Empirical Patterns of Time Value Decay in Options

Ryan McKeon
Department of Finance
School of Business Administration
University of San Diego
Olin Hall 112
5998 Alcala Park
San Diego, CA 92110
Phone: +1 (619) 260 7868
E-mail: rmckeon@sandiego.edu

I conduct and empirical analysis of the pattern of time value decay in listed equity options, considering both call and put options and various degrees of moneyness for both classes of options. I find that empirical patterns differ from model or theory based predictions in important ways. While model-based simulations commonly predict slow decay in time value with rapidly accelerating decay as the option approaches expiry, the empirical results show that time value decay is often very rapid early in the holding period of an option. This result holds regardless of holding period duration (30, 60 and 90 days are considered) and moneyness. Further analysis reveals the differences between empirical results and model-based predictions are largely due to changes in stock price during the holding period, with deviations in the market price of the option from model-based prices being a minor factor. The only options to exhibit rapidly accelerating time value decay are out-the-money calls or puts purchased in low-volatility environments. I discuss the implications of these results for the management of option positions.

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This paper studies the behavior of option time value, using empirically observed option prices to obtain the time value. I find that time value decay is steadier over time than previously noted in books or studies that rely on the *ceteris paribus* assumption to derive option time value, or those that rely on model-generated prices of the underlying asset to infer the option time value. This has implications for the timing of when to roll over option positions and for selecting the maturity of option contracts when initially setting up trades.

Financial options are well known to be a "wasting" asset, meaning that all else equal the value of the option will decline as time passes and the option approaches its expiry date. However, this predictable decline in value relies heavily on the *ceteris paribus* assumption, which typically does not hold. Most notably, the price of the underlying asset typically changes significantly with the passage of time, and the price of the underlying asset is a strong influence on the option price.

Tannous and Lee-Sing (2008) models the time value decay of put options using a simulation based on model-generated prices for the underlying asset. This procedure is highly effective in considering the effect that changes in the price of the underlying asset have on the option price while time is passing. The paper finds that time value decay can be substantial for time periods more than a month prior to option maturity. This result is in stark contrast to well-known textbook diagrams of time value decay *ceteris paribus*, which show that time value changes are typically trivial until an option is within two weeks of expiry. Tannous and Lee-Sing, by contrast, show that a significant portion of time value decay for a 90-day option can be expected to take place between 90 and 60 days prior to expiry.

Studying option time value decay via simulation has obvious weaknesses however. Specifically, the price of the underlying asset is modelled and the model will likely not match the behavior of actual financial assets precisely. Furthermore, the options must be priced with a model

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which, again, will not always precisely match the pricing of options in actual markets. In this paper I study option time value decay using closing prices of listed stock options reported and recorded by Optionmetrics.

For a variety of different maturities, 30-, 60- and 100-day options, both call and put options, and a variety of different moneyness ranges, I study the empirical patterns of time value decay. In all cases, the same option is held for the entire period without its classification being changed. In other words, once an option is classified as, for example, at-the-money, it maintains that classification for the remainder of the holding period.

I find a consistent result that time value decay is more rapid earlier in the holding period than predicted by standard models of option pricing and reported in various textbooks. This pattern holds for calls and puts, and options of all maturities and moneyness levels. The only options to exhibit the well-known and widely accepted pattern of accelerating decay as expiry approaches are out-the-money calls or puts initially purchased in very low implied volatility environments.

The findings in the paper have importance for managing options portfolios, specifically the choice of options for various strategies in terms of maturity, and for the frequency of rolling over positions. I discuss the implications of the results for these risk management issues.

Theory on Time Value Behavior

This section summarizes the things we know about time value and how time value behaves according to models of option pricing. This section also discusses the importance of understanding time value behavior and the implications for managing option investments.

Behavior of Time Value Based on Models

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The most well-known features of time value behavior are the *ceteris paribus* pictures of time value behavior over time. This pattern is well known for the feature of time value decay significantly increasing as option expiry date approaches. Theta is the traditional measure for the sensitivity of the option price to the passage of time and is given by:

$$\theta = \frac{dC}{dT} = -\frac{S_0 N'(d_1)\sigma}{2\sqrt{T}} - rXe^{-rT}N(d_2)$$

$$\theta = \frac{dP}{dT} = -\frac{S_0 N'(d_1)\sigma}{2\sqrt{T}} + rXe^{-rT}N(-d_2)$$

where θ is the symbol for theta, the sensitivity of option price to the passage of time[1], *C* is the price of a Call option, *P* the price of a Put option, S_0 the current stock price, σ the expected volatility in the returns of the stock price during the life of the option, *X* is the option strike price and *T* the amount of time remaining until the options expires express as a fraction of a year. $N'(d_1)$ is given by:

$$N'(d_1) = \frac{1}{\sqrt{2\pi}} e^{-(d_1)^2/2}$$

where:

$$d_1 = \frac{In(S_0/K) + (r + \sigma^2/2)T}{\sigma\sqrt{T}}$$

$$d_2 = d_1 - \sigma\sqrt{T}$$

and *N(x)* indicates the cumulative normal distribution of *x*.

Figure 1 illustrates the sensitivity to the passage of time for in-, at- and out-the-money Call options based on the above equations for theta (which are derived from differentiating the

[1] Interpretation of theta can often be confusing. Some describe time value decay as “positive” theta since a decrease in the amount of time remaining on the option results in a decrease in the price of the option *ceteris paribus (*in other words, the effect is in the same direction). Others describe time value decay as “negative” theta since the passage of time results in a decrease in option price *ceteris paribus.* This paper follows the latter convention in referring to time value decay as negative theta.

famous Black-Scholes equation for the value of an option with respect to time.[2]) The chart is produced by calculating theta for the Call options in both a high-volatility and low-volatility environment. All factors are then held constant besides the number of days remaining until the option expires. Days remaining until expiry is plotted on the horizontal axis.

Reading from right to left, and recalling that a more negative theta indicates a strengthening of the option price's sensitivity to the passage of time, we see general confirmation of the well-known result that time value decay accelerates as expiry approaches. Four out of the six cases considered exhibit patterns of theta consistent with time value decay increasing as expiry approaches. The two exceptions are in- and out-the-money Call options in low volatility environments. For these two types of options and that specific volatility environment, theta is weak at all points in time and weakens further as option expiry approaches.

Theta provides us with the expected change in the Dollar value of the option as time passes. However, the Dollar change does not necessarily provide us with the best insight into the significance of the time value decay when there is no comparison to the original price of the option. Figure 2 illustrates the results of plotting the ratio of time value to option price over time. For each point in time the ratio T_t/C_0 is calculated and depicted in the chart (where T_t is the time value of the option at time t, and C_0 is the Black-Scholes price of the Call option at time 0). This ratio provides an indication of the effect of time value decay on the returns an option trader can expect to receive on the option position.

In Figure 2, the effect of time value decay confirms the key features identified by the analysis of theta in Figure 1. Out-the-money options in low volatility environments show a clear pattern of early time value decay, with time decay weakening as we approach expiry. In-the-

[2] See Black and Scholes (1973).

money options in low volatility environments exhibit a constant rate of time value decay. The other four options studied all exhibit the well-known pattern of time value decay accelerating as expiry approaches.

The behavior of time value has important implications for a number of aspects of managing option investments. Specifically, the behavior of time value directly affects the choice of option maturity when first establishing a trade, affects the frequency with which positions are rolled over prior to the expiry of the option, and has relevance to issue of how profitable trading of out-the-money options is.

Choice of option maturity and rollover frequency

The pattern of time value decay in options has great significance for the frequency with which positions are rolled over. Under the standard understanding that time value decay accelerates as the expiry of an option approaches, holders of long positions in options would typically be looking to hold the option long-term and roll over the position relatively close to the expiry date before the late acceleration of time decay. By contrast, holders of short positions looking to profit from the time value decay would need to hold the positions all the way to the expiry date, with the majority of profits being realized in the days immediately prior to option expiry.

However, the results reported in this paper imply the opposite. With time value decay being found to occur very early in the holding period of the options trade, this implies that investors with short positions will realize the bulk of any profits very early in the holding period of any trade. Therefore, more frequent rollover of trades, far ahead of expiry, would appear optimal. This, of course, needs to be weighed against the increased costs of trading related to more frequent rollovers.

By contrast, holders of long positions would appear to have little incentive to roll over positions well ahead of expiry under these results. With the bulk of time value decay occurring early in any holding period, there appears little opportunity for option buyers to avoid the majority of the costs of time value decay. Therefore, exact timing of rollover becomes less important and minimizing costs of trading becomes the only goal.

Profitability of out-the-money options

A well-documented feature of options performance is that out-the-money options, both calls and puts, deliver strong negative returns which are below the returns predicted by standard asset pricing models. Bondarenko (2003) and subsequent papers document the negative returns to out-the-money puts, and Ni (2009), McKeon (2013) and related papers cited therein document the negative returns to out-the-money calls, in stark contrast to the strong positive returns predicted by standard asset pricing theory (as outlined in Coval and Shumway (2001)).

The surprising negative returns which have been documented for out-the-money options rely on analysis of the data which assumes a certain holding period over which the options have been bought and hold. However, the question arises: what about the time in between the simulated buying and selling conducted on these papers? Is it possible that a vigilant options trader might find opportunity to close out the position in the middle of the holding period for a profit? This could be the case if temporary short-term spikes in implied volatility increase the value of the option in the short-term. For an out-the-money option which remains out-the-money during such a period of elevated implied volatility, this would essentially amount to a short-term increase in time value which elevates time value above the original time value when the option was bought.

Empirical Patterns of Time Value Behavior

Data and Methodology

Data for this study comes from the Optionmetrics database. The data starts in 1996 and I use all data from that year to the present. I compile all call and put options which have T days remaining to expiry (in the paper I consider 30, 60 and 100 for T). I separate the data into in-, at- and out-the-money options by calculating K/S_0, where K is the option strike price and S_0 is the stock price at time 0. At-the-money options are those where the stock price is within 1% of the strike price, and in- and out-the-money options are those between 4% and 6% from the strike price.

I collect data for each day for each option for closing bid, closing ask and closing price of the underlying asset. I also collect the reported implied volatility for later analysis of the effect of volatility environment. At each point in time, time t, I calculate the percentage time value based on the option premium minus intrinsic value. The option premium is considered to be the midpoint of the reported closing bid and ask prices, and intrinsic value is calculated based on the reported closing stock price.

The time value included in all analysis in the paper is then: $[TIME_t / C_0] \times 100$. In other words, the time value considered in the paper is the time value as a percentage of the original option premium. This gives us the best measure of the effect of time value on an investor's profit or loss on the option trade.

Results

Figure 3 reports the results for the time value decay of 100-day call options. Again, the time value reported is the time value at any point in time as a percentage of the original option premium. Therefore, for at- and out-the-money options, this number is 100 at time 0 since intrinsic value is $0 for these options and the entire option premium comprises time value. For in-the-money options, the time value is approximately 50% of the option premium at the start of the holding period, although there is considerable cross-sectional variation in this.

The pattern of time value decay comes closest to conforming to the textbook versions for out-the-money calls. Figure 3 reports a relatively stable pattern of time decay of the holding period, but there is a minor increase in the decay as expiry approaches. In-the-money and at-the-money calls, by contrast, exhibit the strongest level of decay early in the holding period, with initial rates of time value decay clearly comparatively strong. This pattern is particularly pronounced for the at-the-money calls, and mild for the in-the-money calls.

Figures 4 and 5 report further patterns of time value decay for call options of various moneyness levels, this time for 60-day calls and 30-day calls respectively. The pictures reported in these figures is consistent with the charts in Figure 3, with the increasing rate of time decay for out-the-money calls being more pronounced for these shorter holding periods.

Figures 6, 7 and 8 report the patterns of time value decay for put options over holding periods of 100, 60 and 30 days respectively. The patterns of time value decay reported in these figures is very consistent with the patterns reported for call options. As with calls, the at-the-money puts exhibit a very strong pattern of early time value decay, with the rate of time value decay as the options approach expiry comparatively weak. In-the-money puts display a very uniform, stable pattern of time value decay. There is little clear evidence of time value decay increasing or decreasing in rate at any point during the holding period. This would suggest that for traders holding in-the-money puts, time decay would be no factor at all in the decision of when to roll the contract over. The goal of the investor can simply become minimizing trading costs by rolling over as infrequently as possible.

Out-the-money put options display a relatively stable pattern of time value decay similar to at-the-money puts. However, in contrast with at-the-money puts, there is some evidence of the rate of decay increasing as expiry approaches.

To summarize the findings, the widely accepted pattern of time value decay rapidly increasing as expiry approaches is not evident in the empirical data. Out-the-money calls and puts reveal mildly increasing rates of time value decay as expiry approaches. However, in- and at-the-money calls and puts do not, with at-the-money options in fact exhibiting rapid time value decay early in the holding period. These patterns of time decay hold regardless of the maturity of option contract. This suggests that option maturity is not a particularly important consideration in choice of option contract, other than its impact on rollover frequency. Rollover frequency would, of course, be less frequent for an investor trading long-term options and holding them to the expiry date.

Effect of Volatility

The volatility environment has a significant effect on time value decay. Simply, time value can only exist if there is some level of volatility in the price of the stock, since time value captures the possible changes in the current state of the asset between the present and expiry. If there is no volatility in the price of the asset then the passing of time will not lead to any future values significantly different to today's price, regardless of how much time passes. Therefore, the amount of time remaining until the option expires works with volatility in forming time value.

In Figure 9, I repeat the previous empirical analysis of option time value decay, but restrict the analysis to options in a high or low implied volatility environment. Figure 9 reports the pattern for 30-day out-the-money call options, but the pattern is similar for 60- and 100-day out-the-money calls. At the beginning of each holding period I note the reported implied volatility for all options and rank them from highest to lowest. Low IV calls are those options falling in the lowest quintile, high IV calls those falling in the highest quintile.

Figure 9 reveals some very interesting facts. Previous charts revealed that out-the-money calls did conform to the accepted pattern of time value decay accelerating as expiry approaches. Figure 9 reveals that this is driven by the pattern of time value decay of OTM calls originally acquired in low IV states. In fact, low-IV calls even exhibit *increasing* time value during the early stages of the holding period. This finding has significance for the literature on returns of out-the-money options.

As previously noted, research has consistently found that returns to out-the-money options are very low. This is true for both Call options (McKeon 2013, Ni 2009, Wilkens 2007) and Put options (Bondarenko 2003). However, a limitation of all such studies is that they specify a particular holding period for the computing the returns, for example one month or one week. The results in Figure 9 suggest that there may be opportunities within such holding periods for an active trader to close out positions in OTM calls for a profit. This appears especially true for calls traded with low IV levels. This suggests that further study on out-the-money call and put returns should more closely examine short-term speculative strategies designed to profit from mean reversion in IV levels from comparatively low levels.

The initial increase in time value for low-IV OTM calls also then explains the rapid increase in time value acceleration as the options approach the expiry date. This is obviously necessary to have the time value reach zero at expiry. High-IV OTM calls do not exhibit any noticeable increase in time value decay as option expiry approaches. Indeed, the pattern of time value decay appears quite stable over time.

Figure 10 reports the pattern of time value decay for at-the-money 30-day calls. The results reported here are similar for ATM calls of 60- and 100-day maturities too. The previous analysis revealed that ATM calls exhibit very strong time value decay early in the holding period. Figure 10 shows that this pattern is largely driven by ITM calls acquired in high-IV environments. The pattern of strong early time value decay is apparent, but not strong, for low-IV ATM calls.

Figure 11 reports the pattern of time value decay for in-the-money 30-day calls. The results reported here are similar for ITM calls of 60- and 100-day maturities too. These charts reveal that the pattern of time value decay is largely stable for ITM calls. For low-IV calls, there is some evidence of early time decay being very weak and increasing over time, and for high-IV ITM calls there is some evidence of time value decay being strong early and then decreasing over time. However, in neither case is this pattern particularly dramatic.

Figures 12, 13 and 14 report the patterns of time value decay for put options in low and high IV environments. The results reported are very similar to the patterns of the corresponding calls options. One minor difference is that for low-IV ITM put options, the pattern of increasing rates of time value decay is more pronounced than it was for low-IV ITM calls.

Size of Time Value Deviations from Predicted

The charts previously discussed reveal the general pattern of time value decay in a variety of different option contracts and environments. In particular, the charts reveal how rare it is for option time value decay to accelerate as the expiry date of the option approaches, with only the specific case of OTM options acquired in low-IV environments exhibiting this feature. This subsection examines the average differences in the empirical time values for each time t, in order to specifically quantify the deviation in time value from that predicted. There are two benchmarks used to compare empirical time value to. The first is time value based on a constant rate of time decay. The second is time value computed by Black-Scholes under the assumption that the only parameter that changes over the course of the holding period is the amount of time remaining until maturity.

The results reported in Table 1 clearly show the dramatic difference between empirical time value levels and those predicted by the two models. Compared to the model of constant time value decay, the 60-day ATM call options exhibit time value that decays very rapidly early in the holding period. Column 5 reveals that large differences in time value emerge immediately after implementation at time 60, with the empirical time value significantly lower than the constant decay model by more than 15% at many points. Interestingly, the difference does turn positive ten days prior to expiry, showing that time value decay does slow substantially and that there is some increase in time value decay in the ten days prior to expiry. This raises the question of whether this late increase in time decay is then consistent with the generally accepted pattern of time decay.

Column 6 provides further insight on this question by reporting the difference between empirical time value and the time value obtained by Black-Scholes using the original stock price and IV level, and the current number of days remaining until expiry. These results confirm that empirical time value is much lower than that predicted by the model early in the holding period.

However, these results now also reveal that empirical time value remains below the Black-Scholes prediction for the entire holding period.

Implications

As noted earlier, the behavior of time value decay has important implications for the setup and management of options positions. Specific trading practices that are highly influenced by consideration of time value decay include long option positions, naked put writing, covered calls and protective puts.

In the case of long option positions, the investor is either attempting to profit from an increase (call option) or decrease (put option) in the price of the underlying asset. From the option buyer's point of view, time value is a cost as this value will diminish over time until the option reaches maturity. This is consistent with the well-known feature of options as a wasting asset, or an investment with negative carry. Therefore, the question arises as to when the option buyer would want to roll the contract over.

Conventional wisdom suggests rolling the contract prior to the expiry date to avoid the bulk of the time value decay, since this is expected to occur late in the trade as the contract approaches expiry. However, the results reported in this paper show that time value decay can be expected to occur early in the holding period of the trade. Therefore, closing or rolling over the position prior to expiry should not be a major concern of the trader, since the costs of time value decay are largely unavoidable and will have already been mostly realized well prior to option expiry.

The exception is the trader who is speculating in out-the-money options. In this case, the results reported in this paper suggest that the trader should close out or roll the position well prior to expiry, as soon as the contract delivers a profit. The pattern of time value for OTM options, particularly in low-IV environments, reveals that any opportunity for profit will come early in the holding period of the trade, and will be followed by dramatically accelerating time value decay if not taken advantage of at that time.

Naked put writers and sellers of covered calls face the same challenge: they attempt to profit from time value decay by selling the option and then having it expire out-the-money or selling it prior to expiry for a profit. Therefore, the pattern of time value decay and when it can be expected to decline most rapidly is of tremendous importance to writers of puts and covered calls.

Conventional wisdom suggests option writers need to hold those positions all the way to the expiry date to realize the bulk of the time value decay, since this is expected to occur late in the trade as the contract approaches expiry. However, the results reported in this paper show that time value decay can be expected to occur early in the holding period of the trade. Therefore, put writers and covered call writers should look to roll over positions frequently as the majority of their profits will be realized early in the holding period of the options. Of course, this advice needs to be considered along with the increased trading costs of more frequent rollovers.

Protective Puts are designed to protect the investor from decreases in the price of the asset and essentially act as investment insurance. Therefore, the put premium represents the cost of insurance for the buyer of a protective put and the trader is naturally concerned with minimizing the cost of that insurance. The basic tradeoff considered by the investor is that a higher strike price on the put provides better protection, but comes with a higher premium. The results reported in this paper reveal a further cost to puts with a higher strike price: these puts (at- or in-the-money) are the contracts which exhibit the earliest decay in time value. Therefore, not only does the higher strike price mean a higher premium for the investor, but the investor can also expect the time value of the option to decay very early and rapidly. This would appear to strengthen a case for use of out-the-money puts as protection, even though the lower strike price provides less protection against a price decline in the asset than the higher option strike prices.

Conclusion

I conduct and empirical analysis of the pattern of time value decay in listed equity options, considering both call and put options and various degrees of moneyness for both classes of options. I find that empirical patterns differ from model or theory based predictions in important ways. While model-based simulations commonly predict slow decay in time value with rapidly accelerating decay as the option approaches expiry, the empirical results show that time value decay is often very rapid early in the holding period of an option. This result holds regardless of holding period duration (30, 60 and 90 days are considered) and moneyness.

Further analysis reveals the differences between empirical results and model-based predictions are largely due to changes in stock price during the holding period, with deviations in the market price of the option from model-based prices being a minor factor. The only options to exhibit rapidly accelerating time value decay are out-the-money calls or puts purchased in low-volatility environments.

The results reported in the paper suggest that the costs of time value decay are largely unavoidable for option buyers, especially those buying in- or at-the-money options. Speculators in out-the-money options should be prepared to take any profits early in the holding period of trades. Results suggest that the very poor returns previously reported for out-the-money calls and puts might be mitigated by restricting trading to options with low implied volatility at the time of acquisition.

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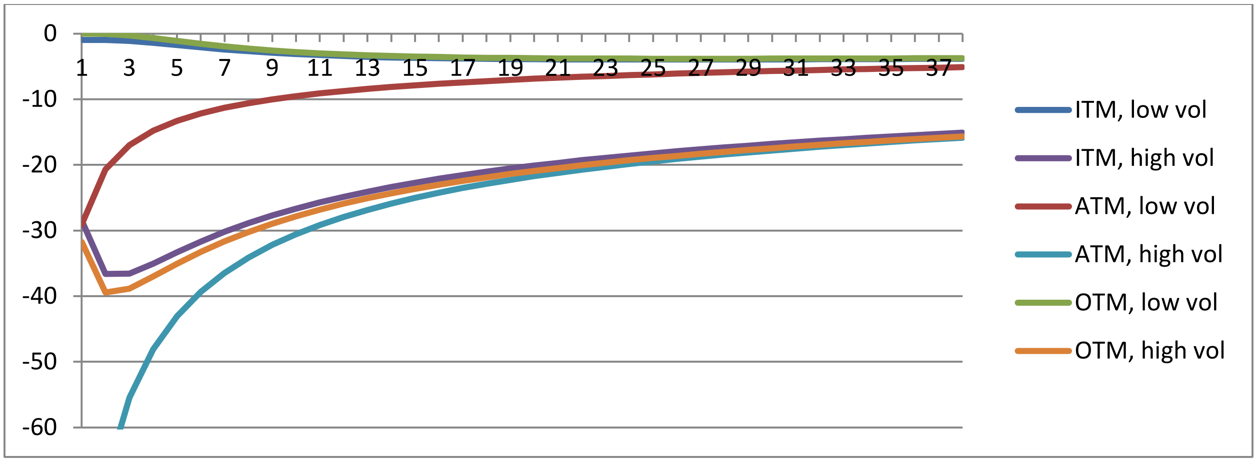


Figure 1: theta as a function of days to option expiry for call options

The figure shows theta for call option contracts of various moneyness classifications and implied volatility levels as a function of the number of days remaining until option expiry. Other than the number of days remaining until expiry, all other variables are held constant. The time value is calculated by the Black-Scholes model, and the parameters used are S_0=\$50, K=\$48 / \$50 / \$52 (for in-, at- and out-the-money respectively), R_f = 2%, σ = 15% / 50% (for low and high volatility environments respectively).

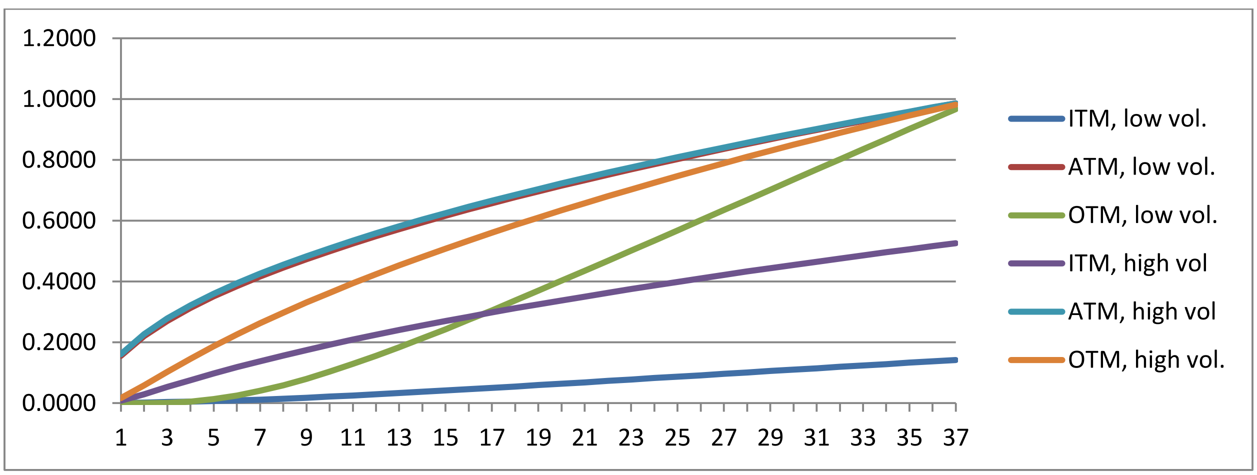


Figure 2: time value as a function of days to option expiry for call options

The figure shows time value as a percentage of the original option price (C_0) for call option contracts of various moneyness classifications and implied volatility levels as a function of the number of days remaining until option expiry. Other than the number of days remaining until expiry, all other variables are held constant. The time value is calculated as T_t/C_0, where T_t is the time value at time *t* and C_0 is the original option premium, using the Black-Scholes model. The parameters used are S_0=\$50, K=\$48 / \$50 / \$52 (for in-, at- and out-the-money respectively), R_f = 2%, σ = 15% / 50% (for low and high volatility environments respectively).

Figure 3: 100-Day Call options

The following three charts illustrate the pattern of time value decay for 100-day Call options of various moneyness levels. In each case the same option contract is tracked for the full 100 days after being classified as in-, at- or out-the-money. In other words, this classification is based on the initial status of the option and may have changed by day 0.

ITM ATM OTM

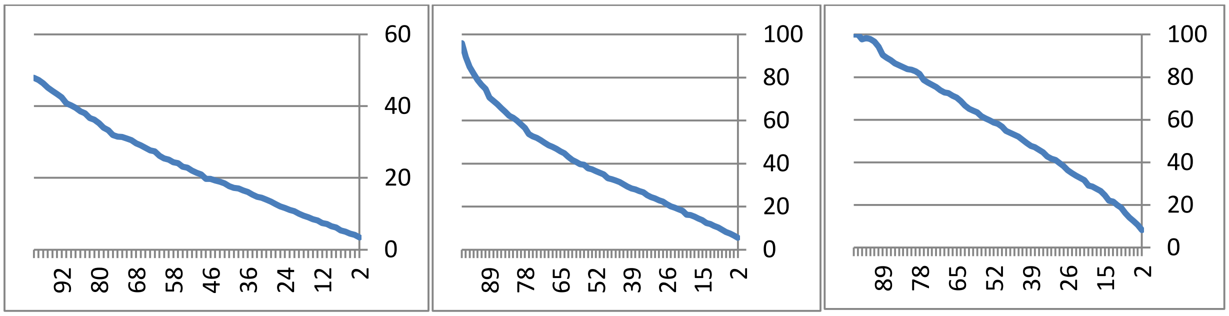


Figure 4: 60-Day Call options

The following three charts illustrate the pattern of time value decay for 60-day Call options of various moneyness levels. In each case the same option contract is tracked for the full 60 days after being classified as in-, at- or out-the-money. In other words, this classification is based on the initial status of the option and may have changed by day 0.

ITM ATM OTM

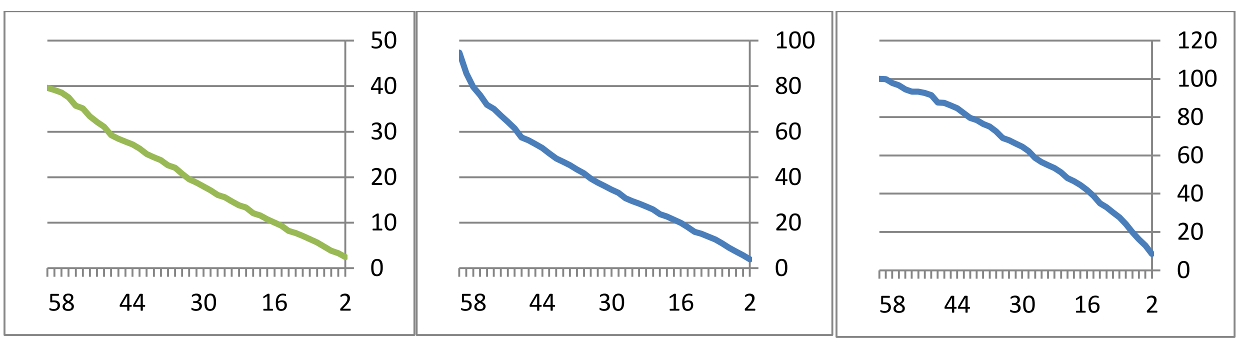


Figure 5: 30-Day Call options

The following three charts illustrate the pattern of time value decay for 30-day Call options of various moneyness levels. In each case the same option contract is tracked for the full 30 days after being classified as in-, at- or out-the-money. In other words, this classification is based on the initial status of the option and may have changed by day 0.

ITM ATM OTM

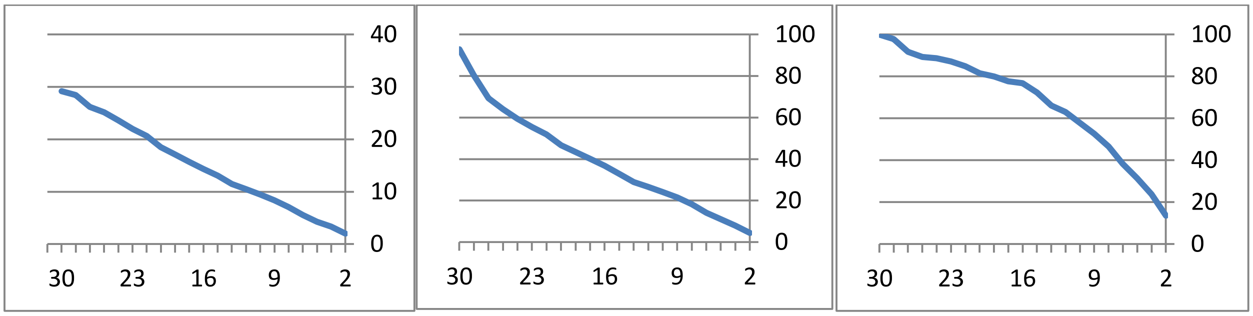


Figure 6: 100-Day Put options

The following three charts illustrate the pattern of time value decay for 100-day Put options of various moneyness levels. In each case the same option contract is tracked for the full 100 days after being classified as in-, at- or out-the-money. In other words, this classification is based on the initial status of the option and may have changed by day 0.

ITM ATM OTM

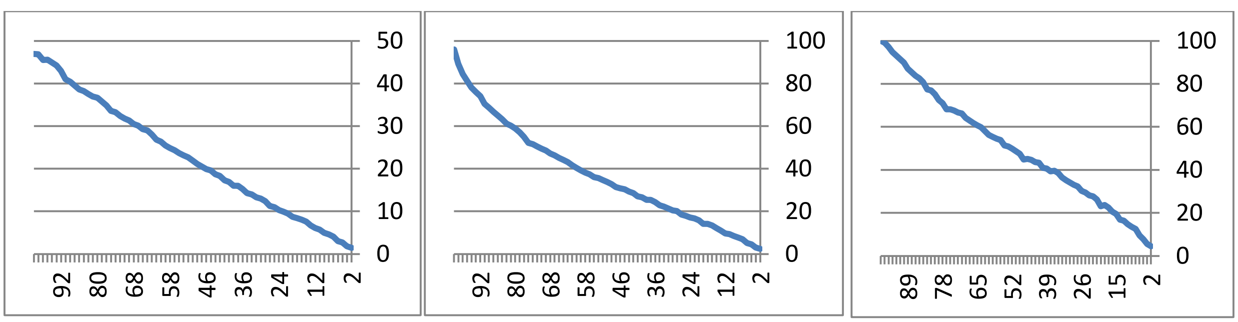


Figure 7: 60-Day Put options

The following three charts illustrate the pattern of time value decay for 60-day Put options of various moneyness levels. In each case the same option contract is tracked for the full 60 days after being classified as in-, at- or out-the-money. In other words, this classification is based on the initial status of the option and may have changed by day 0.

ITM ATM OTM

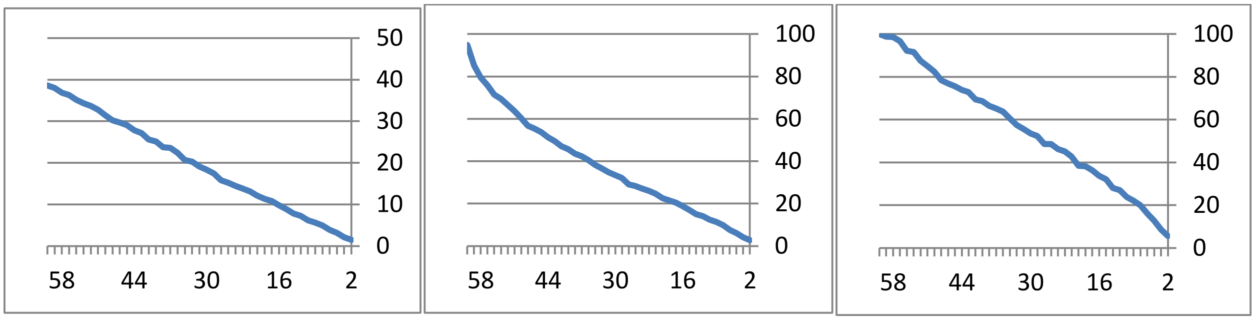


Figure 8: 30-Day Put options

The following three charts illustrate the pattern of time value decay for 30-day Put options of various moneyness levels. In each case the same option contract is tracked for the full 30 days after being classified as in-, at- or out-the-money. In other words, this classification is based on the initial status of the option and may have changed by day 0.

ITM ATM OTM

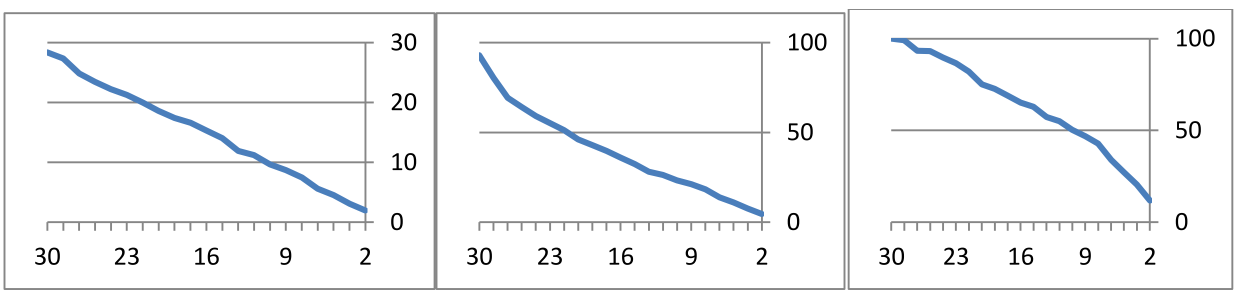
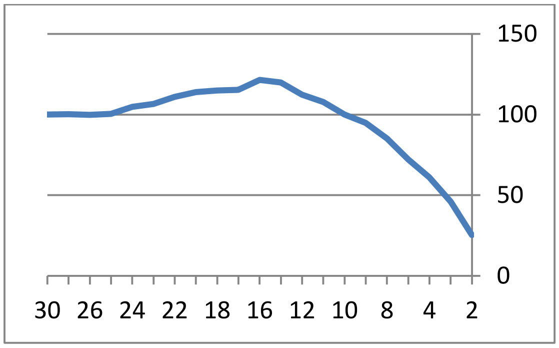


Figure 9: OTM Call options

The following two charts illustrate the pattern of time value decay for 30-day Out-The-Money Call options of in different volatility environments. Volatility is classified as high or low based on the implied volatility of the option at the 30-day mark. Volatility groups are created by evenly dividing the options into the two groups based on this initial implied volatility level.

Low IV



High IV

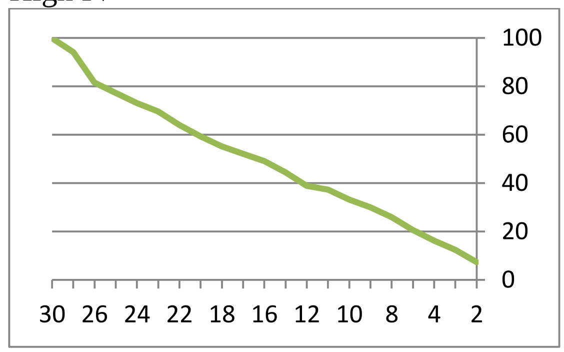
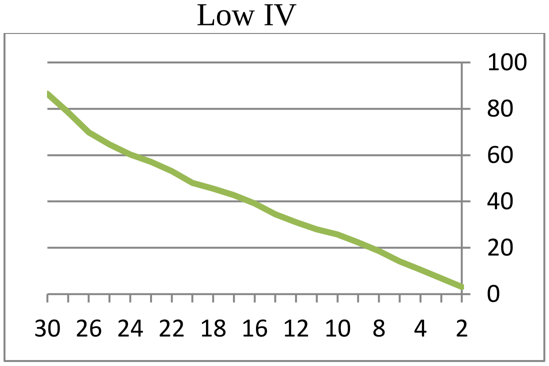


Figure 10: ATM Call options

The following two charts illustrate the pattern of time value decay for 30-day At-The-Money Call options of in different volatility environments. Volatility is classified as high or low based on the implied volatility of the option at the 30-day mark. Volatility groups are created by evenly dividing the options into the two groups based on this initial implied volatility level.

Low IV



High IV

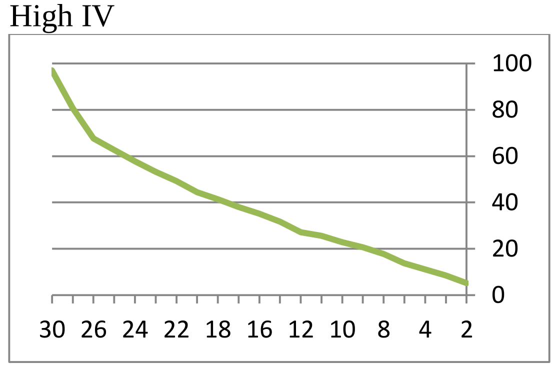
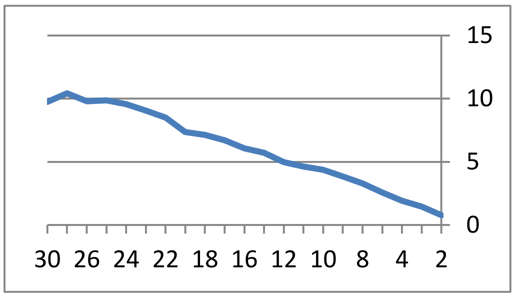


Figure 11: ITM Call options

The following two charts illustrate the pattern of time value decay for 30-day In-The-Money Call options of in different volatility environments. Volatility is classified as high or low based on the implied volatility of the option at the 30-day mark. Volatility groups are created by evenly dividing the options into the two groups based on this initial implied volatility level.

Low IV



High IV

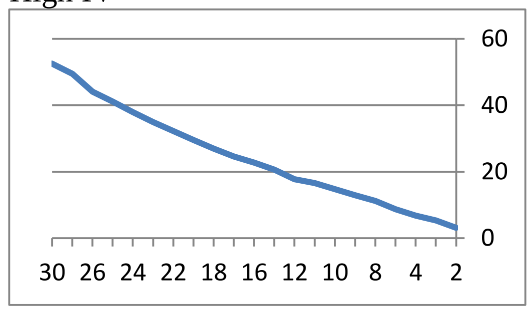
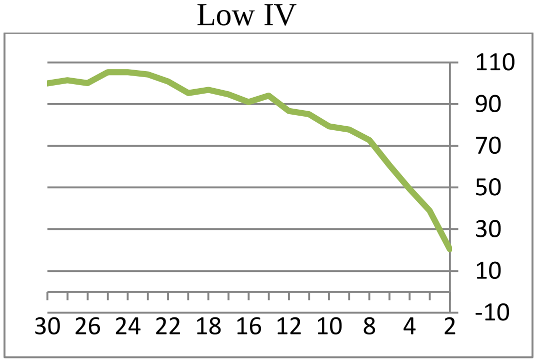


Figure 12: OTM Put options

The following two charts illustrate the pattern of time value decay for 30-day Out-The-Money Put options of in different volatility environments. Volatility is classified as high or low based on the implied volatility of the option at the 30-day mark. Volatility groups are created by evenly dividing the options into the two groups based on this initial implied volatility level.

Low IV



High IV

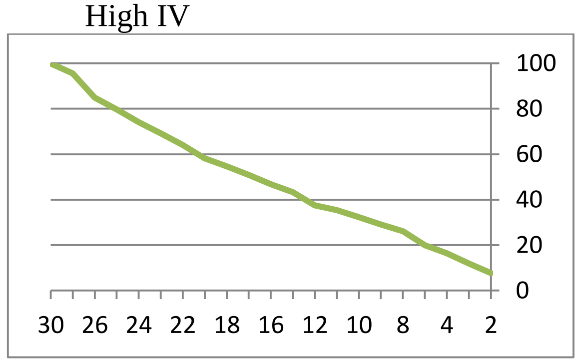
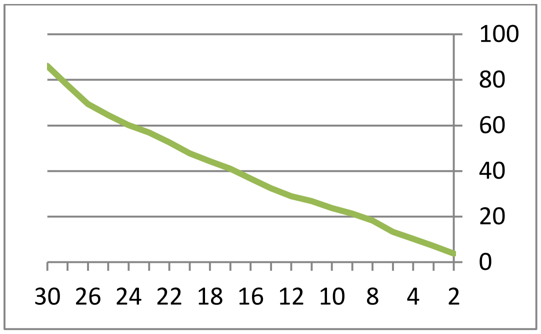


Figure 13: ATM Put options

The following two charts illustrate the pattern of time value decay for 30-day At-The-Money Put options of in different volatility environments. Volatility is classified as high or low based on the implied volatility of the option at the 30-day mark. Volatility groups are created by evenly dividing the options into the two groups based on this initial implied volatility level.

Low IV



High IV

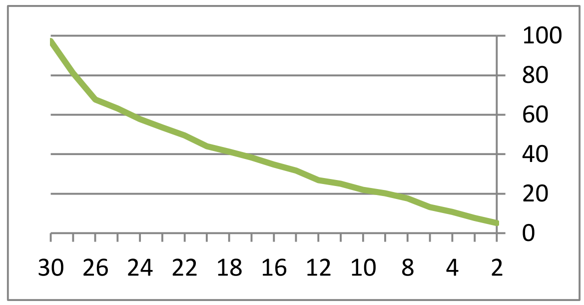
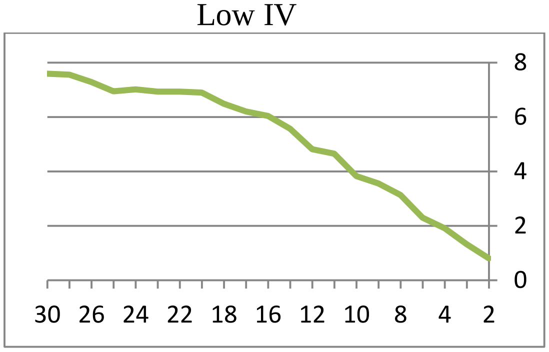


Figure 14: ITM Put options

The following two charts illustrate the pattern of time value decay for 30-day In-The-Money Put options of in different volatility environments. Volatility is classified as high or low based on the implied volatility of the option at the 30-day mark. Volatility groups are created by evenly dividing the options into the two groups based on this initial implied volatility level.

Low IV



High IV

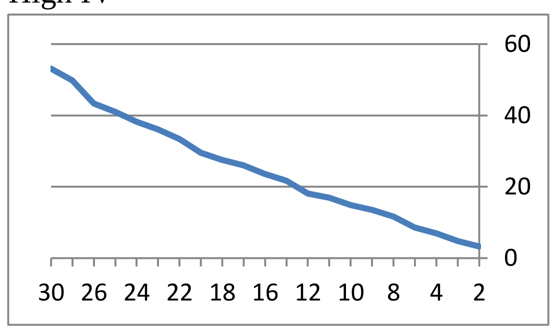


Table 1: Differences Between Actual Time Value Percentage and Predictions Based on Black-Scholes and Constant Decay Models: 60-day At-The-Money Call option

This table reports the differences between actual time value and predicted time value percentage as a function of time to maturity. At the time of the initial trade, the option is a 60-day at-the-money Call option. Time value percentage is calculated as $Time_t/C_0$ where $Time_t$ is the time value of the option at time *t*, and C_0 is the original call option premium at time *0*. For constant decay, the time value percentage is assumed to decay at a constant rate from 100 at time *0* to 0 at time T. For the Black-Scholes forecast (B-S Ceteris Paribus) the time value percentage is calculated by pricing the option with the Black-Scholes formula and assuming the only parameter that changes from time *0* is the time to expiry.

T	Actual (2)	Constant Decay (3)	B-S Ceteris paribus (4)	(2) – (3)	(2) – (4)
2	9.12	3.15	13.22	5.97	-4.10
3	10.29	4.73	17.32	5.56	-7.02
4	11.77	6.32	20.85	5.45	-9.08
5	13.34	7.91	24.00	5.43	-10.66
8	14.75	12.67	31.92	2.08	-17.17
9	16.07	14.26	34.18	1.81	-18.11
10	17.17	15.85	36.37	1.33	-19.19
11	18.23	17.44	38.45	0.79	-20.22
12	18.75	19.00	40.28	-0.25	-21.53
15	20.88	23.80	45.90	-2.92	-25.02
16	22.15	25.40	47.63	-3.25	-25.49
17	23.60	26.97	49.27	-3.37	-25.67
18	24.72	28.58	50.91	-3.85	-26.19
19	25.60	30.17	52.48	-4.57	-26.88
22	27.22	34.94	56.93	-7.72	-29.71
23	28.02	36.52	58.35	-8.50	-30.33
24	29.20	38.12	59.78	-8.92	-30.58
25	30.04	39.71	61.14	-9.67	-31.09
26	31.53	41.31	62.50	-9.78	-30.97
29	33.53	46.08	66.40	-12.54	-32.86
30	35.10	47.68	67.67	-12.57	-32.57
31	36.55	49.26	68.89	-12.71	-32.34
32	38.05	50.85	70.12	-12.80	-32.06
33	39.74	52.43	71.31	-12.69	-31.57
36	42.01	57.22	74.84	-15.21	-32.83
37	43.85	58.81	75.97	-14.95	-32.12
38	45.60	60.39	77.09	-14.79	-31.48
39	47.16	62.00	78.24	-14.83	-31.08
40	47.68	63.53	79.52	-15.85	-31.83
43	50.79	68.37	82.55	-17.58	-31.76
44	52.89	69.95	83.58	-17.06	-30.69
45	54.72	71.55	84.62	-16.83	-29.90
46	56.36	73.12	85.65	-16.76	-29.29
47	57.84	74.71	86.64	-16.86	-28.80

50	61.42	79.48	89.63	-18.06	-28.21
51	64.67	81.06	90.59	-16.39	-25.92
52	67.22	82.65	91.55	-15.43	-24.33
53	69.88	84.27	92.51	-14.38	-22.63
54	71.87	85.88	93.48	-14.01	-21.61
57	75.82	90.61	96.27	-14.79	-20.45
58	79.49	92.18	97.15	-12.68	-17.66
59	85.70	93.77	98.08	-8.07	-12.37