount rate of 0.05, Γ equals 4.23.[12] In other words, the hurdle rate for investment is driven up by a factor of more than four. The effect on cumulative investment is quite dramatic. Initial investment falls from 25% to roughly 1% and after 20 years is less than 5%.

Investment also follows a pattern of bursts of activity, followed by periods in which no investment occurs. No investment occurs during periods in which energy prices are stable or falling, while investment occurs once prices rise sufficiently to clear the hurdle rate. The value to waiting to invest

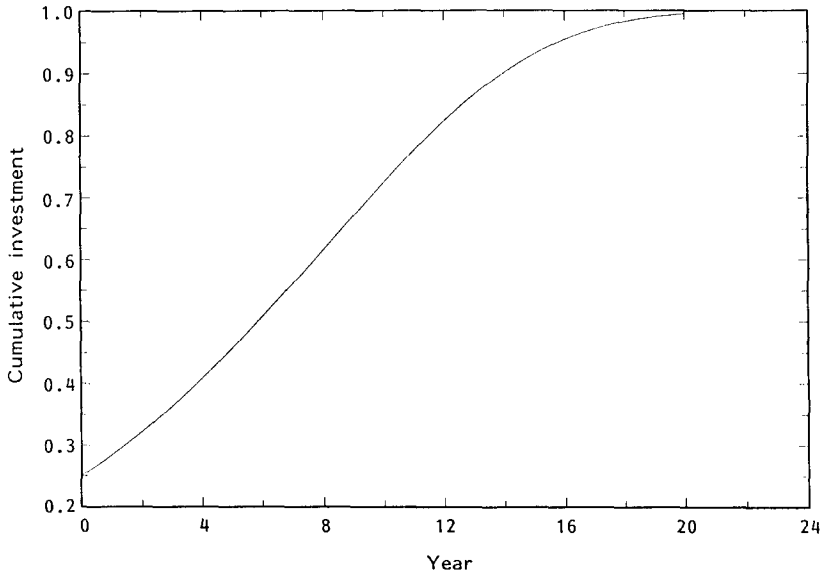

Figure 3. Cumulative investment: $\sigma = 0$.

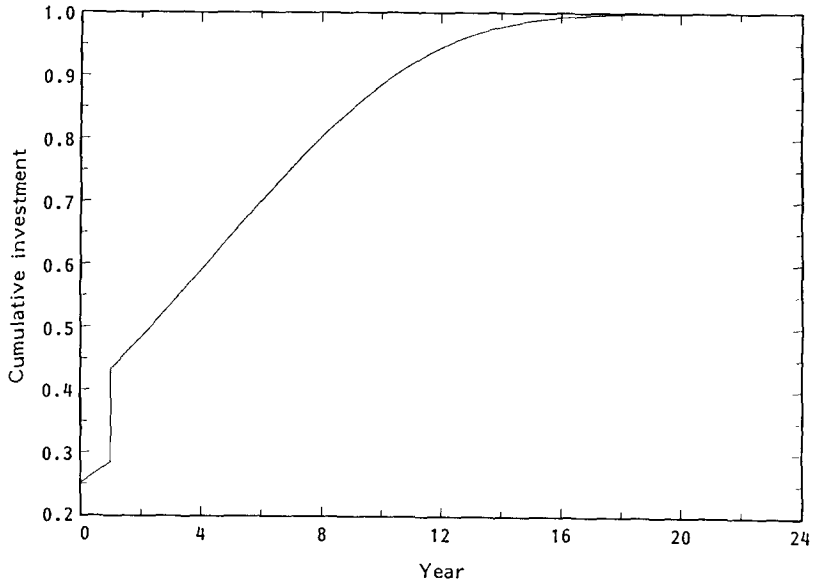

Figure 4. Tax credit at $t = 1$: $\sigma = 0$.

to ensure that prices will rise sufficiently to lessen the risk of an *ex post* poor investment critically delays investment.

In the face of uncertainty over future returns, the effect of a tax credit is dramatically attenuated (Figure 6). The initial effect of a 15% tax credit in year 1 is roughly a 0.2% increase in investment. Cumulative investment after 20 years has only increased by about 2.5%. Clearly the effect of uncertainty on delaying investment swamps the positive effects of a tax credit on encouraging investment.

Policy implications

Before evaluating current or proposed policies to encourage energy-efficient investment, we must ask why the government should promote *any* energy conservation policies at all. If the argument is that the rate of investment is low given the rate of return on conservation investment calculated by engineers (ie people irrationally set their discount rate too high), then there is probably not a role for government to play. It is important to recognize that the investment behaviour of potential investors in energy-efficient capital can be rationalized by a plausible economic model in which individuals optimize with full information and reasonable discount rates. In this context, providing more information about the benefits of conservation investment will be unproductive.[13]

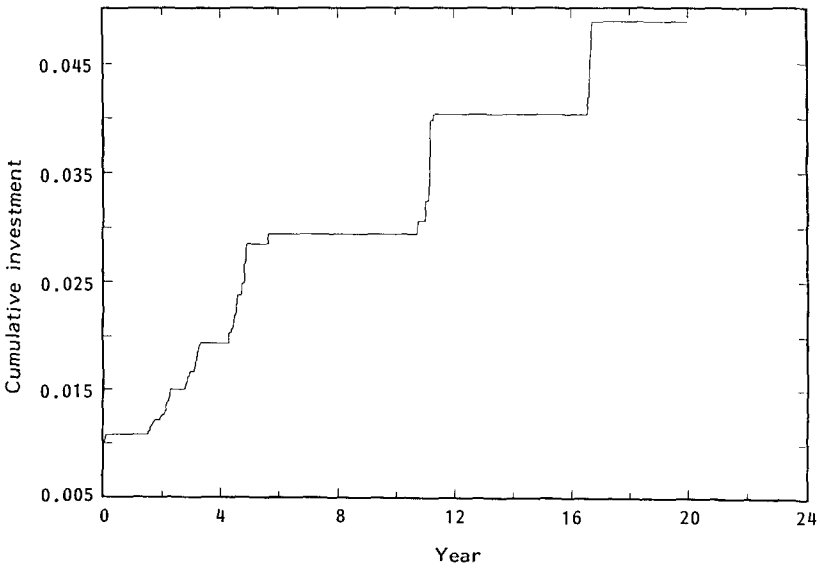

Figure 5. Cumulative investment: $\sigma = 0.093$.

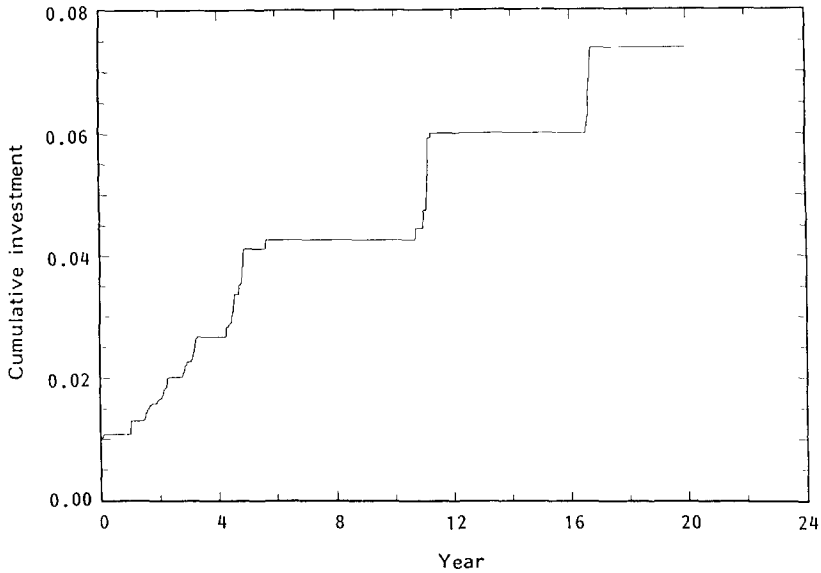

Figure 6. Tax credit at $t = 1$: $\sigma = 0.093$.

Thus we must turn to other arguments for encouraging conservation behaviour. An obvious reason is the existence of externalities in energy use (eg national security concerns about overreliance on imported energy, or CO_2 emissions as a byproduct of energy use). We find many of these types of arguments persuasive, but argue that our model of investment under uncertainty renders many of the policy prescriptions ineffective. For example, the simulations reported above suggest that the added benefits of a tax credit programme are likely to have a very small effect on cumulative investment. In addition, empirical work we have carried out suggests that implementing an energy conservation tax credit of 10 percentage points would only increase the fraction of households investing by 1.5% per year.[14]

If a tax credit will not substantially increase energy-efficient investment, what other policies should be considered? Two possibilities occur to us. First, the use of energy-efficiency standards for appliances as proposed in the recently passed Senate National Energy Security Act may be well advised.[15] In effect, standards act indirectly as quantity controls and will generate energy savings regardless of consumers' perceptions of future energy savings.[16]

Alternatively, a tax on energy consumption may be effective at reducing energy use. Returning to Equation (4) above, it is readily apparent that a tax on energy costs increases the return to an investment (since the return to an energy saving investment is the energy consumption avoided). However, an energy tax which raises the cost of energy from P to $(1+\tau)P$ is equivalent to a tax credit for the purchase of capital where the tax credit (k) and energy tax are related by the relation

$$\frac{1}{1+\tau} = 1-k \tag{5}$$

If a tax credit is ineffective at increasing investment, then an energy tax will be equally ineffective. However, unlike an investment tax credit, the energy tax will encourage conservation with the existing capital stock. Hence in a broader model of investment and energy consumption a tax credit for the purchase of energy-efficient capital and a tax on energy use are not formally equivalent, and a tax on energy use will be a more effective conservation inducing policy instrument.

Conclusion

In summary, we find that a simple model of irreversible investment predicts energy-efficient capital investment rates similar to rates observed in the 1970s and 1980s in the USA. This suggests that the slow diffusion of new energy technologies may not, as policy makers have argued in the past, be the result of consumer ignorance, but rather be the result of rational cost minimizing behaviour on the part of consumers. We believe this insight is critically important in evaluating the probable impact of policies seeking to increase investment, and conclude that: tax credit programmes should produce very small investment responses; information dissemination alone is likely to be an ineffective impetus to new investment. Energy-efficiency standards or taxes on energy consumption may be the

most effective policy options if we wish to improve national energy efficiency.

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[1]Robin Gates, 'Investing in energy conservation: are homeowners passing up high yields?' *Energy Policy*, Vol 11, No 1, March 1983, pp 63–71.

[2]This belief is not out of fashion. Consider the following quotation from R. Carlsmith, W. Chandler, J. McMahon and D. Santino, *Energy Efficiency: How Far can we Go?*, Oak Ridge National Laboratory, TM-11441, 1990: 'The primary barrier [to improving energy efficiency] is insufficient implementation of existing cost-effective technologies' (page 25). The energy paradox has also been referred to as the payback gap, a term first ascribed to Ralph Cavanaugh, 'Electrical energy futures', *Environmental Law*, Vol 14, No 1, Autumn 1983, pp 133–175.

[3]For example, Eric Hirst, 'Individual and institutional behavior related to energy efficiency in buildings', *Journal of Environmental Systems*, Vol 16, No 1, 1986–87, pp 57–74, writes 'In actuality, people do not think in terms of the time value of money' (page 59).

[4]See, for example, Jerry Hausman, 'Individual discount rates and the purchase and utilization of energy-using durables', *Bell Journal of Economics*, Vol 10, No 1, March 1979, pp 33–54 and the articles cited in Kenneth Train, 'Discount rates in consumers' energy-related discussions: a review of the literature', *Energy*, Vol 10, No 12, December 1985, pp 1243–1253.

[5]For example, Paul Stern, ed, *Improving Energy Demand Analysis*, National Research Council, National Academy Press, Washington, DC, 1984.

[6]More precisely, we assume that the investment is irreversible. There is no resale value if the investor wishes to sell the capital. This is a stronger assumption than we need. So long as there are imperfect resale markets so that sellers cannot recoup the full remaining value of the investment on resale our explanation will hold.

[7]It is not obvious that uncertainty in energy prices should be symmetric. One alternative is to model energy prices as following a mean reversion process ie $dP_t = -\lambda(P_t-\alpha)P_t d_t + \sigma P_t dz$. Here α is a mean reversion price and $\lambda>0$ gives the speed of adjustment. While the algebra becomes more complicated, the story remains unchanged: delaying investment becomes an optimal strategy.

[8]Kevin Hassett and Gilbert Metcalf, *Energy Tax Credits and Residential Conservation Investment*, National Bureau of Economic Research Working Paper No 4020, March 1992. Γ is a function of σ ($\Gamma(\sigma)$) with the property that $\Gamma(0) = 1$ and $\Gamma' > 0$.

[9]To clarify the point about the option value associated with not investing, rewrite Equation (4) as $\delta P_t > (\gamma-\alpha)C + (\Gamma-1)(\gamma-\alpha)C$. The first term on the right-hand side of this equation is the annualized cost of the investment adjusted for the expected growth in energy costs (see Equation (3)). The second term is the value of the option which is lost when the investment is made. Hence, the optimal rule is to invest when the benefits of the investment exceed the annualized investment cost plus the value of the option now lost.

[10]*Op cit*, Ref 8. In brief, our measure of P is the ratio of the household fuel oil price index divided by the durable commodities price index. The latter proxies for the cost of conservation capital and serves as a deflator for energy prices. With this interpretation, the cost of the energy investment (C) in Equation (3) can be treated as a constant. Price index data come from the *1991 Economic Report of the President*.

[11]The residential energy conservation tax credit allowed a 15% credit for expenditures on conservation up to US$2000 (maximum credit: US$300) per house and a 40% credit for the purchase of solar, wind or geothermal equipment up to US$10 000.

[12]This is based upon the estimated standard deviation of the price process, which is equal to 0.093. If the volatility were twice as high ($\sigma = 0.186$) Γ would climb to 5.21. If the volatility were half as large ($\Gamma = 0.0465$) Γ would fall to 3.97.

[13]We do not argue that information is of no value. Clearly, one role of improved information in our model would be to help potential investors generate unbiased estimates of δ. We might argue that current estimates are biased downward (individuals underestimate the potential for energy savings), although we know of no empirical evidence for this potential bias.

[14]*Op cit*, Ref 8.

[15]Senate Bill 2166 passed by the Senate on 19 February 1992.

[16]Quantity controls affect the actual consumption of energy while price controls affect the price (and hence quantity indirectly). A standard analysis of the two types of controls is given by Martin Weitzman, 'Prices versus quantities', *Review of Economic Studies*, Vol 61, No 4, 1974, pp 477–491.