Modifying The Black-Scholes-Merton Model to Calculate the Cost of Employee Stock Options

Public firms must report their employee stock option (ESO) expense in their income statements at fair value under Financial Accounting Standards Board (FASB) Accounting Standards Codification 718 (ASC 718). Most firms use the Black-Scholes model as modified by Merton to incorporate dividends at a continuous constant proportional rate and substitute the estimated average term for the contractual expiration. This model, which we refer to as the ASC 718 Black-Scholes-Merton (BSM) model, systematically overprices ESOs and hence overstates a firm’s ESO expense. Nevertheless, while a variety of more accurate, though more complex, ESO pricing models exist in the literature, Table 1 shows that at year-end 2010, 80 percent of the S&P 500 firms that issued ESOs used the BSM model to calculate their entire ESO expense, and 81 percent used it to calculate at least some of their ESO expense. These percentages changed only slightly between 2006 and 2010.

The FASB and International Accounting Standards Board (IASB) accounting standards provide guidance on measuring the firm’s ESO expense (FASB, 2004; IASB, 2004). ASC 718 does not endorse any specific valuation model but it explicitly permits firms to use either the BSM model or a lattice model to value ESOs provided appropriate adjustments are made for ESO features. ASC 718 allows firms to use the expected term in place of the contractual term to capture the effects of early exercise and post-vesting forfeiture, which attempts to capture the effects of these special features of ESOs in a single stroke. The ASC 718 BSM model overprices ESOs because the BSM formula price is a concave function of the term of the option.

Pricing ESOs is more challenging than pricing conventional call options. Unlike conventional call options, ESO transfer is severely restricted if permitted at all, ESOs have vesting requirements, are subject to forfeiture, and employees tend to exercise ESOs much earlier than unrestricted call options.

Black-Scholes-Merton (BSM) model, systematically overprices ESOs and hence overstates a firm’s ESO expense. Nevertheless, while a variety of more accurate, though more complex, ESO pricing models exist in the literature, Table 1 shows that at year-end 2010, 80 percent of the S&P 500 firms that issued ESOs used the BSM model to calculate their entire ESO expense, and 81 percent used it to calculate at least some of their ESO expense. These percentages changed only slightly between 2006 and 2010.

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1 All references in this article are provided in the original article. Finnerty, John D., 2014, “Modifying the Black-Scholes-Merton Model to Calculate the Cost of Employee Stock Options,” Managerial Finance 40 (No. 1), 2-32.
2 Three trends are evident in Table 1: (a) fewer S&P 500 (i.e., large) firms are issuing ESOs, (b) the number and percentage of S&P 500 firms that grant ESOs that apply the BSM model decreased each year between 2006 and 2009, and (c) more firms are failing to identify which ESO valuation model(s) they use.
3 The Financial Accounting Standards Board (FASB) and the International Accounting Standards Board (IASB) have adopted substantially very similar rules for measuring the cost of employee services purchased with ESOs (FASB, 2004; IASB, 2004). Both use the fair value of the equity instruments the firm issues as the basis for measurement. Both view the vesting date as the issue date and consequently ignore the impact of the transfer restrictions prior to vesting. The effect is to measure the firm’s cost of meeting its ESO obligations for ESOs that vest. The expense recorded at the time of grant is based on the number of ESOs the firm expects to vest. ESO expense is periodically adjusted up to the vesting date to reflect any differences between actual and expected vesting.
4 ESOs differ from conventional American equity call options in four critical respects: (1) ESOs are either nontransferable or else transferable subject to severe restrictions; (2) ESOs must vest before they are eligible for exercise; (3) ESOs are subject to forfeiture or forced early exercise if an employee terminates employment due to dismissal, retirement, death or disability, or voluntary termination; and (4) employees tend to exercise ESOs earlier than they would be expected to exercise unrestricted options because of transfer restrictions, limited employee wealth diversification, and risk aversion.
Most of the more recent ESO valuation models are built on binomial share price lattices. The binomial model is preferred by academics but the BSM model is the overwhelming choice of public firms for reporting their ESO expense. How important is this difference? Ammann and Seiz (2004) find that except for the standard BSM and ASC 718 BSM models, the models they test provide consistent pricing when they are all calibrated to the same expected term. Our research suggests that the BSM model can also provide consistent pricing when it is properly adjusted for the ESO’s special features and calibrated to the same exercise and forfeiture data.

This article develops such a model. It is an abridged version of an article with same title that was recently published in Managerial Finance.

The modified BSM model permits the user to make explicit the assumptions regarding exercise and post-vesting forfeiture rates that firms now subsume within a single expected term parameter.

This article does not claim that our recommended modification of the BSM model is more accurate than competing models, only that:

- It prices ESOs as accurately as the more computationally intensive utility maximization models and lattice models with specified exercise boundaries but is easier to use.
- It avoids the ASC 718 BSM model’s overpricing bias.

If firms prefer the BSM model over more mathematically elegant alternatives, they should consider using a BSM model that is free of overpricing bias. In this article, we modify the BSM model to incorporate the special features of ESOs and avoid the systematic overpricing bias that afflicts the ASC 718 BSM model.

### Modifying the BSM model for ESO features

This article extends the discrete valuation framework described in our previous research to develop a closed form expression for the value of an ESO.
First, we model the cost of conventional nonqualified stock options and assume that the firm’s shareholders are fully diversified with respect to ESO risk. The firm’s ESO liabilities account for no more than an inconsequential fraction of each shareholder’s total wealth, and any ESO risk that the shareholder cannot hedge with the underlying common stock is idiosyncratic across the securities in the shareholder’s portfolio and can be diversified away. ESOs are almost always issued at-the-money. At the grant date, there is some fraction of the newly granted ESOs that can be expected to vest. They usually vest in stages, called graded vesting. Graded vesting is easily handled in ESO valuation models by treating the option grant as a set of separate grants, one for each vesting date.

ESOs are forfeited if an employee leaves the firm before they vest. Forfeiture can also occur after vesting. Many ESO plans provide that after vesting, the employee must forfeit any unexercised ESOs if terminated for cause. Employees might also voluntarily forfeit ESOs, for example, if they voluntarily resign and do not exercise the ESOs within the allowed period or cannot exercise them because their departure falls within a blackout period. However, if the ESOs are vested and in-the-money, employees will exercise rather than forfeit. As a result, the forfeiture rate decreases substantially after vesting. To allow for both types of forfeiture, we specify $F_1$ before vesting and $F_2$ after vesting.

This article modifies the BSM model to explicitly account for ESO vesting, transfer restrictions, forfeiture, and early exercise. $V(S_t, X, r, q, \sigma, T_t, t)$ is the BSM value as of time $t$ of a European call option, which expires at $T_t$ in the absence of any ESO restrictions; $S_t$ is the underlying share price at $t$ when the share is also free of any transfer restrictions; $X$ is the exercise price; $r$ is the riskless rate; $q$ is the average annualized continuous dividend yield ($q = 0$ for non-dividend-paying stocks); and $\sigma$ is the stock price volatility.

The current share price and the current option price for call options that are free of any restrictions are $S_t$ and $V_t$, respectively. Define $V_e(S_t, X, r, q, \sigma, T_t)$ as the value as of time $t$ of an ESO, which vests at $T_t$ and expires at $T_v$. Holders may exercise anytime between $T_t$ and $T_v$.

$E*$ is the probability the holder exercises the ESO conditional on it being vested and in-the-money and not having been exercised or forfeited previously. $F_2*$ is the probability the holder forfeits the ESO during the vesting period conditional on it not having been forfeited previously. $F_2*$ is the probability of involuntary forfeiture after the ESO vests conditional on it not having been exercised or forfeited previously. The model assumes that $E*$ is constant throughout the life of the ESO, and that $F_1, F_2*$ are constant during the pre-vesting period, $F_1*$ is constant during the post-vesting period, and both are zero otherwise. $E*$, $F_1, F_2*$ are thus the long-run average proportional exercise rate and forfeiture rates, respectively.

To obtain a closed form expression for grant date ESO value, it is more convenient to work in continuous time. The modified BSM formula is below (Figure 1).

Equation (1) values a single ESO. Treat the ESOs as a portfolio of grants, one per vesting date. Evaluate $V_e(S_t, X, r, q, \sigma, T_t)$ separately for each vesting date. Multiply by the number of ESOs that are expected to vest on $T_t$ to obtain the value of the batch of ESOs that will vest on that date. Sum the resulting values for all the vesting dates to obtain the total value of the grant.

An example

The following example illustrates the use of the modified BSM model. The example assumes four-year graded vesting and the model parameters estimated in Finnerty (2014). When the ESO plan

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**Figure 1: Modified BSM Formula**

\[
\begin{align*}
V_e(S_t, X, r, q, \sigma, T_t) &= A(T_t) S_t \left[ e^{-r(T_t-t)} \left( \frac{\mu_1 - q - \lambda \sigma^2}{\sigma} - \lambda q^* \right) N \left( \frac{\mu_1 - q - \lambda \sigma^2}{\sigma} \right) - \frac{\mu_1 - q - \lambda \sigma^2}{\sigma} \right) \\
&\quad \quad + E^* e^{-r(T_t-t)} \left[ \left( \frac{\mu_1 - q - \lambda \sigma^2}{\sigma} \right) N \left( \frac{\mu_1 - q - \lambda \sigma^2}{\sigma} \right) - \frac{\mu_1 - q - \lambda \sigma^2}{\sigma} \right] \\
&\quad \quad - \frac{\mu_1 - q - \lambda \sigma^2}{\sigma} \left( \lambda q^* \right) N \left( \frac{\mu_1 - q - \lambda \sigma^2}{\sigma} \right) - \frac{\mu_1 - q - \lambda \sigma^2}{\sigma} \right) \\
&\quad \quad - q* e^{-r(T_t-t)} \left( \frac{\mu_1 - q - \lambda \sigma^2}{\sigma} \right) N \left( \frac{\mu_1 - q - \lambda \sigma^2}{\sigma} \right) - \frac{\mu_1 - q - \lambda \sigma^2}{\sigma} \right)
\end{align*}
\]

where $A(T_t) = e^{-\lambda q\sigma^2/2}$, $\mu_1 = r - q + \lambda \sigma^2 / 2$, $\mu_2 = \mu_1 - \lambda \sigma^2$, $\lambda = q + E^* + F_2^*$, and $N(\cdot)$ is the standard normal cumulative distribution function.

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specifies annual graded vesting spread equally over the vesting period, divide the number of originally granted ESOs into $T_V$ equal groups that vest sequentially in years 1, 2, . . . , $T_V$. Apply equation (1) separately to each group. The example assumes $E^* = 0.1824$. With one- to four-year vesting, none of the ESOs exercise the first year, 4.56 percent of the available ESOs ($\frac{1}{4}$ of 18.24 percent) exercise the second year, 9.12 percent of the available ESOs ($\frac{1}{2}$ of 18.24 percent) exercise the third year, 13.68 percent the fourth year, and 18.24 percent each year beginning in the fifth year.

Table 2 values a grant of 3,000,000 ESOs. The unadjusted BSM value is $10.11 per ESO, or a total of $30,330,000. The modified BSM model value is $19,207,500, or about $6.40 per ESO, assuming no blackout periods. This is the value the firm would use to calculate its ESO expense for financial reporting purposes. The firm would prorate this expense over the four-year vesting period and report first year ESO expense equal to $4,801,875 (= 19,207,500/4).

**Comparison of ESO pricing models**

Next, the article compares the ESO pricing from the modified BSM model to the pricing from four well-known ESO pricing models: the Hull and White trinomial lattice model, the Brisley and Anderson $\mu$ model, the Carpenter utility maximization model, and the ASC 718 BSM model. The ASC 718 BSM model simply substitutes the estimated average term of the ESOs for the time to expiration. This comparison demonstrates that the modified BSM model prices ESOs consistently with the utility maximization,
We use the trinomial implementations of the Hull and White and Brisley and Anderson μ models because the early exercise strategy these models assume – exercise occurs with certainty when a specified exercise boundary is reached – makes the ESO a barrier option.

We test the sensitivity of ESO pricing from the five models considered in this article to a range of parameter values. Since most ESOs have four-year vesting, the article tests $T_V = 1, 2, 3, \text{ or } 4$.

First, we chose $M$, the ratio of the stock price to the exercise price at which ESO exercise occurs. A consistent set of parameter values must be used to facilitate an unbiased comparison of the five ESO valuation models. We also assume $25$ stock price, $25$ exercise price, $10$-year maturity, $6\%$ risk-free rate, $2\%$ dividend yield, and zero pre-vesting forfeiture rate ($F_1^* )$.

Figure 2 compares the ESO valuations from the modified BSM model to those from Carpenter’s utility maximization model, Hull and White’s trinomial lattice model, and the trinomial implementation of Brisley and Anderson’s μ model. The modified BSM model produces estimates of ESO value generally consistent with the other three models over a wide range of parameter values when the models are all calibrated to the same estimated average term.

Figure 3 compares the ESO valuations from the ASC 718 BSM model to those from the other four models. The figure includes the modified BSM model with the first three in this comparison because Figure 2 shows that it provides ESO valuations consistent with the other three models.
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Table 3: Comparison of Modified BSM, Trinomial Lattice, and $\mu$ Model ESO Grant Date Valuation Assuming No Blackout Periods

This table compares the grant date ESO values estimated by applying the modified BSM model (1), the Hull and White (2004) trinomial lattice model, and the Brisley and Anderson (2008) $\mu$ model to the nine sample firms that remained as of an assumed grant date, December 31, 2007. Two sample firms merged in 2003. Values were calculated using a risk-free rate of 3.44%, and all ESOS are 10-year grants at-the-money. An exercise multiple of 1.5 was used in the trinomial lattice model. The exercise multiple $\mu$ is estimated based on the historical exercise data for the eight firms for which there are sufficient data. The t-statistic for the average percentage difference is in parentheses below the average percentage difference.

### Panel A. Assumptions

<table>
<thead>
<tr>
<th>Company</th>
<th>Industry</th>
<th>Price $</th>
<th>Dividend Yield</th>
<th>$E^*$</th>
<th>$F^*$</th>
<th>$F^*_n$</th>
<th>$\sigma^*$</th>
<th>$\mu^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Property &amp; Casualty Insurance</td>
<td>72.67</td>
<td>0.01%</td>
<td>0.1824</td>
<td>0.0901</td>
<td>0.0064</td>
<td>0.1954</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Jewelry Stores</td>
<td>46.03</td>
<td>1.13%</td>
<td>0.1785</td>
<td>0.0589</td>
<td>0.0025</td>
<td>0.3204</td>
<td>0.7041</td>
</tr>
<tr>
<td>3</td>
<td>Scientific &amp; Technical Instruments</td>
<td>73.18</td>
<td>—</td>
<td>0.1523</td>
<td>0.0400</td>
<td>0.0065</td>
<td>0.2506</td>
<td>0.8065</td>
</tr>
<tr>
<td>4</td>
<td>Medical-Biomedical/Gene</td>
<td>47.98</td>
<td>—</td>
<td>0.2501</td>
<td>0.0607</td>
<td>0.0074</td>
<td>0.3615</td>
<td>0.8853</td>
</tr>
<tr>
<td>5 / 6</td>
<td>Entertainment - Diversified</td>
<td>16.51</td>
<td>1.42%</td>
<td>0.1232</td>
<td>0.0897</td>
<td>0.0109</td>
<td>0.2536</td>
<td>0.9447</td>
</tr>
<tr>
<td>7</td>
<td>Communication Equipment</td>
<td>23.99</td>
<td>0.42%</td>
<td>0.2138</td>
<td>0.0250</td>
<td>0.0073</td>
<td>0.4914</td>
<td>0.7645</td>
</tr>
<tr>
<td>8</td>
<td>Major Integrated Oil &amp; Gas</td>
<td>93.69</td>
<td>1.46%</td>
<td>0.0388</td>
<td>0.0901</td>
<td>0.0064</td>
<td>0.2061</td>
<td>0.9215</td>
</tr>
<tr>
<td>9</td>
<td>Communication Equipment</td>
<td>16.04</td>
<td>1.25%</td>
<td>0.1484</td>
<td>0.0195</td>
<td>0.0083</td>
<td>0.3448</td>
<td>0.8145</td>
</tr>
<tr>
<td>10</td>
<td>Processing Systems &amp; Products</td>
<td>12.50</td>
<td>—</td>
<td>0.1421</td>
<td>0.1413</td>
<td>0.0063</td>
<td>0.4654</td>
<td>0.7825</td>
</tr>
</tbody>
</table>

### Panel B: Cost of ESOs at the Time of Grant

<table>
<thead>
<tr>
<th>Company</th>
<th>Industry</th>
<th>$V_E^*(X = S)$</th>
<th>Cost of ESOs</th>
<th>Difference$^{(3)}$</th>
<th>Cost of ESOs</th>
<th>Difference$^{(4)}$</th>
<th>$V_E^*(X = S)$</th>
<th>Cost of ESOs</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Property &amp; Casualty Insurance</td>
<td>13.99</td>
<td>15.05</td>
<td>(1.06)</td>
<td>-7.05%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Jewelry Stores</td>
<td>13.04</td>
<td>12.79</td>
<td>0.25</td>
<td>1.93%</td>
<td>12.30</td>
<td>0.73</td>
<td>5.96%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Scientific &amp; Technical Instruments</td>
<td>21.88</td>
<td>20.67</td>
<td>1.21</td>
<td>5.86%</td>
<td>21.95</td>
<td>(0.07)</td>
<td>-0.31%</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Medical-Biomedical/Gene</td>
<td>15.65</td>
<td>15.11</td>
<td>0.54</td>
<td>3.54%</td>
<td>15.54</td>
<td>0.11</td>
<td>0.69%</td>
<td></td>
</tr>
<tr>
<td>5 / 6</td>
<td>Entertainment - Diversified</td>
<td>3.70</td>
<td>3.83</td>
<td>(0.13)</td>
<td>-3.29%</td>
<td>3.81</td>
<td>(0.11)</td>
<td>-2.83%</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Communication Equipment</td>
<td>10.43</td>
<td>9.55</td>
<td>0.88</td>
<td>9.20%</td>
<td>11.02</td>
<td>(0.59)</td>
<td>-5.38%</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Major Integrated Oil &amp; Gas</td>
<td>19.44</td>
<td>18.49</td>
<td>0.95</td>
<td>5.14%</td>
<td>19.25</td>
<td>0.19</td>
<td>0.99%</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Communication Equipment</td>
<td>5.20</td>
<td>5.08</td>
<td>0.12</td>
<td>2.40%</td>
<td>5.63</td>
<td>(0.42)</td>
<td>-7.55%</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Processing Systems &amp; Products</td>
<td>4.37</td>
<td>3.59</td>
<td>0.78</td>
<td>21.63%</td>
<td>3.54</td>
<td>0.83</td>
<td>23.50</td>
<td></td>
</tr>
</tbody>
</table>

**Average Percentage Difference** 4.37% 1.89% (1.62) (0.55)

**Average Absolute Percentage Difference** 6.67% 5.90%

Notes:

1) Firm 5 and firm 6 merged in 2003.
2) The $\mu$ for each firm is the median of the annual $\mu$ values calculated for the firm. There was insufficient data to estimate $\mu$ for company 1.
3) Calculated as $V_E^*(X = S)$ minus the trinomial lattice model value.
4) Calculated as $V_E^*(X = S)$ minus the $\mu$ model value.
The ASC 718 BSM model values are consistently greater than the respective average ESO values obtained from the other four models for the entire range of volatilities considered. They are above the high end of the range when the volatility exceeds about 45 percent for $M = 1.5$ and when it exceeds about 55 percent for $M = 2.75$. The ASC 718 BSM model's overpricing is more severe at higher volatilities.

**Implementing the modified BSM model**

The remainder of the article illustrates the practical application of the modified BSM model by calculating the cost of ESOs for nine firms.

ESO exercise and forfeiture are stochastic. Calibrating an ESO model requires historical exercise and forfeiture data. All ESO models necessarily involve some path dependency to the extent calibration uses historical data. This article tries to minimize the effect of this path dependency by using a large number of ESO grants covering a long time period.

This article models the conditional exercise and forfeiture probabilities as mean-reverting diffusion processes and calculates the risk-neutral long-run average conditional exercise and forfeiture probabilities $E^*, F_1^*,$ and $F_2^*$ for these processes.

Our previous research provides two tables that summarize ESO exercise and forfeiture data obtained from nine firms, all but one of which are publicly traded. Those tables have not been reproduced in this abridged article to conserve space. The exercise and forfeiture data cover 127 separate ESO grants between 1981 and 2004 and 1,308,528,739 ESOs.

The average time to exercise is 4.82 years. More than 50 percent of the ESOs were exercised by the end of the fifth calendar year after grant. The average forfeiture rates fall in the range from 2% to 7% per year prior to vesting, decline thereafter, and are a small fraction of 1% for most years after vesting. They exhibit a less pronounced time pattern than the average exercise percentages, and they do not vary from firm to firm as much as the exercise patterns. The conditional exercise and forfeiture probabilities are estimated for the nine sample firms.

Next, the calibrated model is used to calculate the year-end grant date values of ESOs for the sample firms that were still independent at year-end 2007, which is the latest year for which exercise and forfeiture data are available. The modified BSM model values are compared to values from the Hull and White trinomial lattice model and the Brisley and Anderson $\mu$ model.

The estimated ESO values are provided in Table 3. The modified BSM, Hull and White, and $\mu$ models produce generally consistent valuations as suggested by Figure 2. We tested the null hypothesis that the average percentage difference between the modified BSM model price and the Hull and White model price is zero against the two-sided alternative hypothesis that the difference is nonzero. The average percentage difference of 4.37% is not significant at the .05 level. We also tested the null hypothesis that the average percentage difference between the modified BSM model price and the $\mu$ model price is zero against the alternative hypothesis that the difference is nonzero. The average percentage difference of 1.89% is not significant at the .05 level. Thus, the modified BSM model is no less accurate than the more complex Hull and White and Brisley and Anderson $\mu$ trinomial lattice models.

**Conclusion**

Public firms overwhelmingly choose the BSM model to calculate their ESO expense. They simply substitute the estimated average term for the contractual time to expiration, which attempts to adjust for the special features of ESOs all in one stroke. The resulting ASC 718 BSM model systematically overprices ESOs. The overpricing worsens as the stock’s volatility increases, and it becomes severe when the stock’s volatility exceeds about 50 percent. If firms prefer the BSM model over more mathematically elegant and potentially more accurate alternatives, they should at least use a BSM model that is free of this overpricing bias.

This article modified the BSM model in closed form to explicitly take into account an ESO’s vesting, lack of free transferability, forfeiture, and early exercise features. The modified BSM model is just as accurate as the more computationally intensive utility maximization and trinomial lattice models with specified exercise boundaries but it is easier to use. It avoids the ASC 718 BSM model’s overpricing bias. The model values ESOs as of the grant date, and it can accommodate blackout periods, which makes it useful for financial reporting and compensation planning purposes. For firms that prefer to use the BSM model to calculate ESO expense and have relatively high stock price volatility, the modified BSM model should produce more accurate employee ESO expense estimates than the ASC 718 BSM model. Such a model should be of interest to firms, their auditors, and accounting regulators.
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