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具有上下障碍的再装期权定价模型与计算*

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摘　要:针对再装期权作为经理股票期权薪酬机制存在的问题,讨论了设置再装期权上下障碍的必要性,建立了考虑经理股票期权的长期激励因素以及在股市低迷时经理股票期权重置特征的改进的再装期权定价模型,并给出了计算公式及相应的模拟分析.

关键词:再装期权;障碍期权;鞅
中图分类号:TN830.9　　**文献标志码**:A

再装期权作为一种变异的欧式看涨期权,它允许期权的持有者在到期日之前的特定日期执行欧式看涨期权,且保证执行日期权处于实值状态,然后获得一个数量为被执行期权的执行价格与执行日股票价格的比,到期日不变,执行价格为执行日股票价格的新的欧式看涨期权.再装期权与标准欧式看涨期权一样可以作为对公司高级管理人员或专业技术人员的股票期权激励方案.再装期权的明显特征是:允许其持有者锁定在再装日的利润,消除了在到期日可能只能获得较低收入的风险,这对一些特定公司来说是一种较好的激励方案.

然而,再装期权作为经理激励的薪酬至少存在2个问题.其一,容易导致经理片面追求股价上升而产生短期行为,在再装日股票价格远高于执行价格时,经理行使期权提前获得一笔巨额报酬和部分新期权,这样不利于经理从公司长远目标决策.而且,由于被执行期权的执行价格与再装日股票价格的比远小于1,所以获得的新的期权数量也较小,且执行价格很高,这样对经理以后的工作激励作用不大.其二,由于外界因素影响,股市处于"熊市"阶段,当公司股价远低于期权执行价时,再装期权就失去了对经理的激励作用,经理人将可能选择离职进入经理人市场,通过与其他公司的谈判来重新给自己定价.在如今经理人市场具有卖方特性的情况下,这种高级人才的流动给公司带来的威胁是不言而喻的.因此,有必要对再装期权的再装条款进行研究,加以改进来更好地解决经理激励问题.

关于再装期权的研究,Johnson等人研究了股票价格服从连续扩散过程的再装股票期权的定价[1].冯广波等研究了服从跳-扩散过程的再装股票期权的定价,导出再装期权的定价公式,并运用二项式期权定价模型来估价美式再装期权[2].李超杰等对再装股票期权执行价格最低水平的决定进行了研究,提出了再装股票期权执行价格最低水平的决定机制[3].傅强等在等价鞅测度下,求出了在风险中性定价模型中,股票价格服从O-U过程的再装期权定价模型[4].然而这些文献没有考虑经理股票的长期激励因素,从公司长期激励角度来看,当股票下跌到一定程度时,再装经理股票期权失去其激励作用,公司会重新发行新的股票期权.Hall等通过实证研究指出,当股价大幅高涨或者股价大幅下跌,期权处于严重虚值状态时,公司会倾向与发行更多的股票期权[5].Brenner等对1992年—1995年的S&P公司的股票期权中的重置合同进行了研究,研究表明公司一般在股价下降到原来价格的60%时重置期权价格,并且有80%的公司会以当时的股价为敲定价格[6].作者对再装期权的再装条款加以改进,认为在再装日允许经理获得的利润应该有个最大限度,而在股市萎靡时,期权应该重新定价,以继续激励经理更好为股东工作.

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1　改进的再装股票期权定价模型

1.1　模型的收益结构

从对经理的激励和约束的角度,考虑改进的再装股票期权的收益结构(这里只考虑只再装一次的情况):期权在再装日的收益为

$$F_1(S_{T_1},S_H,K) = \begin{cases} \max\{S_{T_1}-K,0\}, & S_{T_1}<S_H \\ \max\{S_H-K,0\}, & \text{否则} \end{cases}, \tag{1}$$

在到期日的收益为

$$F_2(S_{T_1},S_T,S_H,S_L,K) = \begin{cases} S_T-K & S_L<S_{T_1}\leqslant K,S_T>K \\ S_T-S_L & S_{T_1}<S_L,S_T>S_L \\ \dfrac{K}{S_{T_1}}(S_T-S_{T_1}) & S_H>S_{T_1}>K,S_T>S_{T_1} \\ \dfrac{K}{S_H}(S_T-S_H) & S_{T_1}>S_H,S_T>S_H \\ 0 & \text{其它} \end{cases}, \tag{2}$$

其中,K 为执行价格,T 为到期日,T_1 为预先设定的再装时点($T_1<T$),S_{T_1}和 S_T 分别为股票在时刻 T_1、T 的价格,S_H 和 S_L 为事先设置的上、下障碍价格,且 $S_H>K>S_L$.

以上模型的经济解释如下:

1)在发行日后的再装日 T_1,若当天的股票价格(S_{T_1})低于或等于原来执行价格(K),且高于下障碍价格(S_L),则无需再装,期权的到期日(T)和执行价格(K)保持不变.

2)若再装日股价低于下障碍价格(即也低于原来执行价格 K),则期权重新定价,执行价格重新设定为下障碍价格(S_L),这样可以保证在股市低靡时留住优秀人才.

3)若再装日股价高于原来执行价格,但低于上障碍价格时,则经理行使期权,每份期权获得利润为($S_{T_1}-K$),同时按每行使一份期权获得数量为 K/S_{T_1} 份新的期权,其执行价格为当日股票价格(S_{T_1}),到期日为 T.

4)若再装日股价高于或等于上障碍价格(S_H),经理行使期权,获得的利润为(S_H-K)(小于 $S_{T_1}-K$),同时每行使一份期权获得数量为 K/S_H 份新的期权,执行价格为 S_H,到期日为 T. 这样就可以避免因再装日股价过高而使经理人提前获得巨大报酬,而以后的激励作用减弱,容易造成经理的短视行为.

1.2　改进的再装期权的价值评估

股票期权的授予虽然是无偿的,但是它是有成本的. 不管是出于会计目的还是从管理视角来看,计算期权的价值来估计股东的代理成本是非常重要的. 假设股东是风险中性的,因此,运用风险中性定价原则来计算再装期权的价值来估计代理成本是合理的. 这里仍用鞅评价方法来给出改进后的再装期权的定价公式. 为了得到改进后的再装期权定价公式,先给出 2 个引理.

引理 1(Girsanov 定理) 若 $E[\exp(\frac{1}{2}\int_0^T\beta_t^2\mathrm{d}t)]<\infty$,并令 $\xi_t=\exp(\int_0^T\beta_t\mathrm{d}w^Q-\frac{1}{2}\int_0^T\beta_t^2\mathrm{d}t)$,则在风险中性 Q 测度下,相对于一个自然布朗讯息集合 F_t, ξ_t 是鞅.

引理 2　如果标的资产价格 $S(t)$ 满足随机方程式 $S(t)=S\exp[(r-q-\sigma^2/2)t+\sigma\Delta W_t^Q]$ (ΔW_t^Q 代表在 Q 测度下,布朗运动的增量),则可知市场是完备的无套利市场,由鞅方法定价理论得:

1) $Pr^Q\{S_{T_1}\geqslant S_H\}=N(d_5^Q)$;

2) $Pr^Q\{K<S_{T_1}<S_H\}=N(d_2^Q)-N(d_5^Q)$;

$$E^Q(S_{T_1}\mid K<S_{T_1}<S_H)=S_0e^{(r-q)T_1}[N(d_2^R)-N(d_5^R)];$$

3) $Pr^Q(S_L<S_{T_1}\leqslant K,S_T>K)=N_2(d_1^Q,d_3^Q;\rho)-N_2(d_2^Q,d_3^Q;\rho)$;

$$E^Q(S_T\mid S_L<S_{T_1}\leqslant K,S_T>K)=S_0e^{(r-q)T}[N_2(d_1^R,d_3^R;\rho)-N_2(d_2^R,d_3^R;\rho)];$$

4) $Pr^Q(S_{T_1}<S_L,S_T>S_L)=N_2(-d_1^Q,d_4^Q;-\rho)$;

$$E^Q(S_T\mid S_{T_1}<S_L,S_T>S_L)=S_0e^{(r-q)T}N_2(-d_1^R,d_4^R;-\rho);$$

5) $Pr^Q(S_H>S_{T_1}>K,S_T>S_{T_1})=N(d_6^Q)[N(d_2^Q)-N(d_5^Q)]$;

$$E^Q(\frac{S_T}{S_{T_1}}\mid S_H>S_{T_1}>K,S_T>S_{T_1})=e^{(r-q)(T-T_1)}N(d_6^R)[N(d_2^R)-N(d_5^R)];$$

6) $Pr^Q(S_{T_1}>S_H,S_T>S_H)=N_2(d_5^Q,d_7^Q;\rho)$;

$E^Q(S_T\mid S_{T_1}>S_H,S_T>S_H)=S_0e^{(r-q)T}N_2(d_5^R,d_7^R;\rho)$.

其中,

$$d_1^Q=\frac{\ln(S_0/S_L)+(r-q-0.5\sigma^2)T_1}{\sigma\sqrt{T_1}},d_1^R=d_1^Q+\sigma\sqrt{T_1};d_2^Q=\frac{\ln(S_0/K)+(r-q-0.5\sigma^2)T_1}{\sigma\sqrt{T}},$$

$$d_2^R=d_2^Q+\sigma\sqrt{T_1};$$

$$d_3^Q=\frac{\ln(S_0/K)+(r-q-0.5\sigma^2)T}{\sigma\sqrt{T}},$$

$$d_3^R=d_3^Q+\sigma\sqrt{T};\ d_4^Q=\frac{\ln(S_0/S_L)+(r-q-0.5\sigma^2)T}{\sigma\sqrt{T}},$$

$$d_4^R = d_4^Q + \sigma\sqrt{T};$$

$$d_5^Q = \frac{\ln(S_0/S_H) + (r - q - 0.5\sigma^2)T_1}{\sigma\sqrt{T_1}},$$

$$d_5^R = d_5^Q + \sigma\sqrt{T_1}; d_6^Q = \frac{(r - q - 0.5\sigma^2)(T - T_1)}{\sigma\sqrt{T - T_1}},$$

$$d_6^R = d_6^Q + \sigma\sqrt{T - T_1};$$

$$d_7^Q = \frac{\ln(S_0/S_H) + (r - q - 0.5\sigma^2)T}{\sigma\sqrt{T}},$$

$$d_7^R = d_7^Q + \sigma\sqrt{T}; \rho = \sqrt{T_1/T}.$$

且 $N(\cdot)$ 表示一维标准正态分布累积函数，$N_2(\cdot)$ 表示二维标准正态分布累积函数.

证明：令 $\xi_t = \exp\left\{-\frac{1}{2}\sigma^2 t + \sigma\Delta B_t^Q\right\}$，注意到 ξ_t 为严格正，且 $E^Q(\xi_t) = 1$，因此，由 $\frac{dR}{dQ} = \xi_T$ 可以定义一个和测度 Q 等价的概率测度 R，由 Girsanov 定理可知，在概率测度 R 下，$B^R(t) = B^Q(t) - \sigma t$ 是一个 Brown 运动.

1)
$$Pr^Q\{S_{T_1} \geqslant S_H\} =$$
$$Pr^Q\left\{S\exp\{(r - \frac{1}{2}\sigma^2)T_1 + \sigma\Delta B_{T_1}^Q\} \geqslant S_H\right\} =$$
$$Pr^Q\left\{\ln S + \left(r - \frac{1}{2}\sigma^2\right)T_1 + \sigma\Delta B_{T_1}^Q \geqslant \ln S_H\right\} =$$
$$Pr^Q\left\{-\frac{\Delta B_{T_1}^Q}{\sqrt{T_1}} \leqslant \frac{\ln\frac{S}{S_H} + (r - \frac{1}{2}\sigma^2)T_1}{\sigma\sqrt{T_1}}\right\} = N(d_5^Q)$$

2)
$$Pr^Q\left\{K < S_{T_1} < S_H\right\} = Pr^Q\{S_{T_1} > K\} - Pr^Q\left\{S_{T_1} \geqslant S_H\right\} =$$
$$Pr^Q\left\{-\frac{\Delta B_{T_1}^Q}{\sqrt{T_1}} < \frac{\ln\frac{S}{K} + (r - \frac{1}{2}\sigma^2)T_1}{\sigma\sqrt{T_1}}\right\} - Pr^Q\left\{-\frac{\Delta B_{T_1}^Q}{\sqrt{T_1}} \leqslant \frac{\ln\frac{S}{S_H} + (r - \frac{1}{2}\sigma^2)T_1}{\sigma\sqrt{T_1}}\right\} =$$
$$N(d_2^Q) - N(d_5^Q);$$
$$E^Q(S_{T_1} \mid K < S_{T_1} < S_H) = S_0 e^{(r-q)T_1} E^Q(\xi_{T_1} I_{\{K < S_{T_1} < S_H\}}) = S_0 e^{(r-q)T_1} E^R(I_{\{K < S_{T_1} < S_H\}}) =$$
$$S_0 e^{(r-q)T_1} Pr^R(K < S_{T_1} < S_H) = S_0 e^{(r-q)T_1}[N(d_2^R) - N(d_5^R)];$$

3)
$$Pr^Q(S_L < S_{T_1} \leqslant K, S_T > K) = Pr^Q(S_{T_1} > S_L, S_T > K) - Pr^Q(S_{T_1} > K, S_T > K) =$$
$$Pr^Q\left\{-\frac{\Delta B_{T_1}^Q}{\sqrt{T_1}} < \frac{\ln\frac{S}{S_L} + (r - \frac{1}{2}\sigma^2)T_1}{\sigma\sqrt{T_1}}; -\frac{\Delta B_T^Q}{\sqrt{T}} < \frac{\ln\frac{S}{K} + (r - \frac{1}{2}\sigma^2)T}{\sigma\sqrt{T}}\right\} -$$
$$Pr^Q\left\{-\frac{\Delta B_{T_1}^Q}{\sqrt{T_1}} < \frac{\ln\frac{S}{K} + (r - \frac{1}{2}\sigma^2)T_1}{\sigma\sqrt{T_1}}; -\frac{\Delta B_T^Q}{\sqrt{T}} < \frac{\ln\frac{S}{K} + (r - \frac{1}{2}\sigma^2)T}{\sigma\sqrt{T}}\right\} =$$
$$N_2(d_1^Q, d_3^Q; \rho) - N_2(d_2^Q, d_3^Q; \rho);$$
$$E^Q(S_T \mid S_L < S_{T_1} \leqslant K, S_T > K) = S_0 e^{(r-q)T} E^Q(\xi_{T_1} I_{\{S_L < S_{T_1} \leqslant K, S_T > K\}}) =$$
$$S_0 e^{(r-q)T} E^R(I_{\{S_L < S_{T_1} \leqslant K, S_T > K\}}) = S_0 e^{(r-q)T} Pr^R(S_L < S_{T_1} \leqslant K, S_T > K) =$$
$$S_0 e^{(r-q)T}[N_2(d_1^R, d_3^R; \rho) - N_2(d_2^R, d_3^R; \rho)];$$

4)
$$Pr^Q(S_{T_1} < S_L, S_T > S_L) =$$
$$Pr^Q\left\{\frac{\Delta B_{T_1}^Q}{\sqrt{T_1}} \leqslant -\frac{\ln\frac{S}{S_L} + (r - \frac{1}{2}\sigma^2)T_1}{\sigma\sqrt{T_1}}; -\frac{\Delta B_T^Q}{\sqrt{T}} < \frac{\ln\frac{S}{S_L} + (r - \frac{1}{2}\sigma^2)T}{\sigma\sqrt{T}}\right\} = N_2(-d_1^Q, d_4^Q; -\rho);$$
$$E^Q(S_T \mid S_{T_1} < S_L, S_T > S_L) = S_0 e^{(r-q)T} E^Q(\xi_T I_{\{S_{T_1} < S_L, S_T > S_L\}}) = S_0 e^{(r-q)T} E^R(I_{\{S_{T_1} < S_L, S_T > S_L\}}) =$$
$$S_0 e^{(r-q)T} Pr^R(S_{T_1} < S_L, S_T > S_L) = S_0 e^{(r-q)T} N_2(-d_1^R, d_4^R; -\rho);$$

5)
$$Pr^Q(S_H > S_{T_1} > K, S_T > S_{T_1}) = Pr^Q(S_H > S_{T_1} > K) \cdot Pr^Q(S_T > S_{T_1}) =$$
$$Pr^Q(S_H > S_{T_1} > K) Pr^Q(S_T > S_{T_1}) \cdot [Pr^Q(S_T > K) - Pr^Q(S_T > S_H)] =$$
$$N(d_6^Q)[N(d_2^Q) - N(d_5^Q)] =$$
$$E^Q\left(\frac{S_T}{S_{T_1}} \mid S_H > S_{T_1} > K, S_T > S_{T_1}\right) = e^{(r-q)(T-T_1)} E^Q(\xi_{T-T_1} I_{\{S_H > S_{T_1} > K, S_T > S_{T_1}\}}) =$$
$$e^{(r-q)(T-T_1)} E^R(I_{\{S_H > S_{T_1} > K, S_T > S_{T_1}\}}) = e^{(r-q)(T-T_1)} Pr^R(S_H > S_{T_1} > K, S_T > S_{T_1}) =$$
$$e^{(r-q)(T-T_1)} N(d_6^R)[N(d_2^R) - N(d_5^R)];$$

6) $Pr^Q(S_{T_1} > S_H, S_T > S_H) Pr^Q.$

$$\left\{-\frac{\Delta B_{T_1}^Q}{\sqrt{T_1}} < \frac{\ln\frac{S}{S_H} + (r - \frac{1}{2}\sigma^2)T_1}{\sigma\sqrt{T_1}} - \frac{\Delta B_T^Q}{\sqrt{T}} < \frac{\ln\frac{S}{S_H} + (r - \frac{1}{2}\sigma^2)T}{\sigma\sqrt{T}}\right\} = N_2(d_5^Q, d_7^Q; \rho),$$

$$E^Q(S_T \mid S_{T_1} > S_H, S_T > S_H) = S_0 e^{(r-q)T} E^Q(\xi_T I_{\{S_{T_1} > S_H, S_T > S_H\}}) = S_0 e^{(r-q)T} E^R(I_{\{S_{T_1} > S_H, S_T > S_H\}}) = S_0 e^{(r-q)T} Pr^R(S_{T_1} > S_H, S_T > S_H) = S_0 e^{(r-q)T} N_2(d_5^R, d_7^R; \rho).$$

根据改进后的再装期权的收益结构特征式(1)及(2),有：

$$V = e^{-rT_1}E^Q[F_1(S_{T_1}, S_H, K)] + e^{-rT}E^Q[F_2(S_{T_1}, S_T, S_H, S_L, K)] = e^{-rT_1}E^Q[\max\{S_{T_1} - K, 0\} \mid S_{T_1} < S_H] + e^{-rT_1}E^Q[\max\{S_H - K, 0\} \mid S_{T_1} \geqslant S_H] + e^{-rT}E^Q[S_T - K \mid S_L < S_{T_1} \leqslant K, S_T > K] + e^{-rT}E^Q[S_T - S_L \mid S_{T_1} < S_L, S_T > S_L] + e^{-rT}E^Q[\frac{K}{S_{T_1}}(S_T - S_{T_1}) \mid S_H > S_{T_1} > K, S_T > S_{T_1}] + e^{-rT}E^Q[\frac{K}{S_H}(S_T - S_H) \mid S_{T_1} > S_H, S_T > S_H]. \quad (3)$$

利用引理 2 对式(3)进行简化可以得到改进后的再装期权定价公式,如下命题.

命题　如果股票价格服从几何布朗运动,给定再装时刻为 T_1,有效期为 T,敲定价为 K,则上下障碍分别为 S_H 和 S_L 的再装期权的定价公式为：

$$V = S_0 e^{-qT_1}[N(d_2^R) - N(d_5^R)] - Ke^{-rT_1}[N(d_2^Q) - N(d_5^Q)] + e^{-rT_1}(S_H - K)N(d_5^Q) + e^{-rT}\{S_0 e^{(r-q)T}[N(d_1^R, d_3^R; \rho) - N(d_2^R, d_3^R; \rho)] - K[N(d_1^Q, d_3^Q; \rho) - N(d_2^Q, d_3^Q; \rho)] + S_0 e^{(r-q)T}N(-d_1^R, d_4^R; -\rho) - S_L N(-d_1^Q, d_4^Q; -\rho) + Ke^{(r-q)(T-T_1)}N(d_6^R)[N(d_2^Q) - N(d_5^Q)] - K[N(d_2^Q) - N(d_5^Q)]N(d_6^Q) + \frac{K}{S_H}S_0 e^{(r-q)T}N(d_5^R, d_7^R; \rho) - KN(d_5^Q, d_7^Q; \rho)\}.$$

2　上下障碍参数对再装期权价值影响的模拟分析

从再装期权定价公式不难看出,上下障碍作为定价公式中的重要参数,它们的值的设定对再装期权价值有重要影响. 假设股票价格和执行价格均为 100,无风险利率为 5%,股票的预期波动率为 30%,再装时刻为第 5 年的年末,期权的有效期为 10 年,上障碍价格在[120, 150]内变化,下障碍价格在[20,60]内变化. 借助数学软件 Matlab 7.0.2 进行仿真计算,可以得到以上、下障碍价格为变量的改进再装期权价值曲面图(如下图 1),从图中可知,当上障碍价格取定后,期权价值随着下障碍价格的递增先减小后增加,这说明下障碍价格不是越低越好. 同理,当下障碍价格取定后,期权价值随着上障碍价格的递增先减小后增加. 因此选择好上、下障碍价格非常关键,可以较好地降低代理成本.

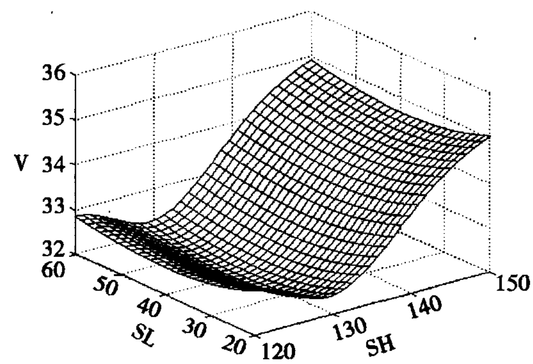

图 1　障碍价格对期权价值的影响

3　结　语

作者在以往再装期权模型的基础上考虑了公司对经理的长期激励因素,从对经理的激励和约束的角度对再装期权设定了上下障碍,给出了改进的再装期权的定价公式. 改进后的再装期权更接近实际,具有较大的实用价值. 对上下障碍参数进行的仿真模拟表明上下障碍参数的设定对改进的再装期权价值有重要影响,这值得进一步深入研究.

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(下转第 152 页)

Multi-dimensional Description and Measurement of Project Risk

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Abstract: The traditional description method of project risk is analyzed and the good and bad points of these methods are discussed. Multi-dimensional structure, a description method of project risk is put forward. A project risk is discribed from five aspects of risk event such as occurrence probability, lost, predictability, manipulability, the degree of information asymmetries and so on. The function of the risk degree and measurement function of project risk are established. An application case study is provided. Multi-dimensional description and measurement of project risk which can reflect comprehensively the real appearance of project risk, and it is advantageous for us to know and gras Pthe rule of project risk.

Key words: project risk; risk description; risk measurement; multi-dimensional structure

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(上接第 147 页)

Model and Computation of Reload Stock Options with Barriers

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Abstract: Reload stock option is proposed as a executive stock option plan having some drawbacks, and prove that it is necessary to treat the reload option as a barrier option with two barriers. The improved reload option pricing model is established which the long incentive and reload feture of executive stock option are included. The pricing formula of the new option and the simulation analysis of it are discussed.

Key words: reload option; barriers option; martingale

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