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Options, option repricing in managerial compensation: Their effects on corporate investment risk

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ABSTRACT

While stock options are commonly used in managerial compensation to provide desirable incentives, they can create adverse incentives to distort the choice of investment risk. Relative to the risk level that maximizes firm value, call options in a compensation contract can induce too much or too little corporate risk-taking, depending on managerial risk aversion and the underlying investment technology. We show that inclusion of lookback call options in compensation packages has desirable countervailing effects on managerial choice of corporate risk policies and can induce risk policies that increase shareholder wealth. We argue that lookback call options are analogous to the observed practice of option repricing.

1. Introduction

Executive stock options have become an increasingly important and controversial component of managerial compensation. Hall and Murphy (2002) report that stock options account for 40% of total pay for the CEOs of S&P 500 companies in 1998. More recently, option usage has in general decreased but is still substantial. Murphy (2013) reports that options on average represent 21% of grant-date pay for S&P 500 CEOs in 2011 while restricted stocks account for another 36%. The incentives provided by executive stock options are at the center of the ongoing debate surrounding the crisis in corporate governance and spectacular failures, such as Enron, Worldcom, and Global Crossing. Thus, a deeper understanding of the managerial incentives induced by option-type contract is warranted. This paper examines the effects of options on corporate investment risk policies.

Options link a manager's pay to stock performance because the value of a call option is an increasing function of the stock price. But options also affect the willingness of managers to undertake risky investments. Since call values are increasing in volatility, it has been argued that options encourage manager to undertake excessively risky investments. But this reasoning ignores managerial risk-aversion. A risk-averse manager may be willing to sacrifice a higher current stock price for lower future uncertainty.

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Ross (2004) examines the interaction of risk aversion and contract payoffs. He shows that a risk-averse manager may dislike greater risk even when compensated with stock options.[1] Our results extend Ross' work by examining risk choice and optimal compensation contracts when contracts can offer a combination of fixed payments, stock, and stock options (ordinary call options or lookback options). Calibrating managerial stock option holdings and risk aversion to observed data, we find that a typical compensation contract with call options induces sub-optimal levels of investment risk. Granting more call options leads to even more conservative risk levels. This is because, even though more call options increase the expected payoff, they also increase the risk level of the payoff.[2] Thus, the distortionary effect of managerial risk aversion on optimal corporate risk is unlikely to be corrected through simple options in managerial compensation.

We then minimize the total cost to the firm by changing the components of company stock and options in the manager's compensation, given a participation constraint. Compensation with restricted stock rather than call options will induce less risk distortion and higher value for shareholders in our base case. We also consider the effects of parametric changes.

Ross and others make the standard assumption that volatility can be changed without affecting underlying asset value. We generalize past studies to consider the case where the risk policy affects both the initial investment value and the distribution of its terminal value. The manager chooses the risk level to maximize expected utility, recognizing these twin effects. Our results focus on the chosen risk levels, their implications for stockholder value, and the optimal compensation contract.

An interesting result is that, in contrast with ordinary call options, lookback options provide effective inducements to more desirable risk choice. Though regular calls may provide reasonable *ex ante* incentives, they may not provide strong incentives *ex post*. For example, deep out of the money calls provide very weak pay-for-performance incentives and thus lead to option repricing. We explicitly consider option repricing in Section 5 and find that it is effective to induce more risk taking *ex ante*. In the same section we find that inclusion of put options in a compensation contract can also induce more risk taking, consistent with Ross (2004). Both features alleviate a risk averse manager's concern with the downside risk in her portfolio. However, they can lead to *ex post* wrong incentives.

Lookback calls are almost surely in the money all the time, and provide a strong positive link between firm value and the manager's utility because the delta of a lookback call is always greater than one.[3] We argue that lookback calls have real world analogs, namely option repricing, but without its drawbacks. We find that lookbacks prove superior to either ordinary call options or stocks in most numerical cases considered.

The rest of the paper is organized as follows. The next section discusses the most relevant literature and contrasts it with our main results. Section 3 characterizes the investment risk technology and the managerial risk decision problem. Section 4 then provides simulation results that allow us to examine comparative statics. Section 5 examines the impact of including put options and option repricing in the compensation on investment risk choice. Section 6 explores the roles of lookback calls in mitigating the costs associated with suboptimal risk policies. Moreover, it provides an argument for lookback calls to have real world analogs, namely option repricing. Section 7 concludes.

2. Related literature and positioning of the paper

Since the seminal works of Jensen and Meckling (1976) and Myers (1977), there has been a large body of literature studying the agency costs associated with the conflict of interests among the firm's various claimants. Barnea et al. (1985) provide a synthesis of the early literature on agency costs associated with corporate financing choices. Parrino and Weisbach (1999) estimate the magnitude of stockholder–bondholder conflict using Monte Carlo simulation. Mao (2003) considers the interaction of debt induced risk-shifting and under-investment. Parrino et al. (2005) consider the agency conflicts when a risk-averse manager decides whether to undertake a risky project when there is debt in place. To simplify the analysis of the agency costs of managerial compensation, we ignore the classic agency conflict between stockholders and bondholders and only consider that between the manager and stockholders, even though managerial actions also affect bondholders. Aggarwal and Samwick (2003) develop an agency model which relates managerial incentives to firm diversification. In contrast, our model relates managerial incentives to corporate risk policies.

Carpenter (2000) considers a money manager's risk incentive, given a call-type compensation contract. Her setting is different from ours. In our model, changing risk may also affect the value of the firm. In her setting, a money manager can change a portfolio's risk without any costs. There is no agency problem in her model, because the diversified owners can costlessly change their risk exposure through other investments. Ross (2004) examines risk incentive effects of common features such as puts and calls. He too finds that increasing call options may not induce more risk taking. But like in Carpenter (2000), the choice of risk level does not affect firm value. Meulbroek (2001) considers the cost to the firm of granting options to the management, but her concern is to identify the gap between managerial private value and the value of the options determined in the financial markets. She does not address incentive issues that may distort company risk policies.

Leland (1998) also considers costless shifting between two risk levels. He is concerned with the asset substitution problem between debtholders and stockholders. He argues that derivatives may be used to change a firm's risk level. We are concerned

[1] Note that unlike individual investors, executives cannot normally trade or hedge their stock options to eliminate the option risks. They are also usually explicitly or implicitly constrained from selling company stocks.

[2] This result is consistent with Carpenter's (2000) finding that a money manager may choose safer portfolios if given more call options.

[3] See the Appendix A for a formal proof that the delta of a lookback call is greater one.

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with risks associated with irreversible long term investments in real production processes such as like plants and machinery. These investment policies not only affect the risk level but also the value of the firm.

Haugen and Senbet (1981) and Green (1984) are closely related to our paper in that they both consider the role options play in resolving agency problems. Haugen and Senbet (1981) consider the conflict between the owner–manager and outsider capital contributors and show that the agency problems of external financing can be resolved through options. In their model the owner–manager holds call options and outside investors hold put options. The agency problem is resolved, because outside investors are insured for bad states. Green (1984) considers the agency costs created by debt financing. He shows that conversion features and warrants can be used to control debt-induced agency conflicts, and such features can restore net present value maximizing, thus providing a rationale for the use of convertible bonds. We are concerned with the potential conflict of corporate investment risk induced by option-type compensations between the manager and shareholders.

Johnson and Tian (2000a,b) consider the value and incentive effects of various nonstandard options. The values of these options are the risk-neutral market prices, and the incentive effects are computed as the derivatives of the market price with respect to various model parameters. This kind of comparative statics holds all other variables constant and ignores the impact of the change of the underlying variable on the firm value. The incentives we consider are those relating to distortions in firm value and corporate risk policies, consistent with contemporary theories of agency. Furthermore, their study relies on risk-neutral pricing and applies to situations where the options can be dynamically hedged.

There are papers which look at the role of compensation structure in counteracting the risk-shifting problem arising from bondholder–stockholder conflict (e.g., John and John, 1993; John et al., 2000). John and John consider compensation structure consisting of equity participation, salary, and bonus/penalty schemes, and show how these features can be optimally structured to deal with the stockholder–bondholder risk-shifting problem. They argue that the pay-for-performance sensitivity is decreasing in leverage, mitigating somewhat the concern of Jensen and Murphy (1990) of observed low sensitivities. Aggarwal and Samwick (1999) provide empirical evidence that pay-for-performance is decreasing in the variance of firm value. John, Saunders and Senbet consider optimal compensation for the banking industry, and show how the pricing of deposit insurance, that includes incentive features of bank management compensation, can be used as a pre-commitment to an efficient bank investment policy and hence efficient banking regulation.

In this paper we deal with the agency problems between the manager and the stockholders associated with options in managerial compensation. In our model, the firm value is linked to the risk level that the manager adopts, unlike the comparative statics commonly used in the literature. We find that the inclusion of lookback options in a compensation package is effective in aligning a risk-averse manager's interest with that of well-diversified stockholders. Lookback calls have positive payoffs in both good states and bad states, and thus have features similar to a combined portfolio of calls and puts. Unlike a combined portfolio of calls and puts, though, the delta of lookback calls is always greater than 1 and thus they provide reasonable incentives for both good states and bad states for the manager. In contrast, the delta of the repriceable options in Johnson and Tian (2000a) and Brenner et al. (2000) is negative for firm values close to the triggering boundary, thus providing the wrong incentives and calling for repricing.

In a different setting, Brenner et al. (2005) show that, in many situations, rescindable options provide better incentives than regular stock options. Rescindable options allow their holders to rescind their exercise decisions. Thus, rescindable option holders obtain a put option upon their exercise of the option. In this case too an insurance feature like the put option implicit in a rescindable option provides the option holder stronger *ex ante* incentives than without it. Ross (2004) shows that the addition of put options to a compensation package moves the manager's portfolio into a less risk averse portion of the payoff domain and thus she is willing to take on more risk. However, inclusion of explicit or implicit put options (as in rescindable options) can lead to negative deltas for certain firm values, and thus provides the wrong incentive *ex post*. In a theoretic model, Acharya et al. (2000) examine the optimality and incentive effects of option repricing. They find that *ex ante* commitment of option repricing can be value-enhancing, but a negative effect on initial incentives exists. Lookback options do not suffer these types of *ex ante* and *ex post* drawbacks.

Finally, while most papers on executive stock option incentives have focused on the sensitivity analysis of the risk-neutral (market) price of the options with respect to various underlying parameters,[4] we focus our analysis on the effects of stock-based compensations on risk-averse managers' choice on corporate investment risk. In our framework, the cost of a compensation package does not only include the direct cost of the compensation itself, but also the cost of suboptimal investments. This is because changing risk can lower the value of the firm. Indeed, the numerical simulations indicate that the direct cost of a typical compensation package is likely to be much smaller than the cost of potential suboptimal investments. The reason is that, as large as it is, the number of company shares and stock options in a typical compensation package is likely to be a very small fraction of the number of outstanding shares. However, previous work has focused on the discrepancy between private and market valuations of alternative compensation packages, ignoring the more important cost of suboptimal investments.

3. Compensation structure and corporate investment risk

3.1. Firm value as a function of risk: the real sector technology

In this section we address how alternative mixtures of company stock, stock options (including ordinary and lookback calls), and wealth unrelated to company stock (cash and stock holdings in other companies) affect the investment risk policy.

It is well-understood that a call option is an increasing function of the underlying volatility. However, the comparative statics of this type of analysis hold the firm value constant while changing the underlying asset's volatility. For example, Johnson and

[4] For example, delta and vega of the option price. The vega of an option is the partial derivative of the option price with respect to the underlying volatility.

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Tian (2000a,b), Hall and Murphy (2000, 20002), among others, examine the effects of executive stock options by considering comparative statics or certainty equivalent without taking into account the effects of stock options on a manager's decisions which affect the risk level, which in turn affects the firm value.

We assume the (initial) value of the firm as a single-peacked function of volatility, which we approximate by a quadratic function[5]:

$$V_0(\sigma) = V_0 - a\left(\frac{\sigma - \sigma_0}{\sigma_0}\right)^2, \tag{1}$$

where V_0 is the optimal firm value and a is a constant measuring the costliness of deviating from the optimal volatility level, σ_0.

We motivate $V_0(\sigma)$ this way. A firm can have many different investment strategies that result in different firm values and risks. $V_0(\sigma)$ represents the "efficient frontier" in the space of firm value and firm risk. That is, it denotes the highest firm value among all same firm risk strategies. This function has a maximum value $V_0(\sigma)$ at risk level σ_0, resulting from the "first-best" investment policy of adopting all positive NPV projects. Any deviation will result in higher or lower firm risk but lower firm value. To the lowest order, $V_0(\sigma)$ is necessarily a quadratic function around σ_0.

With our base case value $a = 50$, getting the volatility wrong by 100% (from σ_0 to zero or $2\sigma_0$) will reduce the value by half. This can be interpreted as that investing only in the riskless asset will reduce firm value by half. In other words, investing all positive NPV (risky) projects (the first-best investment policy) will double firm value from 50 to 100, i.e. PVGO = 50. The market to book is 2. Thus, the costliness parameter a is a measure of market to book. It is more costly for higher M/B firms to deviate from its optimal investment policies because a higher portion of firm value is derived from these investments. Alternatively, the best investment policy to result in $2\sigma_0$ (an efficient frontier point) has zero PVGO, the same as only investing in the riskless asset. Any other investment policy that results in a firm risk level $2\sigma_0$ will have negative NPV.

3.2. Expected return as a function of risk: the financial sector

In the Black–Scholes framework, because the options can be dynamically hedged, they can be priced as if the return were the risk-free rate. Since they are normally not allowed to sell and hedge their stock options, risk-averse executives will need to use their subjective return distribution to compute their expected utilities. To this end, we consider the following specification:

$$\mu_V(\sigma) = r + \frac{\sigma}{\sigma_0}(\mu_V(\sigma_0) - r), \tag{2}$$

where $\mu_V(\sigma)$ is the expected return corresponding to risk level σ and r is the risk-free rate.

We motivate our choice in the following way. Within the CAPM framework,

$$\frac{\mu_V(\sigma) - r}{\mu_V(\sigma_0) - r} = \frac{\mathrm{Cov}(\tilde{\mu}_V(\sigma), \tilde{\mu}_m)}{\mathrm{Cov}(\tilde{\mu}_V(\sigma_0), \tilde{\mu}_m)}, \tag{3}$$

where $\tilde{\mu}_V(\sigma)$ is the (random) return corresponding to σ and $\tilde{\mu}_m$ the return of the market. Now if we make the assumption that the covariance is proportional to the risk level, σ, then we obtain Eq. (2).

3.3. Firm value dynamics

For a given volatility level, we assume that the firm value evolves according to the following diffusion process,

$$\frac{dV_t(\sigma)}{V_t(\sigma)} = \mu_V(\sigma)dt + \sigma dB_t^V, \tag{4}$$

where B_t^V is a standard Wiener process. Note that the initial firm value $V_0(\sigma)$ is given by Eq. (1) and $\mu_V(\sigma)$ by Eq. (2).

For simplicity we assume that the value of her holdings in other companies follows another diffusion process given by

$$\frac{dS_t}{S_t} = \mu_S dt + \sigma_S dB_t^S, \tag{5}$$

[5] The characterization of the investment risk technology is in the same spirit as earlier papers (e.g., Green and Talmor, 1986; Haugen and Senbet, 1981). For instance, Green and Talmor (1986) assume that the firm value is a decreasing function of the firm's volatility, while examining the asset substitution problem between stockholders and bondholders.

where B_t^S is another standard Wiener process. Let ρ denote the correlation between B_t^V and B_t^S. The terminal values (at T) are given by

$$V_T(\sigma) = V_0(\sigma)e^{(\mu_V(\sigma)-\sigma^2/2)T+\sigma B_T^V}, \tag{6}$$

$$S_T = S_0 e^{(\mu_S-\sigma_S^2/2)T+\sigma_S B_T^S}. \tag{7}$$

3.4. The executive's terminal wealth

Following Hall and Murphy (2002), we assume that the executive has risk-free investment F, holdings of shares of other companies S_0, N_S shares of company stock $V_0(\sigma)$, and N_C call options with strike price K and maturity T years in her portfolio.

To determine the executive's terminal wealth, we first obtain the value of her company holdings (shares and call options). If $V_T(\sigma) < K$, then the options will be out of the money, and the value of her company holdings is $N_S V_T(\sigma)$. If, on the other hand, $V_T(\sigma) > K$, she will exercise her options by paying the strike price K and the original shares will be diluted by the factor $1 + N_C$.[6] In this case the value of her company holdings is

$$N_S\left(\frac{V_T(\sigma)+N_C K}{1+N_C}\right)+N_C\left(\frac{V_T(\sigma)+N_C K}{1+N_C}-K\right) = N_S V_T(\sigma)+\frac{N_C(1-N_S)}{1+N_C}(V_T(\sigma)-K).$$

Therefore, the executive's terminal wealth can be written as

$$W_T = Fe^{rT}+S_T+N_S V_T(\sigma)+\frac{N_C(1-N_S)}{1+N_C}\max(V_T(\sigma)-K,0). \tag{8}$$

Note that F in Eq. (8) can be interpreted as the sum of the base pay and the manager's non-company wealth that is invested in the riskless asset, as in Eq. (2) in Dittmann and Maug (2007). However, we will not consider base pay as a choice variable explicitly even though inevitably it is an important consideration in any compensation. The reason is that if we choose the riskless F, shares N_S and calls N_C in Eq. (8) to satisfy utility and minimize cost, N_S and N_C will be zero, resulting in no incentive.

3.5. Optimal corporate risk policy

Given her terminal wealth, the executive makes her decision to maximize her expected utility. To this end, we assume that the manager has a constant relative risk-aversion utility function,

$$U(W_T) = \frac{W_T^{1-\Lambda}}{1-\Lambda}, \tag{9}$$

where Λ is her relative risk-aversion coefficient. The executive chooses the volatility level by maximizing her expected utility,

$$\max_{\sigma} E\left[\frac{\left(Fe^{rT}+S_T+N_S V_T(\sigma)+\frac{N_C(1-N_S)}{1+N_C}\max(V_T(\sigma)-K,0)\right)^{1-\Lambda}}{1-\Lambda}\right], \tag{10}$$

where $V_T(\sigma)$ and S_T are respectively given by Eqs. (6) and (7).

The risk level σ affects the expected utility in Eq. (10) in two ways. First, it affects the distribution of the terminal firm value $V_T(\sigma)$. The call options prefer a more volatile distribution resulting from a higher σ while a risk averse manager prefers a less volatile distribution resulting from a lower σ. The tradeoff between these two effects determines the optimal maximizing σ even if the initial value V_0 does not depend on σ. Second, in our model, σ also affects the expected utility more directly through its effect on the initial value $V_0(\sigma)$ specified in Eq. (1).

The optimal risk choice by the manager may depart from the firm value maximizing strategy, σ_0. Problem (10) cannot be solved analytically. The first order condition can be expressed as an integral and the resulting risk policy can be obtained by solving the root of the first order condition. Alternatively, as it is done in this paper, the risk policy can be obtained as the solution of the maximization problem. It is obvious that the solution depends on the parameters of the problem. Numerical simulations are used to assess the comparative statics.

[6] We normalize the original total number of shares outstanding to 1.

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Table 1
Risk effects of compensation contracts with regular calls.

	σ	$V_0(\sigma)$	VC	TC	$E[U(W_T)]$	$10^3\ \frac{\partial E[U]}{\partial V}$	10^3PPS
Base	0.270	95.846	32.504	4.583	−0.9812	4.707	4.890
$\Lambda = 0$	0.553	89.599	47.529	10.868	1.6371	12.148	12.148
$\Lambda = 4$	0.174	85.299	23.425	15.062	−0.5146	7.994	4.480
$a = 10$	0.184	97.352	27.385	3.063	−0.9526	4.872	5.369
$a = 30$	0.239	95.896	30.479	4.526	−0.9710	4.796	5.086
$a = 70$	0.290	96.094	33.902	4.342	−0.9875	4.636	4.753
$a = 90$	0.304	96.392	34.923	4.048	−0.9919	4.580	4.655
$N_C = 0.0\%$	0.290	97.201	34.283	3.110	−1.0952	4.863	4.055
$N_C = 0.2\%$	0.280	96.552	33.393	3.824	−1.0273	4.774	4.523
$N_C = 0.5\%$	0.264	95.349	31.917	5.114	−0.9554	4.670	5.116
$N_C = 1.0\%$	0.240	93.185	29.633	7.406	−0.8738	4.558	5.970
$N_S = 0.0\%$	0.348	99.636	39.119	0.512	−1.5761	2.412	0.971
$N_S = 0.2\%$	0.283	96.767	33.679	3.554	−1.1406	4.466	3.433
$N_S = 0.5\%$	0.259	94.942	31.456	5.651	−0.8129	4.673	7.070
$N_S = 1.0\%$	0.244	93.629	30.071	7.420	−0.5534	4.026	13.144
$f_{NC} = 0.0$	0.275	96.155	32.884	4.277	−1.0656	5.386	4.743
$f_{NC} = 0.5$	0.274	96.098	32.813	4.333	−1.0017	4.822	4.806
$f_{NC} = 1.0$	0.270	95.846	32.504	4.583	−0.9812	4.707	4.890
$K = 0.5\ V_0(\sigma)$	0.236	92.850	57.136	7.663	−0.8636	4.905	6.577
$K = 0.8\ V_0(\sigma)$	0.253	94.432	40.246	6.022	−0.9418	4.799	5.410
$K = 1.2\ V_0(\sigma)$	0.284	96.780	26.585	3.630	−1.0100	4.661	4.569
$K = 1.5\ V_0(\sigma)$	0.295	97.517	19.877	2.870	−1.0391	4.646	4.303
$NCW_0 = 0.2$	0.250	94.154	30.608	6.263	−1.2360	7.326	4.796
$NCW_0 = 0.5$	0.293	97.374	34.535	3.068	−0.7557	2.881	5.045
$NCW_0 = 1.0$	0.332	99.197	37.863	1.263	−0.4684	1.195	5.448

Column 1 represents the value of one parameter. The other parameters are fixed at their base values. Columns 2–7 report the volatility chosen, the current firm value, the market value of one regular call, the total cost to the firm which is defined as the cost of deviating from the optimal σ_0, $a((\sigma - \sigma_0)/\sigma_0)^2$, plus the market values of company shares and regular calls in the compensation, the expected utility, partial derivative of the expected utility with respect to the initial firm value, and PPS which is defined as the partial derivative of the manager's certainty equivalent with respect to the initial firm value, i.e. PPS $= \frac{\partial U^{-1}(E[U])}{\partial V}$, respectively.

4. Simulation results

In this section we report results from numerical simulations. First, let NCW_0 be the initial non-company wealth and f_{NC} be the fraction of NCW_0 invested in other companies.[7] We adopt the following base values: $V_0 = 100$, $r = 5\%$, $\sigma_0 = 0.38$, $\mu_V(\sigma_0)–r = 7\%$, $\sigma_S = 0.2$, $\rho = 0.2$, $\mu_S = 12\%$,[8] $\Lambda = 2$, $NCW_0 = 0.32$, $f_{NC} = 0.8$, $T = 5$,[9] $N_S = 0.32\%$ and $N_C = 0.38\%$.[10] For the base case, we assume the parameter for the costliness to deviate from optimal risk, $a = 50$. The strike price of the call option is fixed at the initial stock price unless stated otherwise. The results are reported in Table 1. Several interesting features are noteworthy, and we discuss them below.

4.1. Effect of risk-aversion

If $\Lambda = 0$, then the option analog applies. The risk-neutral manager always chooses a risk level higher than the firm value maximizing one. The reason is that the first order derivative of $V_0(\sigma)$ at σ_0 is zero, but that of the expected utility (expected payoff in this case) is positive. Therefore, the option effect dominates the decline of $V_0(\sigma)$ for σ near σ_0. On the other hand, if Λ is large, the manager is so risk-averse that she will only adopt very safe investments. For a given set of parameters, there is a particular Λ such that the manager will choose the optimal volatility level (0.38).

4.2. Effect of investment technology

For the base parameters, the easier it is to deviate from the optimal risk policy, the more the manager deviates. However, more deviation from the optimal risk level when a is small does not necessarily mean the agency cost is larger because a smaller a means that it is less costly to deviate.[11] It appears, in our examples, that the agency cost is most severe for moderate values of a. There are three factors at play. First, the manager wants to keep σ at σ_0. Any deviation lowers the initial firm value. Second,

[7] That is, investment in the riskless asset is $F = (1 - f_{NC})NCW_0$ and that in other companies is $S_0 = f_{NC}NCW_0$.

[8] A manager's outside stock holdings should be considered as a well-diversified portfolio. $\sigma_S = 0.2$ is the typical market volatility level and $\rho = 0.2$ is the correlation coefficient of a typical stock with the market. $\mu_S = 12\%$ is the historical average return of the market.

[9] Executive stock options have maturity up to ten years. Since they are normally exercised early, the effective maturity is shorter. See Hall and Murphy (2002) for details.

[10] Parrino et al. (2005) estimate that on a normalized basis the average manager among 1405 firms has 0.32% company shares and 0.38% calls. They also report that the volatility of a typical firm is 0.38.

[11] Agency cost is defined as the deviation of the firm value, $V_0(\sigma)$, from $V_0(\sigma_0) = V_0$.

because she is risk-averse, she has an incentive to lower the risk level. Third, she wants to increase the risk level because of the call option in her portfolio. The resulting risk level the manager takes depends on the relative strength of these factors. For our parameters, the risk-aversion factor dominates.

4.3. Effect of increasing the portion of call option or company shares or non-company shares

Intuition suggests that the larger the call option portion in her portfolio, the higher the risk level the manager is going to take. Certainly, the intuition holds for a risk-neutral manger. However, the third group of results (changing the number of call options) shows that, if the manager is risk-averse, she may take lower risk level as the call option portion in her portfolio increases. The reason is that as the call portion becomes larger and larger, her overall portfolio becomes riskier and riskier for a given σ. Therefore, she may reduce the risk level of the firm to reduce her portfolio risk. The effect of increasing the company stock component in a manager's portfolio is similar to that of increasing stock options and leads to lower risk taking. By increasing the portion of non-company wealth in shares of other companies, the resulting portfolio also becomes riskier, thus the manager will optimally choose safer investments.

4.4. Effect of option strike price

Table 1 shows that, for most of the cases we considered, the resulting σ is below the value maximizing σ_0. Now we consider the incentive implications if we change the strike price of the call option (the sixth group of results). Confirming our intuition, the higher the strike price, the higher the risk level the manager is going to take. For very low strike prices, the manager chooses low risk level, since the option is already deep in the money. For deep out of the money options, high volatility is needed to ensure that the options have a non-negligible probability to finish in the money. Note also that higher strike price has the effect of reducing the value of the option portion of the compensation, and thus reduces the overall risk level of the manager's portfolio. This is consistent with the conclusion from the previous paragraph.

This then raises the question why commonly observed executive stock options are granted at the money. Hall and Murphy (2000, 2002) have specifically analyzed this question. They argue that "Accounting and tax considerations may explain why discount and indexed options are not popular, but do not explain the paucity of premium options." Their explanation to the paucity of premium options is based on their analyses on the incentives (pay for performance sensitivity, PPS) that these options provide. They find that on the basis of equal cost of options, for most reasonable parameter values, premium options provide fewer incentives than those of at-the-money or near-the-money options.

To examine the incentives options with different strike prices provide in our model, we calculate the PPS for their five entries with different strike prices in Table 1 (base case plus the four cases in the second to last group with four different K's). Although Table 1 already indicates that the PPS declines with the strike price, the comparison is not very meaningful since the entries yield different utility. To this end, we choose the number of calls to yield the same utility as in the base case. We find these values for the PPS: $10^{-3}(5.10,5.00,4.89,4.76,4.58)$, corresponding to $K = (0.5,0.8,1.0,1.2,1.5)V_0(\sigma)$. The corresponding total cost to firm is given by: $\text{TC} = (5.09,5.05,4.58,3.98,3.23)$. If we choose the number of calls to yield the same cost of call options as in the base case, the corresponding values are given by: $\text{PPS} = 10^{-3}(5.44,5.14,4.89,4.66,4.42)$ and $\text{TC} = (5.69,5.37,4.58,3.81,2.96)$.

Thus, our analysis reveals that while premium options can induce higher risk-taking as the intuition suggests, they provide fewer incentives. In our model discount options provide more incentives but are also more costly to provide because they induce less risk taking which reduces firm value. Total cost consideration calls for higher strike prices but the PPS consideration calls for lower strike prices. Besides accounting and tax considerations, at-the-money options offer a good balance.

4.5. Effect of diversification

If the relative portion of the company stock and call option is small in the manager's portfolio (large NCW_0),[12] the manager has incentives to increase risk to maximize her call option payoff, since she does not have much concern if the options finish out of the money.

The results with different f_{NC} in Table 1 seem to suggest that a significant flat fee component will induce the manager to take higher (more desirable) risk level, because lower f_{NC} corresponds to higher portion of riskless holdings. However, caution is needed. First, NCW_0 represents the manager's non-company wealth, mostly her well-diversified holdings of securities of other companies and riskless asset. Therefore, NCW_0 (and its investment) are not controllable by the firm. It is better to interpret that each different NCW_0 represents a different manager rather than the same manager.[13] Second, as we have emphasized earlier, $V_0(\sigma)$ is not the only possible firm value for the risk level σ, but it happens to be the highest among different investment policies. If the manager's compensation is not tied to the firm's performance (e.g. via a flat fee), then the manager may adopt any one of many possible investment policies that can result in lower firm values for the same risk level.

[12] Since NCW_0 is the well-diversified portion (outside stock holdings and riskless asset) of her portfolio which is independent of company performance, by changing the value of NCW_0, we change the diversification of her overall portfolio.

[13] Similarly, different a's should be interpreted as representing different investment technologies (different firms).

Table 2
Minimizing the total cost with company shares and regular calls.

	σ	$V_0(\sigma)$	10^2N_S	VC	10^2N_C	TC	$10^3\frac{\partial E[U]}{\partial V}$	10^3PPS
Base	0.281	96.609	0.407	33.468	0.000	3.784	4.907	5.097
$\Lambda = 0$	0.506	94.534	0.563	47.235	0.000	5.998	11.514	11.514
$\Lambda = 4$	0.204	89.267	0.371	26.243	0.000	11.065	7.898	4.427
$a = 10$	0.192	97.565	0.402	27.950	0.029	2.835	5.008	5.518
$a = 30$	0.250	96.489	0.408	31.363	0.000	3.905	4.977	5.279
$a = 70$	0.300	96.869	0.406	34.808	0.000	3.524	4.853	4.976
$a = 90$	0.313	97.177	0.405	35.800	0.000	3.217	4.807	4.886
$N_C = 0.0\%$	0.290	97.178	0.320	34.249	0.001	3.133	4.865	4.056
$N_C = 0.2\%$	0.285	96.863	0.369	33.810	0.000	3.495	4.901	4.644
$N_C = 0.5\%$	0.279	96.467	0.430	33.282	0.000	3.948	4.902	5.371
$N_C = 1.0\%$	0.273	96.021	0.511	32.718	0.000	4.470	4.848	6.350
$N_S = 0.0\%$	0.355	99.778	0.046	39.665	0.186	0.341	3.000	1.208
$N_S = 0.2\%$	0.294	97.425	0.291	34.611	0.000	2.858	4.817	3.702
$N_S = 0.5\%$	0.268	95.683	0.583	32.307	0.000	4.876	4.770	7.218
$N_S = 1.0\%$	0.251	94.229	1.078	30.686	0.000	6.787	4.042	13.198
$f_{NC} = 0.0$	0.287	97.022	0.409	34.030	0.000	3.375	5.646	4.973
$f_{NC} = 0.5$	0.285	96.860	0.408	33.806	0.000	3.536	5.047	5.030
$f_{NC} = 1.0$	0.281	96.609	0.407	33.468	0.000	3.784	4.907	5.097
$K = 0.5\ V_0(\sigma)$	0.272	95.965	0.523	59.516	0.000	4.536	4.838	6.486
$K = 0.8\ V_0(\sigma)$	0.278	96.391	0.442	42.249	0.000	4.035	4.898	5.521
$K = 1.2\ V_0(\sigma)$	0.285	96.866	0.352	26.711	0.173	3.520	4.787	4.693
$K = 1.5\ V_0(\sigma)$	0.298	97.650	0.291	20.104	0.757	2.785	4.453	4.124
$NCW_0 = 0.2$	0.265	95.454	0.399	32.038	0.000	4.927	7.519	4.922
$NCW_0 = 0.5$	0.297	97.640	0.411	34.936	0.020	2.768	3.037	5.319
$NCW_0 = 1.0$	0.332	99.205	0.314	37.884	0.402	1.257	1.190	5.423

Column 1 represents the entries of Table 1. The other parameters are fixed at their base values except the number of company shares and the number of regular calls which are chosen to minimize the total cost but yield the same utility level as each corresponding entry in Table 1. Columns 2–8 report the volatility chosen, the current firm value, the number of shares chosen, the market price of one regular call, the number of regular calls chosen, the total cost to the firm which is defined as the cost of deviating from the optimal σ_0, $a((\sigma-\sigma_0)/\sigma_0)^2$, plus the market values of company shares and regular calls in the compensation, and the partial derivative of the expected utility with respect to the initial firm value, and PPS which is defined as the partial derivative of the manager's certainty equivalent with respect to the initial firm value, i.e. PPS $= \frac{\partial U^{-1}(E[U])}{\partial V}$, respectively.

Table 3
Minimizing the total cost with regular calls and puts.

	σ	$V_0(\sigma)$	VC	10^2N_C	10^2N_P	TC	$10^3\frac{\partial E[U]}{\partial V}$	10^3PPS
Base	0.293	97.397	34.568	0.310	0.829	3.032	4.684	4.866
$\Lambda = 0$	0.553	89.589	47.529	0.370	0.221	10.890	12.150	12.150
$\Lambda = 4$	0.220	91.130	27.762	0.296	2.846	9.251	7.401	4.148
$a = 10$	0.224	98.317	30.228	0.348	3.025	2.112	4.757	5.242
$a = 30$	0.268	97.402	32.878	0.323	1.215	3.025	4.729	5.015
$a = 70$	0.309	97.576	35.716	0.302	0.672	2.854	4.645	4.764
$a = 90$	0.321	97.823	36.595	0.296	0.585	2.608	4.612	4.687
$N_C = 0.2\%$	0.291	97.245	34.347	0.165	0.455	3.128	4.785	4.535
$N_C = 0.5\%$	0.293	97.402	34.576	0.405	1.083	3.063	4.623	5.065
$N_C = 1.0\%$	0.292	97.348	34.496	0.803	2.169	3.265	4.383	5.741
$N_S = 0.0\%$	0.401	99.846	42.886	0.317	0.344	0.303	2.570	1.034
$N_S = 0.2\%$	0.312	98.382	36.171	0.314	0.683	1.940	4.460	3.428
$N_S = 0.5\%$	0.278	96.367	33.153	0.304	0.998	4.225	4.640	7.022
$N_S = 1.0\%$	0.256	94.693	31.182	0.290	1.322	6.352	3.999	13.058
$f_{NC} = 0.0$	0.295	97.517	34.747	0.318	0.831	2.916	5.377	4.735
$f_{NC} = 0.5$	0.295	97.519	34.751	0.314	0.819	2.912	4.809	4.793
$f_{NC} = 1.0$	0.293	97.397	34.568	0.310	0.829	3.032	4.684	4.866
$K = 0.5\ V_0(\sigma)$	0.270	95.808	59.387	0.335	2.244	4.716	4.756	6.378
$K = 0.8\ V_0(\sigma)$	0.282	96.646	42.539	0.322	1.269	3.813	4.717	5.318
$K = 1.2\ V_0(\sigma)$	0.302	97.890	28.351	0.299	0.579	2.516	4.669	4.577
$K = 1.5\ V_0(\sigma)$	0.309	98.251	21.214	0.285	0.376	2.129	4.672	4.326
$NCW_0 = 0.2$	0.277	96.354	33.136	0.302	0.995	4.064	7.218	4.725
$NCW_0 = 0.5$	0.311	98.368	36.147	0.318	0.694	2.072	2.890	5.061
$NCW_0 = 1.0$	0.345	99.565	38.883	0.330	0.528	0.894	1.207	5.499

Column 1 represents the entries of Table 1. The other parameters are fixed at their base values except that the regular calls are replaced with regular calls and puts. The strike price of the puts is set at half of the initial firm value and their number is determined such that their total market value is 10% of that of the calls. Columns 2–8 report the volatility chosen, the current firm value, the market price of one regular call, the number of regular calls which is chosen to yield the same utility level as each corresponding entry in Table 1, the number of regular puts, the total cost to the firm which is defined as the cost of deviating from the optimal σ_0, $a((\sigma-\sigma_0)/\sigma_0)^2$, plus the market values of company shares and regular calls and puts in the compensation, and the partial derivative of the expected utility with respect to the initial firm value, and PPS which is defined as the partial derivative of the manager's certainty equivalent with respect to the initial firm value, i.e. PPS $= \frac{\partial U^{-1}(E[U])}{\partial V}$, respectively.

Table 4
Risk effects of compensation contracts with repriciable calls.

	σ	$V_0(\sigma)$	VLB	$10^2 N_L$	TC	$10^3 \frac{\partial E[U]}{\partial V}$	10^3PPS
Base	0.297	97.615	37.152	0.337	2.821	4.496	4.670
$\gamma = 0$	0.548	90.188	53.168	0.384	10.303	12.451	12.451
$\gamma = 4$	0.208	89.787	27.109	0.151	10.541	6.838	3.832
$a = 10$	0.215	98.116	30.164	0.383	2.313	4.677	5.154
$a = 30$	0.272	97.586	34.900	0.355	2.849	4.559	4.836
$a = 70$	0.312	97.790	38.627	0.326	2.647	4.448	4.562
$a = 90$	0.323	97.964	39.638	0.318	2.475	4.414	4.487
$N_C = 0.2\%$	0.298	97.648	37.216	0.179	2.731	4.593	4.352
$N_C = 5.0\%$	0.297	97.619	37.160	0.441	2.856	4.429	4.852
$N_C = 1.0\%$	0.291	97.254	36.466	0.875	3.373	4.210	5.515
$N_S = 0.0\%$	0.435	98.950	49.853	0.256	1.177	2.339	0.941
$N_S = 0.2\%$	0.322	98.835	39.911	0.314	1.488	4.196	3.225
$N_S = 0.5\%$	0.277	96.340	34.897	0.362	4.267	4.531	6.857
$N_S = 1.0\%$	0.252	94.363	32.051	0.408	6.710	3.984	13.011
$f_{NC} = 0.0$	0.298	97.666	37.252	0.334	2.770	5.279	4.649
$f_{NC} = 0.5$	0.298	97.655	37.231	0.363	2.792	4.721	4.705
$f_{NC} = 1.0$	0.297	97.615	37.152	0.337	2.821	4.496	4.670
$K = 0.5\ V_0(\sigma)$	0.273	96.071	62.955	0.354	4.457	4.650	6.236
$K = 0.8\ V_0(\sigma)$	0.288	97.045	45.923	0.341	3.421	4.549	5.129
$K = 1.2\ V_0(\sigma)$	0.305	98.039	30.352	0.335	2.376	4.468	4.380
$K = 1.5\ V_0(\sigma)$	0.311	98.340	22.547	0.333	2.049	4.468	4.139
$NCW_0 = 0.2$	0.275	96.160	34.610	0.355	4.270	7.051	4.615
$NCW_0 = 0.5$	0.321	98.807	39.838	0.313	1.633	2.725	4.772
$NCW_0 = 1.0$	0.358	99.833	43.619	0.262	0.600	1.104	5.032

Column 1 represents the entries of Table 1. The other parameters are fixed at their base values except that regular calls are replaced by repriciable calls. The strike price of the calls is reduced by half if the firm value ever falls below half of its initial value. Columns 2–7 represent the volatility chosen, the current firm value, the market price of one repriciable call, the number of repriciable calls which is chosen to yield the same utility level as each corresponding entry in Table 1, the total cost to the firm which is defined as the cost of deviating from the optimal σ_0, $a((\sigma-\sigma_0)/\sigma_0)^2$, plus the market values of company shares and repriciable calls in the compensation, the partial derivative of the expected utility with respect to the initial firm value, and PPS which is defined as the partial derivative of the manager's certainty equivalent with respect to the initial firm value, i.e. PPS $= \frac{\partial U^{-1}(E[U])}{\partial V}$, respectively.

Table 5
Risk effects of compensation contracts with lookback calls.

	σ	$V_0(\sigma)$	VLB	$10^2 N_L$	TC	$10^3 \frac{\partial E[U]}{\partial V}$	10^3PPS
Base	0.301	97.864	49.555	0.213	2.554	4.588	4.766
$\gamma = 0$	0.540	91.163	63.627	0.344	9.346	12.318	12.318
$\gamma = 4$	0.216	90.722	38.019	0.082	9.599	6.821	3.823
$a = 10$	0.242	98.672	43.998	0.246	1.752	4.687	5.165
$a = 30$	0.280	97.906	47.475	0.224	2.513	4.638	4.920
$a = 70$	0.316	97.992	50.950	0.206	2.426	4.547	4.663
$a = 90$	0.326	98.156	51.956	0.201	2.262	4.514	4.589
$N_C = 0.2\%$	0.299	97.734	49.266	0.118	2.637	4.650	4.406
$N_C = 0.5\%$	0.302	97.896	49.627	0.272	2.552	4.550	4.985
$N_C = 1.0\%$	0.302	97.897	49.630	0.497	2.661	4.405	5.770
$N_S = 0.0\%$	0.433	99.037	61.540	0.179	1.073	2.688	1.082
$N_S = 0.2\%$	0.325	98.945	52.298	0.202	1.359	4.351	3.345
$N_S = 0.5\%$	0.282	96.643	47.047	0.225	3.946	4.578	6.928
$N_S = 1.0\%$	0.256	94.690	43.665	0.248	6.364	3.990	13.031
$f_{NC} = 0.0$	0.303	97.941	49.730	0.211	2.476	5.391	4.748
$f_{NC} = 0.5$	0.303	97.922	49.686	0.228	2.504	4.828	4.812
$f_{NC} = 1.0$	0.301	97.864	49.555	0.213	2.554	4.588	4.766
$K = 0.5\ V_0(\sigma)$	0.302	97.888	49.610	0.529	2.685	4.384	5.878
$K = 0.8\ V_0(\sigma)$	0.302	97.906	49.650	0.306	2.558	4.528	5.106
$K = 1.2\ V_0(\sigma)$	0.300	97.784	49.377	0.152	2.604	4.628	4.537
$K = 1.5\ V_0(\sigma)$	0.299	97.715	49.226	0.095	2.644	4.661	4.317
$NCW_0 = 0.2$	0.282	96.653	47.067	0.213	3.756	7.153	4.683
$NCW_0 = 0.5$	0.323	98.856	52.042	0.208	1.568	2.791	4.888
$NCW_0 = 1.0$	0.357	99.814	55.672	0.189	0.610	1.128	5.142

Column 1 represents the entries of Table 1. The other parameters are fixed at their base values except that regular calls are replaced by lookback calls. Columns 2–7 represent the volatility chosen, the current firm value, the market price of one lookback call, the number of lookback calls which is chosen to yield the same utility level as each corresponding entry in Table 1, the total cost to the firm which is defined as the cost of deviating from the optimal σ_0, $a((\sigma-\sigma_0)/\sigma_0)^2$, plus the market values of company shares and lookback calls in the compensation, the partial derivative of the expected utility with respect to the initial firm value, and PPS which is defined as the partial derivative of the manager's certainty equivalent with respect to the initial firm value, i.e. PPS $= \frac{\partial U^{-1}(E[U])}{\partial V}$, respectively.

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Table 6
Minimizing the total cost with company shares and lookback calls.

	σ	$V_0(\sigma)$	10^2N_S	VLB	10^2N_L	TC	$10^3\frac{\partial E[U]}{\partial V}$	10^3PPS
Base	0.353	99.741	0.000	55.261	1.068	0.843	3.685	3.828
$\Lambda = 0$	0.503	94.751	0.581	63.814	0.000	5.799	11.852	11.852
$\Lambda = 4$	0.237	92.914	0.000	40.986	1.604	7.732	4.338	2.432
$a = 10$	0.332	99.842	0.000	53.468	1.151	0.766	3.715	4.094
$a = 30$	0.345	99.740	0.000	54.541	1.097	0.852	3.700	3.924
$a = 70$	0.357	99.744	0.000	55.649	1.051	0.835	3.677	3.771
$a = 90$	0.361	99.766	0.000	55.985	1.039	0.809	3.670	3.729
$N_C = 0.0\%$	0.367	99.937	0.000	56.601	0.781	0.501	3.669	3.059
$N_C = 0.2\%$	0.358	99.831	0.000	55.776	0.941	0.690	3.689	3.496
$N_C = 0.5\%$	0.349	99.673	0.000	54.921	1.147	0.950	3.679	4.030
$N_C = 1.0\%$	0.339	99.426	0.000	53.884	1.439	1.338	3.630	4.753
$N_S = 0.0\%$	0.380	100.000	0.066	57.781	0.055	0.098	2.990	1.204
$N_S = 0.2\%$	0.372	99.979	0.000	57.117	0.689	0.412	3.640	2.798
$N_S = 0.5\%$	0.331	99.180	0.003	53.027	1.700	1.709	3.576	5.411
$N_S = 1.0\%$	0.298	97.667	0.000	49.121	3.854	4.156	3.035	9.910
$f_{NC} = 0.0$	0.349	99.677	0.000	54.941	1.072	0.905	4.307	3.793
$f_{NC} = 0.5$	0.351	99.710	0.000	55.104	1.089	0.883	3.878	3.865
$f_{NC} = 1.0$	0.353	99.741	0.000	55.261	1.068	0.843	3.685	3.828
$K = 0.5\ V_0(\sigma)$	0.338	99.387	0.000	53.740	1.481	1.397	3.621	4.854
$K = 0.8\ V_0(\sigma)$	0.347	99.634	0.000	54.738	1.191	1.010	3.674	4.142
$K = 1.2\ V_0(\sigma)$	0.356	99.794	0.000	55.553	0.987	0.749	3.690	3.618
$K = 1.5\ V_0(\sigma)$	0.359	99.854	0.000	55.927	0.911	0.652	3.688	3.415
$NCW_0 = 0.2$	0.327	99.029	0.000	52.551	1.194	1.591	5.617	3.677
$NCW_0 = 0.5$	0.373	99.983	0.025	57.186	0.903	0.554	2.349	4.112
$NCW_0 = 1.0$	0.378	99.999	0.217	57.631	0.393	0.444	1.079	4.917

Column 1 represents the entries of Table 1. The other parameters are fixed at their base values except that regular calls are replaced by lookback calls. The number of company shares and number of lookback calls are chosen to minimize the total cost but yield the same utility level as each corresponding entry in Table 1. Columns 2–8 represent the volatility chosen, the current firm value, the number of shares chosen, the market price of one lookback call, the number of lookback calls chosen, the total cost to the firm which is defined as the cost of deviating from the optimal σ_0, $a((\sigma - \sigma_0)/\sigma_0)^2$, plus the market values of company shares and lookback calls in the compensation, the partial derivative of the expected utility with respect to the initial firm value, and PPS which is defined as the partial derivative of the manager's certainty equivalent with respect to the initial firm value, i.e. PPS $= \frac{\partial U^{-1}(E[U])}{\partial V}$, respectively.

4.6. Utility and pay-performance sensitivities with respect to the firm value

In column 7, we report the partial derivative of the expected utility with respect to the firm value (utility sensitivity). In column 8, we report the partial derivative of the certainty equivalent of the manager's wealth with respect to the firm value (pay-performance sensitivity denoted by PPS). While a pay-for-performance sensitivity level or the derivative of the manager's utility with respect to the firm value can be optimized, we argue that minimizing the total cost to the firm is more critical. Basically, we have two choices. Given that a compensation package satisfies a given level of utility (reservation level), we could either minimize the total cost to the firm (including the agency cost of deviating from the optimal σ_0) or maximize the sensitivity level (either pay-for-performance or utility-performance). We have chosen to keep the utility level in Tables 2–6 the same for each corresponding entry in Table 1 and minimize the total cost to the firm. The reason is that a sensitivity analysis on utility depends only on the value and structure of the compensation package and does not measure the magnitude of agency cost resulting from suboptimal choice of the risk level. Since the stock-based compensation of a typical manager is normally a very small fraction of a firm's capitalization, concentrating only on the compensation package severely underestimates the true cost to the firm, because the (neglected) agency cost can be a major component. Consequently, we have chosen to minimize the total cost to the firm by changing the mixture of the stock-based components (restricted stocks vs. regular calls or lookback calls).

4.7. Minimizing the total cost to the firm

Having examined the effects of various combinations of input values, we now consider the optimal combinations between the stock-based components of the compensation (company shares and stock options). The optimal combination is the one that minimizes the total cost to the firm, while preserving the manager's utility. That is, we seek to choose combinations of the number of shares and number of calls such that the manager achieves the same utility as she would from the portfolio corresponding to each entry in Table 1.

The total cost to the firm is defined as the agency cost, $a((\sigma - \sigma_0)/\sigma_0)^2$, plus the value of shares and calls held by the manager. We do not include the non-company wealth as a choice variable, because it is beyond the control of the firm. We note from Table 1 that in most cases the value of shares and calls held by the manager is a small fraction of the total cost to the firm, and the agency cost of distortion from the first best optimal value predominates. Therefore, reducing the agency cost is more important than controlling the cost of the compensation. However, most papers on executive options have concentrated on the

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compensation's cost to the firm and/or certainty equivalent to a risk-averse manager. Ours, on the other hand, focuses on the potential conflicts between risk-averse managers and well-diversified shareholders generated by option-type compensations.

Table 2 indicates that, for most cases, it is more cost-effective to use company shares than regular options to achieve a given level of utility for the manager, consistent with the finding in Dittmann and Maug (2007).[14] This is because, for a risk-averse manager, options are the most risky assets in her portfolio. This then brings the difficult question whether a model is correct or the current practice of awarding options is flawed. Granted, no model can capture the complex contracting problem, but there is a trend of relying less on options. For example, Microsoft has completely abandoned awarding options in employee compensations.

However, we do notice that if the manager has substantial non-company wealth (NCW_0 in the last group of entries), call options may become desirable. For example, the last entry indicates that the manager should increase her option holding from 0.38% to 0.402%, compared with the entry in Table 1. The implication is that options will be more desirable for wealthier managers if they diversify their wealth away from company related holdings.

5. The impact of put options and option repricing on investment risk choices

A risk-averse manager prefers a lower risk level (below σ_0) because she is concerned with her portfolio value for low firm values. At maturity, for firm values below the strike price, the call option portion of her portfolio is worthless. Any relief of her concern for low firm values will induce her to choose higher and more desirable risk levels. Here we consider two commonly observed features in compensation packages which can be explicit or implicit, namely severance packages and option pricing. To mimic severance packages, we include put options in the compensation package.

5.1. The impact of put options on investment risk choice

Table 3 considers those cases in Table 1 with put options. The strike price of the put options is chosen to be half of the initial firm value. The number of put options is chosen in such a way that the total Black–Scholes (market) value for the puts is 10% that of the call options while the number of calls is chosen such that the manager achieves the same utility in Table 1. The table shows that it is quite effective to use put options to reduce the agency cost associated with deviations from the optimal risk level. There are two reasons. First, like a call, a put is also an increasing function of the volatility. Second, a put insures the manager when the firm's fortune deteriorates. Since the manager's marginal utility at lower wealth is bigger, a put option is very effective in reducing her concern for low firm values. Therefore, she is willing to take riskier and more desirable risky investments.

Put options are only incentive compatible *ex ante*. If near the maturity date, the call options are deep out-of-the-money, the manager may want to take actions to drive the price down so that her put options will be in-the-money. Therefore, put options are not *ex post* incentive compatible. This problem can be constrained in that the manager may want to preserve her reputation; or she does not want to reduce the value of her holdings in company stock; or the call options will be repriced; or because most investments are long term and irreversible so that the manager's ability to change the short-run stock price may be limited.

5.2. Interpreting put options: severance packages

Even though put options have been shown to be effective in reducing agency conflicts resulting from risk aversion, they are not explicitly included in observed compensation contracts. Haugen and Senbet (1981) consider the effect of including a negative position in put in their manager–owner's compensation to eliminate the agency problem. They interpret their results by arguing that a put option feature exists if one takes a close look at corporate securities issued in practice, particularly convertible bonds.

Here we wish to provide analogous real world interpretation of the put options. In Haugen and Senbet (1981), the put options are held by outsiders. However, in our present modeling, the put options are held by the manager. Even though put options are not explicitly observed in a manager's compensation contract, we interpret that severance packages offered explicitly or implicitly serve as an insurance for the manager if a bad draw of the firm value occurs.[15] Therefore, severance packages (explicit or implicit or the possibility of them) have effects analogous to put options and give the manager the incentives to take more (desirable) risk.[16] In a recent empirical work, Rau and Xu (2013) find that severance packages can be a valuable component in compensation packages.

5.3. The impact of option repricing on investment risk choice

When executive options are deep out of the money, they provide very little managerial incentives. For example, their delta is very small. The strongest argument of option repricing is to restore managerial incentives. In this section we consider explicitly the impact of option repricing on investment risk choice.

[14] In models where the manager can choose both effort and risk, Hirshleifer and Suh (1992), Feltham and Wu (2001), and Dittmann and Yu (2011) find that options can become an optimal component in a compensation. A drawback of our model is that effort is not included.

[15] Brenner et al. (2005) identify another implicit put feature in some compensation packages: rescindable options. They interpret a rescindable option as a call option with a put feature conditional on the call option has been exercised. They show that rescindable options provide better incentives than regular call options.

[16] For a theoretical treatment of the advantages of put options, see Ross (2004).

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We have seen in Table 1 that a risk-averse manager chooses suboptimal safer investments even though the expected payoff is an increasing function of firm risk. However, since she is risk averse, higher expected payoff does not necessarily result in higher expected utility. When she is risk averse enough, she chooses a risk level below the optimal one σ_0. Indeed, when she is risk neutral ($\Lambda = 0$, third entry in Table 1) or not too risk averse, the option effect dominates and the chosen risk level is above σ_0.

In the previous section, the put options alleviate the manager's concern for the downside risks and thus she is willing to choose higher and more desirable risk level. Here we examine another commonly observed feature, namely option repricing. In Table 4, we allow the call options to be repriciable. We reset the strike price to be half of the original value if the firm value ever falls below half of the initial value. We then choose the number of such repriciable options to yield the same utility. Table 4 indicates that option repricing can reduce the total cost substantially, for example, the base case cost is reduced from 4.583 to 2.821.

Option repricing has been criticized as a reward for poor performance and severance packages have been criticized as golden parachutes for managers. However, they can provide important *ex ante* incentives for taking more desirable risk level. It may not be a reward for failures as sometimes alleged. Our analysis indicates that inclusion of option repricing and/or severance payments can significantly reduce the compensation package's total cost to the firm.

6. The roles of lookback calls in reducing managerial incentive costs

The previous sections have explored the role of various combinations of components in a manager's portfolio in reducing managerial incentive costs: non-company wealth, company shares, call options, put options and repriciable options. Here we explore the roles played by lookback options, which we argue are analogous to observed option repricing.

We begin by providing a brief description of lookback call options. Let V_T^{min} be the minimum firm value from time zero to time T. Then the payoff function at maturity of a European lookback call is defined as the difference between the terminal firm value V_T and V_T^{min}, $V_T - V_T^{min}$. Note that since V_T^{min} is the minimum firm value during the life of the option, $V_T - V_T^{min}$ is always non-negative.[17] In the following, we first examine the impact on investment risk choice of using lookback calls in managerial compensation. We then explore the link between lookback calls and automatic strike price resetting and the advantages and possible disadvantages of lookback calls.

6.1. The impact of lookback calls on investment risk choice

Tables 1 and 2 indicate that risk aversion plays an important role in determining the risk level chosen by the manager. In fact, for all the entries, the risk level chosen by the risk-averse manager ($\Lambda = 2$) is below the optimal level. Table 2 further illustrates that, in most cases, the less risky company shares are more cost-effective than the more risky options. Therefore, how to provide the manager the incentives to take more risk is of central importance. Tables 3 and 4 reveal that put options and repriciable options are quite effective in this regard. However, they can provide the wrong incentives *ex post*. In this section, we show that lookback calls can play an effective role in providing the right risk incentives.

Tables 5 and 6 replace the corresponding regular calls in Tables 1 and 2 with lookback calls. The number of lookback calls in Table 5 is chosen to yield the same utility level as each corresponding entry in Table 1. Comparing Tables 1 and 5 indicates that lookback calls are more effective in reducing the agency costs associated with deviating from the optimal risk level. The reason is that, unlike regular calls, lookback calls are always in the money and thus the manager is willing to take a higher and more desirable risk level. Table 5 also indicates that the total cost to the firm is substantially lower when lookback calls are used instead of regular calls.

Interestingly, the entries corresponding to different Λ's indicate that when regular calls induce too little risk taking ($\Lambda = 4$), lookback calls induce more, and when regular calls induce too much risk taking, ($\Lambda = 0$), lookback calls induce less. This may seem puzzling because intuition suggests that lookback calls should always entail more risk taking than regular calls. However, we can appreciate these results using lookback delta. Note that, in Appendix A, we prove that the delta of a lookback call is always greater than that of a regular call. Compared with regular calls, when σ is below σ_0, lookback calls induce higher risk level, because higher risk results in higher firm value. The reason is that an increase in firm value yields a higher proportional increase in option value for lookback calls than for regular calls (delta effect). Similarly, when σ is above σ_0, relative to regular calls, lookback calls have a preference for lower σ (higher firm value), because their delta is higher than that of regular calls.

It should be recalled from Table 2 that regular calls were dominated by company shares in the compensation package. Such is not the case with lookback calls. Comparing Tables 2 and 6 shows that lookback calls are very cost-effective in achieving the same utility level. Table 2 shows that, when the choice is between company shares and regular call options, a risk-averse manager prefers shares, because she is concerned that the calls may finish out of the money. Table 6 indicates that, when the choice is between company shares and lookback calls, the manager prefers lookbacks. There are two reasons. First, the manager is willing to choose a higher and more desirable risk level because the lookbacks will never finish out of the money. Second, because the delta of a lookback call is greater than 1 (a share has a delta of 1), lookback calls have a stronger preference (than company shares) for higher firm value through higher risk level when the risk level is below σ_0. Comparing Tables 2 and 6 shows that,

[17] For valuation of lookback options, see Goldman et al. (1979).

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when the choice is between company shares and lookback calls, the total cost to the firm is further reduced. Taken together, Tables 5 and 6 indicate that lookback calls are more effective than regular calls.

In our framework, portfolios with a higher portion of stock-based payments are riskier, and thus the risk-averse manager is more concerned about risks. Comparing Tables 1 and 6 indicates that an insurance feature, such as option repricing (implicit in lookback calls), is effective in reducing the manager's risk concerns in situations where the manager's portfolio is highly concentrated in stock-based payments. This is consistent with the empirical finding in Chen (2004) where firms, that provide more stock-based incentives, such as stock and stock options, are more likely to reprice their executive stock options. Our result is also consistent with the empirical findings in Brenner et al. (2000), Chance et al. (2000), Chidambaran and Prabhala (2003) that smaller, younger and rapidly growing firms are more likely to reprice their executive stock options, because these firms, on average, are riskier. Our story for option repricing is that it mitigates a risk-averse manager's concern for risks, and hence she is willing to adopt more desirable risk levels.

The efficacy of lookback calls can be further exemplified if we consider their effect on the sensitivity of manager's expected utility. Comparing Tables 1 and 2 reveals that for most parameter combinations a compensation package with no regular calls can not only reduce total cost to the firm (TC) but increase the manager's utility sensitivity ($\partial E[U]/\partial V$) and her certainty equivalent sensitivity ($\partial U^{-1}(E[U])/\partial V$). Table 6 reveals that in most cases lookback calls without company shares can further reduce the total cost to the firm, but they also induce lower values of $\partial E[U]/\partial V$ and $\partial U^{-1}(E[U])/\partial V$, compared with Table 1. Thus, it is possible to choose (should we wish) compensation contracts using stocks and lookbacks that have both lower TC's than compensations using stock and ordinary calls, but provide equal incentives ($\partial E[U]/\partial V$) or $\partial U^{-1}(E[U])/\partial V$. For example, in the base case, if the compensation package contains 0.368% company shares and 0.097% lookback calls, the manager achieves the same utility incentive ($\partial E[U]/\partial V$), 0.47% as in Table 1, but the total cost TC is reduced from 4.583 to 3.067.

However, we note that the pure cost of the compensation is higher in Table 6 than in Table 2. The reason is that lookback options are still riskier than shares. For a risk averse manager, the most cost-effective compensation (to achieve her utility) is cash pay. However, cash compensations provide very little incentive. As large as they are, direct cost of executive compensation is only a very small fraction of firm value. For example, in our base case, a typical manager has only 0.32% company shares and 0.38% calls. Similarly, Dittmann and Maug (2007) report that in their base case 19.6% of total cost of CEO compensation can be saved by moving to optimal contract suggested by their model, but the savings is only 0.34% of firm size because CEO pay is a very small fraction of firm value. So, while the direct cost is important, it is even more important that a compensation contract provides the right incentives. The total cost savings from 3.784 in Table 2 to 0.843 in Table 6 is economically significant. As a matter of fact, the proper comparison should be with Table 1 where the number of shares and number of calls are from the estimates in Parrino et al. (2005). The savings from 4.583 to 0.843 is even more significant.

While the total cost in Table 6 is lower than that in Table 2, the PPS is also lower. Obviously, both will be important considerations. As we have explained, an all cash compensation minimizes total cost but provides little incentive. Can lookback options induce more PPS but also incur lower total cost? The answer is yes. For example, for the base case in Table 6, suppose we fix the number of lookback looks at 1.068% and include some shares. With 0.111% shares, the compensation induces the same PPS 5.097 (10^{-3}) as in Table 2 but increases utility from −0.9812 to −0.8794. With 0.150% shares, PPS increases to 5.549 (10^{-3}) and utility improves to −0.8481.[18]

6.2. Interpreting lookback calls: option strike resetting

The previous subsection clearly indicates that lookback calls can provide better incentives than either restricted stocks or regular call options. We note that a lookback call is identical to a call option whose exercise price is reset to the current stock price, whenever new stock price lows are reached. Thus, lookbacks are similar to ordinary executive stock options that are repriced automatically.[19] In the following, we further explore the advantages and possible disadvantages of lookback call options.

First, the relative value of lookback calls increases more than the relative value of restricted stock or regular call options, as the stock price increases because of the delta effect.[20] Lookback calls provide stronger initial pay-for-performance incentives for management to increase firm value from the level at which they were granted. In most cases, lookback calls provide better risk-taking incentives for risk-averse managers as Tables 5 and 6 indicate.

One may argue that the fact that the delta of a regular call is always smaller than that of a lookback call does not necessarily make regular calls less desirable than lookback calls because one may be able to give the manager more (regular) call options since they are cheaper. However, there are three factors to be considered. First, even if the *ex ante* total delta of a portfolio of regular calls is matched with that of a portfolio of lookback calls by including more regular calls in the (regular call) portfolio, the *ex post* total delta of the regular call portfolio can still become very small when the calls are deep out of the money and option repricing is needed. However, if lookback calls are used, option repricing becomes unnecessary. Second, our calculations in Section 4 indicate that including more regular calls in a compensation package may induce less desirable risk choices because of

[18] In Table 6, we could not match both the utility and the PPS. The reason is that in Table 2 the number of calls N_C is zero. Therefore, the solution of matching both in Table 6 will still be only shares and zero (lookback) calls.

[19] Automatic adjustment between stock and cash occurs in Edmans et al. (2012). In our model, no other component of the compensation portfolio is changed. The resetting of the strike price is an inherent feature of the lookback itself.

[20] Again, the delta of an option is the derivative of its price with respect to the underlying stock price. The delta of a lookback call is greater than 1 while that of a regular call is smaller than 1.

the risk-aversion effect as we have mentioned. Third, our calculations in Section 6 indicate that using lookback calls is more cost effective to achieving the same utility level for the manager. In sum, with their desirable *ex ante* (i.e. more cost effective) and *ex post* (i.e. strong performance incentive — delta always greater than 1) properties, we argue that lookback options can be a useful incentive component in compensation packages.

Second, we argue that lookback calls are effective vehicles for enhancing the pay-for-performance incentives without explicitly rewarding the manager for low stock prices as an option repricing decision seems to suggest. The reason is that, even though lookback calls can be regarded as regular calls with their strikes reset automatically whenever the stock price falls to a new low, the reset feature is part of the contract and its cost at grant date is properly accounted for. With lookback calls, explicit option repricing is not needed and the frequently heated debates associated with it are avoided. Hall and Murphy (2000) argue that the pay-for-performance incentives for risk-averse managers are typically maximized by at the money calls and thus provide an explanation why almost all executive options are granted at the money. While the grant date pay-for-performance incentives are maximized, the incentives are severely weakened when the options become deep out of the money after they are granted. This weakness has been the strongest argument for option repricing in managerial compensation. Callaghan et al. (2003) report that for both the pre-repricing period and post-repricing period, repricing firms exhibit significantly positive industry-adjusted stock performance. Therefore, allowing repricing has a positive influence on a firm's stock performance. If so, why not reprice the options whenever the pay-for-performance incentives are too weakened? The pay-for-performance incentives provided by lookback calls remain significant even after substantial price declines because they are always in the money and their deltas are always greater than 1. Furthermore, like ordinary call options, lookback calls are at the money when they are first issued. Thus, they are not subject to immediate tax consequences and there is no tax impediment of their adoption.

Third, if the (terminal) stock price V_T is positively correlated with any benchmark index, the (lookback call) strike price V_T^{min} is also positively correlated with the index. Consequently, the payoff, $V_T - V_T^{min}$, will filter out part of industry (or market-wide) component of the price movement in V_T. Option repricing is intended to restore incentives when the previously granted options are deep out of the money. Repricing can provide the right incentives when it can be determined that the negative shocks contributing to the stock price decline are beyond factors under the control of the manager. However, filtering out the managerial actions is a challenge, and it can be improved by the use of index options. It turns out that lookback options can provide a mechanism for automatic option strike resetting in a way consistent with indexation. Thus, the manager is not rewarded for stock price run-ups unrelated to actions taken by her and penalized for actions beyond her control. The added advantage is that lookback options do not require explicit knowledge of an index. Determining a well-defined index for indexation of options grants has been an issue when discussing the use of such options in contemporary compensation contracts.

Having explored some of the advantages of lookback calls, now we address one potential disadvantage.[21] It might appear that lookback options will create disincentives in the short run. If managers could make decisions that temporarily depress stock prices to a new low, and subsequently could reverse such decisions, their options would be more valuable due to a lower strike price. If, however, such temporary decisions can be rationally anticipated, their short-run stock price impact will be small. More importantly, value creation typically is much more difficult than value destruction. While the manager may be able to lower the strike on a lookback by destroying value, restoring the lost value may be no easier than creating value prior to value destruction. Thus, while the manager may be able to create downward jumps or a downward path by destroying value, we do not think there is a symmetry on the upside. For example, for the same lookback payoff, a higher return is required when starting from a lower minimum. To see this, suppose the current price and minimum is $100. It requires a 20% return to yield a payoff of $20 for the lookback. On the other hand, if the manager drives the price down to $50, it would require a 40% return for the same payoff of $20. It may not be easier to drive the price from $100 to $50 then back to $70 than to raise it from $100 to $120. Finally, we observe that the potential for abuse already has been noted when standard call options are repriced, but the continued practice of repricing suggests that the benefits outweigh these potential costs.

To compare potential disincentives of lookback options and put options and repriciable options, assume that the put strike price is $50 and the initial call strike price is $100 (initially at-the-money) and the strike price will be reset to $50 if the stock price ever falls to $50 (reset to at-the-money). Suppose stock price drops to a new low from an initial $100 to $60. A manager with put options may have incentives to depress the stock price below $50 to drive the put options into the money. A manager with repriciable options may have incentives to depress the stock price down to $50 to trigger resetting the strike price. From there on the incentive is restored. If the stock price rises $10 from $50 to $60, the options will be in the money for a $10 payoff. Without resetting, if the stock price rises $10 from $60 to $70, the options are still deep out of the money. Now consider the lookback options. In either case, a $10 rise yields a $10 payoff. In fact, a $10 rise from $50 requires a higher percentage rise. Unless the manager is sure that she can drive down the price to $50 and then a more than 20% rise, it will be likely easier for her to drive a 17% rise from $60 for a $10 payoff. Clearly, the incentives to depress stock price are weaker for lookback options.

We emphasize again that unlike the delta of a combined portfolio of calls and puts, rescindable options, and repriciable options that can be negative *ex post* and thus provides the wrong incentives, the delta of lookback calls is always greater than 1 and thus they provide reasonable incentives for both good states and bad states for the manager. A manager may have incentives to depress share price to trigger the event of repricing or rescinding the options or drive the put options into the money, lookback options do not offer such incentives. A manager's incentives to depress share price are much reduced.

[21] Adverse effects of stock options have been studied from different angles, e.g. inducing account fraud (Burns and Kedia, 2006), earnings management (Bergstresser and Philippon, 2006), more risk-taking (Coles et al., 2006; Gormley et al., forthcoming), reducing dividends (Lambert et al., 1989), making opportunistic voluntary disclosure (Aboody, and Kasznik, 2000).

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Though our model does not include the reputation and career concern effects, they are something the manager needs to consider if she tries to follow the strategy of first destroying value and then subsequently trying to create it. Another reason that the manager may not want to drive down the firm value intentionally is that the company stock component of her own portfolio will suffer. Finally, we observe that the potential for abuse already has been noted when standard call options are repriced, but the continued practice of repricing suggests that the benefits outweigh these potential costs.

7. Conclusions

Pay-for-performance is now a widely accepted dictum in the design of managerial compensation structure. Stock options are an integral part of managerial contracts in the hope of aligning management with shareholders. Well-diversified shareholders' value maximizing and risk-averse managers' utility maximizing can lead to different desired actions. Relative to the optimal risk level for the firm, a call-type contract can induce both over or under investment in risk depending on managerial risk-aversion. Given a compensation package, we examine agency costs associated with deviating from the optimal corporate risk policies. In particular, we have shown that the inclusion of option repricing features has countervailing effects and is very effective in reducing these costs.

While deep out of the money call options may provide little incentive because the probability for the option to finish in the money is very small, a lookback call option is always in the money and provides the incentive for the manager to increase the stock price above the current level. Thus, lookback options provide not only the *ex ante* incentives but also the *ex post* ones as well. In fact, a lookback call can be interpreted as a call with strike price reset whenever a new minimum price is reached. Moreover, we have argued that lookback calls have properties analogous to those embedded in indexed options, because both the terminal price and the minimum price are likely to be correlated with market returns and their difference (the payoff of a lookback call) filters out part of the market movement.

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Appendix A. The lookback call Δ is greater than 1

Here we prove that the delta (Δ) of a lookback call is always greater than 1 and thus greater than that of a regular call which is always smaller than 1. We make the usual assumption that the underlying asset price dynamics follow a standard Black–Scholes Geometric Brownian motion,

$$\frac{dS_t}{S_t} = \mu dt + \sigma dB_t, \tag{A.1}$$

where μ and σ are constants and B_t is a standard Wiener process.

Let $m_t^T = inf(S_u : u \in [t,T])$ be the minimum price during $[t,T]$. The terminal payoff of a lookback call is given by $S_T - m_0^T$. The market price of a lookback call at time t is given by the discounted risk-neutral expected value,

$$C_{LC}(S_t) = e^{-r(T-t)} E_t^Q \left[S_T - m_0^T \right] = S_t - e^{-r(T-t)} E_t^Q \left[min\left(m_0^t, m_t^T \right) \right], \tag{A.2}$$

where m_0^t is the minimum so far and m_t^T is the minimum in $[t,T]$, and Q denotes the risk-neutral measure.

Let $f(x)$ be the risk-neutral density of the minimum price during $[t,T]$ for the process in (A.1). Using $f(x)$ we can write (A.2) as

$$C_{LC}(S_t) = S_t - e^{-r(T-t)} \int_0^{m_0^t} x f(x) dx - e^{-r(T-t)} m_0^t \int_{m_0^t}^{S_t} f(x) dx. \tag{A.3}$$

Closed form formula for $C_{LC}(S_t)$ has been obtained by Goldman et al. (1979). Its delta can be obtained explicitly. However, the calculation is tedious and it is difficult to prove that the resulting Δ is greater than 1.

Here we follow a simpler strategy without explicitly computing the delta. If we change the price at t from S_t to $S_t + \ S_t$, the terminal price will be $(1 + \ )S_T$ and the minimum during $[t,T]$ will be $(1 + \ )m_t^T$, where S_T and m_t^T are the corresponding values if the process in (A.1) starts at S_t. The lookback call price can now be written as

$$C_{LC}(S_t + \ S_t) = \begin{array}{l} (1 + \ )S_t - e^{-r(T-t)} \int_0^{\frac{m_0^t}{1+}} x f(x) dx \\ - e^{-r(T-t)} m_0^t \int_{\frac{m_0^t}{1+}}^{S_t} f(x) dx.A.4. \end{array} \tag{A.4}$$

From (A.4) and (A.3) the change of the lookback call price is given by

$$C_{LC}(S_t+\ S_t)-C_{LC}(S_t) = \begin{array}{l} S_t + e^{-r(T-t)} m_0^t \int_{\frac{m_0^t}{1+\ }}^{m_0^t} f(x)dx \\ -\, e^{-r(T-t)} \int_{\frac{m_0^t}{1+\ }}^{m_0^t} x f(x)dx.. \end{array} \tag{A.5}$$

Thus, the delta of the lookback call is given by

$$\Delta = \lim_{\ \to 0} \frac{C_{LC}(S_t+\ S_t)-C_{LC}(S_t)}{\ S_t} = 1 + \lim_{\ \to 0} \frac{e^{-r(T-t)}}{\ S_t} \int_{\frac{m_0^t}{1+\ }}^{m_0^t} \left(m_0^t - x\right) f(x)dx. \tag{A.6}$$

Since $m_0^t > x$ for $x \in [m_0^t/(1+\ \ ), m_0^t]$, $\Delta > 1$ **Q.E.D.**

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