Uncertainty, Real Option Valuation, and Policies toward a Sustainable Built Environment

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Abstract: Real option value can severely hinder investments in energy conservation in real estate. This paper evaluates whether policy incentives to invest now, instead of tomorrow can be tailored to compensate for any option value to defer. A case study reviews a Dutch government subsidy program with the Cox, Ross, and Rubinstein (1979) binomial method. Based on market priced risk, the subsidy properly compensates investors for the real option value they forego by exercising the option and investing in a solar hot water system. A survey amongst homeowners reveals that private risks are an important part of the perceived uncertainty when investing in energy efficiency and should be included in the model. A practitioners’ method is proposed that uses a binomial real option model to design policy incentives and surveys to assess the relevant uncertainties to include in the model. The results displayed in strategy spaces makes intuitive decisions possible.

In recent years climate change and energy shortages have become mainstream problems. Their importance is now widely accepted. In the real estate sector this has led to initiatives like ENERGY STAR and LEED, and landmark buildings such as One Bryant Park in New York City. These are some clear signals that sustainability and energy efficiency are becoming a central focus in the real estate industry.

The built environment is a major energy consumer. Schools, offices, shops, and homes use many times the energy that the aviation industry uses. If in any sector sustainability can make an impact both environmentally and economically, it is in real estate. Although the environmental benefits are clear, the economical benefits are still largely unclear.

Recent literature such as Miller, Spivey, and Florance (2008), Eichholtz, Kok, and Quigley (2010), and Kok, Eichholtz, Bauer, and Peneda (2010) shows the first evidence of the financial benefits of green buildings. Green buildings command higher rents and higher transaction values (Eichholtz, Kok, and Quigley, 2010). Miller, Pogue, Gough, and Davis (2009) link greener buildings with higher productivity and give an indication of the added net present value this may create. However, benefits like higher productivity of the occupants and the marketing advantage related to corporate social responsibility remain rather difficult to measure and are therefore difficult to value. The one benefit that is relatively easy to measure is energy conservation.
To show how much energy a green building can save as opposed to a traditional building is rather straightforward, especially in hindsight. It is more difficult however to estimate before investing what the green investment is worth. The answer to this question depends a great deal on the expectation of the energy price development, because energy conservation is expressed in the price of conventional fuels. This is where uncertainty plays an important role. Prices of crude oil, electricity, and natural gas are known to be volatile. In 2008, there was a surge in the oil price to over $140 per barrel while today (March 2010) oil trades in the region of $70 to $90 per barrel. Since 1994, natural gas has traded at the Henry Hub in the United States at annual volatilities between 49% and 218% (Mastrangelo, 2007), which makes the price of natural gas highly uncertain.¹

Due to the volatility of energy prices, it can be interesting to delay investments in energy conservation until prices have risen far enough to assure a handsome return. In fact the owner of real estate has the option to invest in his property’s energy efficiency but does not have an obligation to do so. An opportunity much like the one a financial call option offers. The tendency to defer investment causes investor inertia in the short-to-medium term. This could explain a lack of investment in greener real estate. To make the investment today rather than tomorrow, the investor will be looking for incentives or carrots. So the inertia toward investment can possibly be countered with policy intervention. When the option value is neglected however, the incentive is unlikely to properly compensate investors for the option value they have to forego by exercising the option they hold to invest in green(er) real estate.

Advances in technology for energy conservation or renewable energy generation may also be worth waiting for, as these may dramatically increase the payoff of the investment. Especially for photovoltaic panels, for which many different technologies have been developed (Curtright, Granger Morgan, and Keith, 2008). These may lead to panels with the same capacity as today but at a much lower price or with much more capacity at the same price. In both cases, the payoff of investment in a greener home will be affected. The first will lead to a lower exercise price, while the latter leads to a higher value of the underlying asset. The uncertainty regarding technological advance will likely increase volatility, which results in a higher option value. Technological development can therefore be worth waiting for.

The value of the option to defer is therefore central to design a carrot or stick that works well. The option value can help explain why investments in energy conservation in property are delayed. Policy incentives to invest now, instead of tomorrow, like subsidies or tax rebates can be tailored to compensate for any option value to defer.

The present paper discusses the role uncertainty and real option valuation can play in creating carrots that work. It uses a case study of a subsidized investment in a more energy-efficient home in the Netherlands to provide empirical evidence that a stimulus should be designed to compensate for any option value in waiting to invest. Does the subsidy make sense from a financial point of view? Or does real option valuation suggest otherwise? The case of a solar hot water system² was chosen for evaluation, because it is an energy efficiency measure that can easily
be added on to most residences and is currently part of a Dutch government subsidy program.

The case study is also intended to show the practical suitability of real option valuation for policy intervention design. For the real option valuation method to be accepted, it should be user-friendly and easy for practitioners to incorporate into their everyday valuation tools.

This paper firstly introduces the concept of real option valuation and then describes the binomial option pricing model and its inputs. The sensitivity analysis of the model results is presented in strategy spaces and discussed. A survey then gives some insight into the perceived uncertainty by Dutch homeowners. Finally, the paper concludes on the suitability of real option valuation for designing incentives that work to achieve a green(er) built environment.

**Real Option Valuation**

Real option valuation (ROV) is an extension of or addition to discounted cash flow (DCF) analysis. DCF is considered quite a rigid valuation method because it uses a fixed discount rate, which is as Brennan and Schwartz (1985, p. 139) state: “...tantamount to assuming that the risk of the project is constant over its life.” In reality, risk is hardly ever constant over the life of the project. The DCF method also implicitly assumes immediate investment, while in real life investments can be timed for optimal entry. Therefore a growing amount of literature agrees that the classical DCF analysis does not capture the value of real life flexibility. For projects with substantial uncertainty, this can lead to underestimation of their value and cause a miss-allocation of scarce resources.

**Option Pricing Theory and Real Assets**

The underlying principle of ROV is option pricing theory (OPT), which was introduced by Black and Scholes (1973) and Merton (1973). OPT was intended to value options on financial assets. The value of real assets as opposed to financial assets also depends on private risks that are not priced in the financial markets (Amram and Kulatilaka, 1999, pp. 47–54). In the present case study, for example, a source of private risk can be that the government changes its subsidy program. The risk that this may happen can make it worthwhile for the homeowner to wait and see if this new subsidy program will offer a higher incentive to invest than the current one. In property development, an example of private risk can be for instance the failure to obtain planning permission. No traded securities are available that represent exactly these private risks. However, by using financial assets that have similar risk characteristics as the real asset, the risk associated to the real asset can be mimicked. Creating a proxy portfolio allows the ability to price the option on the real asset. Looking at the example of real estate, an appropriate proxy that can reasonably replicate the value of real estate as an underlying asset can be a portfolio of real estate investment trusts (REITs). Ott
and Yi (2001), for example, used REIT data as a proxy to find the volatility for their real options model.

**Real Options, Policies, and Sustainable Real Estate**

Real option valuation has numerous fields of application. Merton (1998) summarized in part of his Noble Prize address some 25 years worth of different real option applications. Without being complete, a number of them are mentioned: valuing insurance contracts, pricing credit derivatives, valuing fishery quotas, pricing licenses for the right to pollute, valuing offshore drilling rights, tax delinquency on real estate, and so on.

Patel, Paxson, and Sing (2005) provided a comprehensive overview of the literature on what they call “real property options” and reviewed a number of practical applications, such as: planning, investment timing, leasing, operation, funding, and industry strategy. They found that mortgage valuation is a particularly useful application for ROV. Azevedo-Pereira, Newton, and Paxson (2003) confirm this. Despite the wide scope of the Patel, Paxson, and Sing (2005) overview, sustainable real estate is not mentioned. Literature like Holland, Ott, and Riddiough (2000) and Grenadier (2002) confirms the presence of the option to delay uncertain investments in real estate. The sustainable built environment, however, appears to be a new avenue of research in the field of real property options.

The present case study focuses on improving the energy efficiency of existing homes. This topic has not yet been much explored within real options valuation. Recently, Hajek (2009) studied the impact of the deferral option on the energy efficiency of homes in Prague. He looked for empirical evidence to show that homeowners in Prague do not invest in the energy efficiency of their homes because of the valuable deferral option they hold. Although he showed the presence of investment deferral, it remained unclear whether this can be entirely attributed to the presence of option value. His study did not take into account much of the private risk sources, such as for instance the propensity of people to move. Also he found that a delay of over two years occurred between a “price signal” and the actual investment in energy efficiency measures. This also raises the question whether the option value to defer investment is entirely related to volatile energy prices.

Besides the deferral option found by Hayek (2009), Kumbaroglu, Madlener, and Demirel (2008) found that investments in renewable power generation technologies are severely hindered by the option to delay these irreversible investments.

So uncertainty can hold back investment in a green(er) built environment. Carrots, incentives or subsidies may be a way to counter the reluctance to invest. Dixit and Pindyck (1994, pp. 282–316) argue that when irreversible investments under uncertainty have to be made in situations or cases where the market does not function, policy intervention may be considered. In the case of investments in a
more sustainable home, the investor has the benefits of a lower utility bill and a hedge against future energy price increases. The benefits like a smaller carbon footprint and a lower dependency on fossil fuels are societal benefits, so-called positive externalities or external benefits. The investor does not count these benefits in his decision to invest and may therefore decide not to invest. A government, however, may judge the market for investment in a green(er) home incomplete. It may find the external benefits important enough to influence the investors’ decision by providing policy incentives, such as subsidies or tax rebates.

Some recent studies give empirical evidence that to design effective policies; a real options approach can be useful. Anda, Golub, and Strukova (2009), for instance, used real option analysis to formulate rules for the selection of an emission target for a climate policy. Fuss, Obersteiner, and Szolgayova (2008) found that even a moderate increase in the price uncertainty of CO₂ emission permits a dramatic increase in investment to reduce emissions. They also showed that a policy of deterministic permit pricing leads to less investment. In their study, real option valuation was used to show the value of volatility and how it can be used in environmental policy making. In this case, the volatility that the cap and trade system creates appears to be an effective stick, which makes CO₂ emitters want to reduce their emissions to have a more stable and predictable cost structure. The option to invest in CO₂ emission reduction is often “in the money” due to the high volatility of the price of CO₂ permits.

The present case study is a first empirical attempt to link an established real option value with consumers’ perception of uncertainty in investments in real estate.

**Methodology**

This research follows two tracks. Firstly, the call option to defer investment was modeled with the Cox, Ross, and Rubinstein (1979) binomial method and the results were presented in a strategy space. Secondly, a survey of homeowners was intended to disclose what they perceive as the most important uncertainties when faced with a decision to invest in a more energy-efficient home.

**Binomial Model**

Amram and Kulatilaka (1999, p. 108) distinguish three solutions for real option problems: (1) partial differential equations (PDEs) such as the Black-Scholes formula;³ (2) dynamic programming, which can be modeled with the binomial model; and (3) simulation, which can be done with, for example, the Monte Carlo method.

Both PDEs and simulation are rather complex methods, which require advanced calculus. This renders them rather unattractive for mainstream use by practitioners. The binomial lattice, however, is similar to a decision tree. The step from this well-known decision tool to the binomial tree is small, making it easy to understand. The binomial method offers a transparent way to value a real option, using only basic algebra instead of complex calculus (Copeland and Tufano, 2004).
Cox, Ross, and Rubinstein (1979), hereafter referred to as CRR, were the first to propose a binomial solution. Their method opened many new ways for the application of OPT. The binomial solution is a discrete-time model in which the price of the underlying asset can move either up or down at each time interval. The price movement of the underlying asset is represented by a binomial lattice or tree. Exhibits 4 and 5 are examples of such trees. Each node represents a possible value at that point in time. These values are the basis for the subsequent option value calculation. The previously mentioned tracking portfolio earns the risk-free rate of return. The CRR method uses that same principle. The option values are found by working from right to left through the lattice (Exhibits 4 and 5) and calculating the option value at each node with the risk-neutral probability. The result is a real option value for the present.

**Survey: What Makes Homeowners Postpone Investment?**

The binomial model described in the previous paragraph uses energy price development as the modeled uncertainty. The uncertainty related to technology advances, which may improve the payoff, was not modeled. The issues that worry investors, the homeowners, may therefore not be reflected correctly in the model. A survey was performed to find out what makes homeowners postpone investment. They were presented a number of uncertainties and were asked to indicate the two most important ones they worry about when making an irreversible investment in the energy efficiency of their home.

The survey sampled 330 people, which is part of the population of all 3.87 million households in the Netherlands, which according to Statistics Netherlands (2009a) own their home. The sample may be somewhat biased as most members live in big cities in the western part of the Netherlands and 19% of them may be more familiar with energy conservation in homes and real estate in general.

The survey was not intended to find out specifically about the investment in a solar hot water system, but about the investment in energy efficiency measures for homes in general. These may include insulation, double-glazed windows, heat pumps, photovoltaic panels, solar hot water systems, and others. This choice was made to be better able to generalize the results to investments in a more energy-efficient home instead of limiting them to the solar hot water system.

**Model Inputs**

The case study deals with an American call option on the subsidized investment in a solar hot water system by homeowners in the Netherlands. To determine the value of this American option, these five inputs were gathered: (1) the time to maturity; (2) the exercise price; (3) the risk-free rate; (4) the current value of the underlying asset; and the volatility of the underlying asset. These inputs are briefly described below; a more detailed account of how these inputs were gathered is available in Van der Maaten (2009). Exhibit 3 summarizes the model inputs for the medium growth scenario.
The Time to Maturity

The time to maturity was obtained from a factsheet (SenterNovem, 2009) about the government subsidy program for solar hot water systems. The option to postpone expires December 31, 2011. May 4, 2009 was chosen as the reference date. The time to maturity was therefore 2.7 years or 32 months.

The Exercise Price

The exercise price is made up of the cost of the solar hot water system and its installation. The reference system for this case study has a capacity of 3.0 GJ and costs €2,485 including VAT and installation costs.

The Current Value of the Underlying Asset

The current value of the underlying asset is the net present value of the investment in a solar hot water system today, at today’s expectation of the energy price development. The net present value is determined using the following inputs.

Annual Volume of Natural Gas Savings. The cash savings that a solar hot water system can generate depends on the volume of natural gas used by households. This volume is directly related to the household demand for hot tap water. The more hot tap water that is used, the more natural gas that is needed to heat it. For a solar hot water system to function optimally, a certain amount of hot water needs to be used. According to Milieu Centraal (2009), for households of three people and more, systems with a capacity of about 1 GJ per person are viable. A household size of three people was chosen as an input for the option pricing model in this study. This household can save between 150 m³ and 200 m³ of natural gas per year (Informatiecentrum Duurzame Energie, 2004; Bosselaar and Gerlach, 2006; SenterNovem, 2007; Milieu Centraal, 2009). It was assumed it would be able to save 175 m³ of natural gas on an annual basis with a solar hot water system with a capacity of 3.0 GJ for a working life of 30 years.

Price Development Scenarios for Natural Gas. The cash flows of natural gas savings depend on the expected price development of natural gas. The historical time series from 1980 to 2008 from Statistics Netherlands (2009b) as displayed in Exhibit 1 were used. The growth rates for a number of periods were extrapolated until 2020.

The three different average annual growth rates of 0.0%, 6.6%, and 9.7% were defined as respectively a zero, medium, and high growth rate scenario. From these price development scenarios, the cash flow projections could be made by multiplying the average annual gas savings for the reference household with the price of natural gas at each point in time for each scenario. Each scenario will generate a different cash flow during the economic working life of the system. All of these cash flows were then discounted at the appropriate discount rate.

From this point on, this paper only deals with the medium scenario result. For the zero and high growth scenario results, the reader is referred to Van der Maaten (2009).
Discount Rate: Capital Asset Pricing Model. The capital asset pricing model (CAPM) was used to obtain a discount rate for calculating the current value of the investment in a solar boiler. The outcomes ranged from 6.9% to 11.73%. This range was also used in the sensitivity analysis for the ROV. The inputs gathered for the CAPM are summarized in Exhibit 2 and obtained as follows: A European energy industry beta derived from Damodaran (2009) was used as a proxy for the beta. The bond “NLRENT0%15JAN37” was the asset that matched the working life of the solar hot water system of 30 years the closest. Its rate of return is based on its quoted value on May 4, 2009 of €30.92 was 3.81% (IEX, 2009). This was used as the risk-free rate ($r_f$). Dimson, Marsh, and Staunton (2003) found that the arithmetic average market risk premium ($r_m - r_f$) measured against bonds for the Netherlands was 5.9%.

The Current Value of the Underlying Asset. With the inputs of Exhibit 2, the NPV of the underlying asset was calculated and varied between €860 and €4,805 depending on both the growth scenario and the applied discount rate. The mean NPV of the underlying asset was €2,833.
Volatility of the Underlying Asset

The seasonal volatility caused by the imbalance between hot water demand and solar heat supply is considered a short-term volatility that has no impact on the long-term volatility of the investment in a solar hot water system. This demand volatility, which constitutes a private risk, was therefore not included in the valuation.

From the historical annual natural gas price data of Exhibit 1, the volatility was calculated for different periods in the entire data period between 1980 and 2008. The volatility differs for each period. For example, the average annual volatility since 1980 until 2008 was 11%, but between 1980 and 1990 the volatility was as high as 16%. The lowest occurring volatility was 7% and the highest was 16%. As input for the model, the middle of this range was chosen, making the models’ annual volatility 12%. For the sensitivity analysis, the volatility was varied with increments of 20%, as can be seen on the horizontal axis of Exhibits 4 and 5. Exhibit 3 resumes the gathered model inputs.

Model Results

In this section the binomial method of CRR is briefly described and implemented. It is followed by a sensitivity analysis.\(^6\)

Binomial Model

The binomial model described here was built in a simple spreadsheet as an addition to an existing DCF spreadsheet template. The method is quite user-friendly and easy for practitioners to add to their valuation tools. The binomial method itself is easy to understand and use. The choice of inputs, however, requires a deeper understanding of the concept of discount rates and volatility since good input is essential for good output. The following describes the basic working of the binomial method (Exhibit 2).
According to the CRR binomial method, the value of the underlying asset follows a random walk and can move either up or down with each time step. The factors for respectively an increase and a decrease in value are described as:

- Increase or up-move: \( u = e^{\sigma \sqrt{\Delta t}} = 1.15 \).  
- Decrease or down-move: \( d = e^{-\sigma \sqrt{\Delta t}} = 0.87 \).

Where \( \sigma \) is the volatility; \( \Delta t = T/n \) is the time step; \( T \) is the time to maturity; and \( n \) is the number of time steps.

As illustrated in Exhibit 4, \( u \) and \( d \) determine the respective up and down movements in the binomial tree. The current value of the underlying asset \((S)\) at \( t = 0 \) is €2,833 (Exhibit 3). \( S_u \) and \( S_d \) are then obtained as follows:

- Increase: \( S_u = S = €2,833 \times 1.15 = €3,257 \).  
- Decrease: \( S_d = S = €2,833 \times 0.87 = €2,464 \).

Where: \( S_u \) is the value of the underlying asset after 1 move up; \( u \) is an increase or move-up factor; \( S_d \) is the value of the underlying asset after 1 move down; and \( d \) is a decrease or move-down factor.

The binomial tree for two time steps will then look like Exhibit 4. The option expires at \( t = 2 \) after 2.7 years or 32 months, which is December 31, 2011. Analogous \( t = 1 \) is 16 months after \( t = 0 \). The value of the underlying asset at \( t = 2 \) is \( S_2 \) minus the exercise price denoted as \( I \). As can be seen in Exhibit 5, the decision rule \( \max[0, S_2-I] \) gives the call option value at \( t = 2 \) of \( C_{uu} = €1,259 \), \( C_{ud} = 348 \) and \( C_{dd} = 0 \).
Exhibit 5 | Binomial Lattice–Call Option Value (C)–Folding Back

<table>
<thead>
<tr>
<th>t = 0</th>
<th>t = 1</th>
<th>t = 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>S_2</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>max [0, 3744-2485] = 1259</td>
<td>max [0, 2833-2485] = 348</td>
<td>max [0, 2143-2485] = 0</td>
</tr>
</tbody>
</table>

Where \( C_u \) is the call option value corresponding to the underlying asset value \( S_u \); \( C_d \) is the option value corresponding to the underlying asset value \( S_d \) and so on. \( S_2 \) is the asset value at \( t = 2 \), \( I \) is the exercise price. This tree was built in a spreadsheet.

The call option value \( C_{uu} \) corresponds to the value of the underlying asset \( S_{uu} \). The lattice was then folded back to obtain the value of the option at \( t = 1 \) and \( t = 0 \). Risk neutrality was assumed. This means that the outcomes for an up and down movement multiplied by their respective probabilities and summed are equal to the risk-free rate \( (r_f = 2.19\%) \). The probability of an upward move of the value of the investment in a solar hot water system is given by Equation 5. The call option values at \( t = 1 \), denoted by \( C \), are then obtained as in Equations 6 and 7.

\[
p = \frac{(e^{r_f \Delta t} - d)}{(u - d)} = \frac{(e^{0.0219 \times 1.35} - 0.87)}{(1.15 - 0.87)} = 0.573
\]

(5)

Where \( p \) is the risk-neutral probability; \( r_f \) is the risk-free rate of interest; \( \Delta t \) is the time step; \( u \) is the increase; and \( d \) is the decrease. The source is CRR (1979, p. 13).

\[
C_u = e^{-r_f \Delta t}(C_{uu} \cdot p + (1 - p)C_{ud}) \\
= 0.97(€1,259 \times 0.573 + (1 - 0.573)€348) = €844
\]

(6)

\[
C_d = e^{-r_f \Delta t}(C_{ud} \times p + (1 - p)C_{dd}) \\
= 0.97(€348 \times 0.573 + (1 - 0.573)€0) = €193
\]

(7)

Where \( C_u \) is the call option value corresponding to the value of the underlying asset after 1 move up \( (S_u) \); and \( C_d \) is the call option value corresponding to the value of the underlying asset after 1 move up \( (S_d) \).

The option value at \( t = 0 \) can be obtained in the same way from the two option values of the previous time step \( t = 1 \). Now that the option value \( C \) is known,
the homeowner can apply the decision rules of Exhibit 6. Payoffs between €0 and €300 were assumed to be amounts that would leave the investor in doubt as to whether to wait a bit longer or exercise immediately. This assumption is the authors’ subjective idea about the decision rules. These should always be agreed upon by those deciding on the investment.

The investment payoff (Equation 8) follows from the call option value \( C \) at \( t = 0 \), the exercise price \( I \), the subsidy, and the current value of the boiler system \( S \):

\[
S - I - C + \text{subsidy} = \text{€2,833} - \text{€2,485} - \text{€549} + \text{€600} = \text{€399}
\]  

(8)

The calculated investment payoff is €399. According to the investment decision rules, the call option is “deep in the money.” It pays to exercise the option immediately. In this medium growth scenario, it can be concluded that for the homeowner the option value he holds for postponing the investment is reasonably compensated by the subsidy amount. In the following section, the effect of different assumptions about the estimated inputs on the option value and the decision to invest in the solar hot water system are studied with sensitivity analysis. The binomial model shows that for the inputs of Exhibit 3, the subsidy is a reasonably sized carrot that should financially convince homeowners to invest.

**Sensitivity Analysis: Strategy Space**

The estimated inputs in this model are to some extent subjective. The assumptions and choices made to arrive at the estimates also reflect the subjective view of the person making them. The sensitivity analysis results are therefore displayed in a graphical form called a strategy or option space. Both Luehrman (1998) and Amram and Kulatilaka (1999) propose this sort of visualization to make intuitive decisions by management possible. This strategy allows the decision maker to see

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**Exhibit 6 | Investment Decision Rules**

<table>
<thead>
<tr>
<th>Investment Payoff</th>
<th>Option</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S - I - C + \text{subsidy} &lt; 0 )</td>
<td>Out of the money</td>
<td>Wait</td>
</tr>
<tr>
<td>( 0 \leq S - I - C + \text{subsidy} &lt; 300 )</td>
<td>In the money</td>
<td>Maybe invest</td>
</tr>
<tr>
<td>( S - I - C + \text{subsidy} \geq 300 )</td>
<td>Deep in the money</td>
<td>Invest</td>
</tr>
</tbody>
</table>

*Note: The source is authors’ own.*

\( S = \text{€2,833} \) = The current NPV of the solar boiler system.

\( I = \text{€2,485} \) = The exercise price of to acquire the solar boiler system.

\( C = \text{€549} \) = The value of the American call option on the solar boiler system.

\( \text{Subsidy} = \text{€600} \) = The subsidy amount offered to acquire the solar boiler system.
how different estimates and assumptions affect the option values. This should make the method suitable for designing stimulus measures for a green(er) built environment.

The discount rate was varied between 6.9% and 11.73%. The annual volatility was varied between 2% and 21% around its estimate of 12%. Exhibit 7 displays the option values for the range of discount rates and the variation of the volatility for this scenario. The call option value increases with increasing volatility and decreases with an increasing discount rate. The highest option value was found at the highest volatility of 21% and the lowest discount rate of 6.90%, while at the lowest volatility of 2% and the highest discount rate of 11.73% the call option value was zero. The option value of €549 obtained in Exhibit 5 was found for a discount rate of 7.32%. In Exhibit 7, this lies between the discount rates of 6.90% and 7.44% for the mean volatility of 12%. The value of €549 fits nicely between the option values of €494 and €687. Once the call option value is known, the investment payoff can be calculated (Equation 8).

According to the sensitivity analysis, an investment payoff with subsidy for the medium growth scenario (Exhibit 8) is highest for low volatility and low discount
rates. The highest payoffs occur in the lower left corner. A volatility of 5% and a discount rate of 7.44% give a payoff of €457.

The results of Exhibit 9 can now be translated to an option or strategy space by applying the decision rules in Exhibit 6. The strategy space in Exhibit 9 shows that when the payoff is negative, the option is “out of the money,” the homeowner should wait until, for instance, energy prices go up or higher subsidies or better technology appear.

A payoff between €0 and €300 for an investment is worth considering, as the option is now “in the money.” When the payoff is over €300, the option is considered to be “deep in the money” and should be exercised. If the decision makers agree on the decision rules, they can now see in the strategy space (Exhibit 9) whether their different views on volatility and discount rate still lead to the same decision.

When it is assumed that the mean values for all estimates are the most likely, then the payoff (Equation 8) for this medium growth scenario (6.6%) is such that the option is in the money or deep in the money for the majority of combinations. Based on Exhibit 9, the subsidized investment in a solar boiler is financially justified when the embedded real option is included in the valuation. The effect of the embedded real option is not clear at this point. In Exhibit 10, the strategy space for the same valuation without the embedded option but with classical DCF analysis is shown.

Both DCF and ROV agree that for higher discount rates, the investment has a negative payoff and should not be undertaken. For higher discount rates, the homeowner should wait until the investment becomes more viable. However, the strategy space in Exhibit 10 shows that when valued with DCF analysis, the homeowner can invest in more cases than when valued with the embedded option. The investment in a solar hot water system would sooner be financially justified.

The value of waiting was not captured by the DCF method. Based on the ROV results, the subsidy will likely have less effect than estimated by the DCF method. The latter will likely overstate the effect of the subsidy.
Survey Results: Homeowners’ Perceived Uncertainty

The binomial tree modeled the option value embedded in the investment in a solar hot water system based on market priced risk. The questionnaire amongst Dutch homeowners was aimed at establishing whether homeowners who are postponing investment do so because of a perceived option value based on market priced risk or for other reasons, which are also known as sources of private risk. Although the model indicates that the Dutch government subsidy program for solar hot water systems makes financial sense based on market priced risk, it is not very popular. Two years after the start of the program, only half of the funds have been applied for, whereas a different fund for photovoltaic cells was depleted within days. This may indicate that the private risks play an important role in the investment decision, as will be confirmed by the following survey results.

The total number of completed responses from homeowners was 100. The response rate was 30%. For the 95% confidence interval, the sampling error was 10%. The sample size was large enough to state that the responses were good estimates of the answers that the population would give.

At the onset of this questionnaire, the author expected that energy price uncertainty would be the main cause for homeowners to postpone investment. However, Exhibit 11 shows that amongst the motives homeowners had for postponing investment in a more energy-efficient home, the market priced risk was not the most important. They gave two main reasons for waiting to invest: (1) “I am waiting for technology to improve” and (2) “I expect to move within the next five years.” Overall, 38% of respondents preferred to wait until energy-saving technology improves. Homeowners apparently find technology development an important uncertainty; 27% of respondents believed they will move within the next five years and are therefore afraid they will not recuperate the entire investment before moving. This question was posed under the assumption that some or all of the cost of the system is sunk and cannot be recovered in the sale of the home.

As can be seen in Exhibit 11, only 11% of the respondents agreed that energy prices are an important uncertainty. The survey by Intomart GfK (2009) showed
that 10% of the respondents thought of rising energy prices when considering whether to invest in energy conservation measures and confirms the result of the present questionnaire. Energy prices may no longer be of serious concern to most of the public. Their drop in the wake of the current world-wide recession may have turned attention away from the energy price rises earlier in 2008. Advances in technology that may lead to a higher payoff, however, are clearly on the mind of homeowners contemplating investment in the energy efficiency of their home.

**Do the ROV and Survey Data Support Each Other?**

The ROV showed that under moderate estimates of the inputs into the model (Exhibit 3), the subsidized investment in the solar hot water systems was justified when the real option value was taken into account. The subsidy appears to compensate for the option value the homeowner has to give up for the investment. This conclusion is based on the market priced risk that was used in the binomial model. The survey results show that for homeowners the most important uncertainties that tend to make them wait are sources of private risk, as the market priced risk was not seen as the main source of uncertainty. The option value may be much higher when the private risks are incorporated into the model. This would explain to some extent the relative unpopularity of the current Dutch government
subsidy program for solar hot water systems. So to establish an effective subsidy, the effects of these private risks should be evaluated.

**Conclusion**

This study has made a first empirical attempt to link an established real option value and the consumers’ perception of uncertainty in investments in real estate. The study followed two lines of research. The first was to model the American call option on a solar hot water system with the binomial model of Cox, Ross, and Rubinstein (1979). The second line was to find out with a survey which uncertainties make homeowners postpone their investment.

The idea behind the methodology choices was to make the results transparent and suitable for intuitive interpretation. This was mainly inspired by Amram and Kulatilaka (1999) and Copeland and Tufano (2004). The binomial lattice is similar to a decision tree. The step from this well-known decision tool to the binomial tree is small, making it easy to understand. The tree was built with algebraic equations and could be added to existing DCF spreadsheets. It was shown that the classical DCF approach can overstate the effect of a subsidy. Including the real option value gives a more realistic idea of the effects a subsidy will have. The study effectively showed that ROV does take the value of waiting into account, where DCF does not. The present application of the binomial model has demonstrated its user friendliness and transparency. Strategy spaces have proven to provide an excellent visual presentation of the sensitivity analysis results and make intuitive decisions possible. The combination of chosen methods proved efficient, transparent, and accessible for practitioners.

The survey results showed that homeowners did not see the market risk of the energy price as the most important source of uncertainty. This was also confirmed by the results of the recent survey by Intomart Gfk (2009). In fact, homeowners found sources of private risk such as the uncertainty about technological development and the chance that they will move homes before recuperating their investment of more importance. These private risks and perhaps others that the survey did not cover should be included in the model to be able to say whether the subsidized investment in solar hot water systems makes financial sense to homeowners. Including them may cause volatility to rise considerably, which will lead to higher option values. This would explain to some extent the lack of popularity of the current Dutch government subsidy program.

The results show that real option valuation is indeed a powerful tool to value investment under uncertainty and to design policy interventions. The use of a binomial model and strategy spaces combined with surveys appears suitable for practitioners that design or evaluate incentive policies. This new method for designing a carrot or stimulus measure with help of real option valuation should be further explored. It follows these steps:

1. Establish the type of real option the investment opportunity holds.
2. Determine the exercise price, the time to maturity, and the risk-free rate.
3. Establish the current value of the underlying asset. That is the value of the investment in, for example, a solar panel when it is made today.
4. Assess with a survey which uncertainties potential investors worry about.
5. Determine an appropriate volatility, preferably with market priced proxies.
6. Build and run a binomial model and display the results in a strategy space.
7. Decide on an appropriate stimulus.
8. Verify with a second survey whether the stimulus is likely to have the desired effect.

The current fiscal deficits of governments around the world, as well as the need and desire for a greener built environment make it important that stimulus money is allocated as optimal as possible. Testing the stimulus viability with the method described in this paper could lead to better and more effective stimulus design and ultimately perhaps to a greener built environment.

Endnotes

1 Dutch households are not exposed to the market volatility of natural gas but face biannual price adjustments by the energy providers. The annual volatility experienced by Dutch households is therefore much lower than the volatilities at the Henry Hub in the United States.

2 A solar hot water system is an installation that consists of a solar collector with tubing connecting it to a heat exchanger in a boiler barrel. The collector is located outside on the rooftop or in the yard where it has maximum exposure to the sun. The boiler can be attached to the collector or located inside the building. The solar heat is transferred from the collector through the heat exchanger to the boiler barrel. The reservoir of hot water is attached to the tap water system of the building.

3 The Black-Scholes formula is a partial differential equation that provides an analytical solution to European options. This type of option can only be exercised on the expiry date, contrary to the so-called American option. An American call option can be exercised at any time until it expires, contrary to a European call option, which can only be exercised on the expiration date.

4 Per household the ownership of the home may be shared, therefore the actual number of homeowners is likely to be larger, but this was not taken into account in this study.

5 Little information was found about the actual working life of the system but estimates range between 20 and 30 years. Deege, Warmerdam, and Zegers (2006) found that the capacity of solar boiler systems hardly declines after 10 years of service. Their data were based on actual field measurements of working systems and indicate that economic working lives of 30 years are quite realistic. For the present study, it was therefore assumed that the 175 m³ will remain constant throughout 30 years of working life.

6 The option values displayed in Exhibit 5 are values for a binomial tree with only two time steps. The tree can also be expanded to many more time steps. The more time steps, the higher the accuracy of the call option value at \( t = 0 \) becomes. In this sensitivity analysis, a binomial lattice with 32 time steps was used (Van der Maaten, 2009).

References


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