Risk, ambiguity, and the exercise of employee stock options

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01 Introduction

- Help clarify a longstanding division (or ambiguity) in the compensation literature over whether risk is positively or negatively associated with the early exercise of executive options.

model

Regression ($y = the\ percentage\ of\ options\ exercised$)

OLS ($y = \frac{intrinsic\ value\ upon\ exercised}{the\ ramaining\ value\ of\ the\ option}$)

Weibull model $Exercise_{i,k,t} = p_r t^{p_r-1} \exp(\beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n)$

Similar as above

fractional-logistic regression

Report that the probability that executives exercise options early decreases with the volatility of the underlying stock return.

Table 1
Previous studies of risk, as measured by volatility, and executive stock option exercises.

The table shows seven previous studies of executive stock option exercises, with information about the sample period, sample size, measurement of volatility, and the estimated impact of volatility (risk) upon early option exercise.

Study	Sample period	Sample size	Measurement of volatility	Impact of volatility on early exercise	Remarks
Huddart and Lang (1996)	c. 1985–1995	85,853 exercises by 58,316 employees (all levels) at 8 companies	Daily stock returns over 1 year prior to exercise month	Mixed	Estimates vary across companies and job ranks and are sensitive to estimation method
Hemmer, Matsunaga, and Shevlin (1996)	1990	110 exercises by 74 officers and directors at 65 firms	Monthly stock returns over 5 years prior to 1990	Positive	Volatility is scaled by Black-Scholes hedge ratio
Bettis, Bizjak, and Lemmon (2005)	1996–2002	141,020 exercises by officers and directors at 3,966 companies	Monthly stock returns over 3 years prior to exercise date	Positive	
Armstrong, Jagolinzer, and Larcker (2007)	c. 1995–2005	17,570 exercises by 15,409 employees (all levels) at 10 firms	Daily stock returns over 1 year prior to exercise date	Not significant	
Klein and Maug (2012)	1996–2008	23,646 exercises by 13,948 officers and directors at 2,008 firms	Weekly stock returns over 1 year prior to vesting date	Weak but positive	Estimates are significant only in certain models
Carpenter, Stanton, and Wallace (2015)	1981–2009	687,594 exercises by 419,822 employees at 102 firms	Daily stock returns over 66 days prior to grant date	Negative	Uses computationally intensive generalized method of moments (GMM) estimation
Heron and Lie (2017)	1994–2011	37,330 exercises by officers and directors at a large number of companies	Daily stock returns over 1 year prior to exercise year	Negative	Differentiates between idiosyncratic and systemic volatility

01 Introduction

- Knight (1921) defines the concept of Knightian uncertainty, also known as ambiguity, as distinct from risk as conditions under which the set of events that may occur is a priori unknown, and the odds of these events are also either not unique or are unknown.

- We develop an empirical estimate of ambiguity and include it in regression models alongside the traditional measure of risk, equity volatility.

- We show that volatility causing executives to hold options longer to preserve option value, and ambiguity increasing the tendency for executives to exercise early.

02 The Model

- Treating ambiguity analytically can help decision makers to rank alternative. With employee stock options, it becomes to the decision whether to continue holding an option or exercise it when the degree of ambiguity changes.

- We distinguish the concepts of risk and ambiguity by using the theoretical framework of expected utility with uncertain probabilities (EUUP) proposed by Izhakian (2017).

- The degree of ambiguity can be measured by the volatility of probabilities—just as the degree of risk can be measured by the volatility of outcomes.

- Aversion to ambiguity means that individuals prefer to choose when probabilities are known, which implies that they are willing to pay in order to avoid choosing in an ambiguous context.

02 The Model

- Let $(\mathcal{S}, \mathcal{E}, P)$ be a probability space, where $P \in \mathcal{P}$ is a probability measure, and the set of probability measures $\mathcal{P}$ is convex.
  $\forall P_1, P_2 \in \mathcal{P}, 0 \le a \le 1,\ a \times P_1 + (1 - a) \times P_2 \in \mathcal{P}$

- An algebra Π of measurable subsets of $\mathcal{P}$ is equipped with a probability measure, denoted ξ .

- The uncertain outcome is then given by the “uncertain” variable, $X : \mathcal{S} \to \mathbb{R}$.

- Like Tversky and Kahneman’s (1992) cumulative prospect theory, EUUP assumes that investors have a reference point, denoted k, relative to which returns are classified as unfavorable (a loss) or as favorable (a gain).

02 The Model

Preferences concerning ambiguity

- defined by preferences over mean-preserving spreads in probabilities
- modeled by $\gamma: [0,1] \to \mathbb{R}$, where γ is strictly increasing and twice-differentiable over probabilities
  - ✓ ambiguity aversion: concave $\gamma(\cdot)$
  - ✓ ambiguity loving: convex $\gamma(\cdot)$
  - ✓ ambiguity neutrality: linear $\gamma(\cdot)$

Let P_1 be a mean-preserving spread of P_2.
Then $\int_{-\infty}^{x} f_1(x)dP_1 = \int_{\infty}^{x} f_2(x)dP_2$

- The expected utility of consuming the future risky and ambiguous outcome on this one-period investment, is formed by

$$V(X) = \int_{z\leq 0}\left[1 - \gamma^{-1}\left(\int_{\mathcal{P}} \gamma\big(P(U(X) \geq z)\big)d\xi\right)\right]dz + \int_{z\geq 0} \gamma^{-1}\left(\int_{\mathcal{P}} \gamma\big(P(U(X) \geq z)\big)d\xi\right)dz$$

where X is the investment payoff and $U(k) = 0$ for some reference point k.

02 The Model

- Consider a discrete state space with only two states of nature: high (H) and low (L) payoffs. Assume an investor with one unit of wealth and whose reference point satisfies $L < k < H$.

→ $V(X) = \left[1 - \gamma^{-1}\left(\int_{\mathcal{P}} \gamma\left(1 - P(L)\right) d\xi\right)\right] U(L) + \gamma^{-1}\left(\int_{\mathcal{P}} \gamma\left(P(H)\right) d\xi\right) U(H)$

where

$Q(L) = 1 - \gamma^{-1}\left(\int_{\mathcal{P}} \gamma\left(1 - P(L)\right) d\xi\right), Q(H) = \gamma^{-1}\left(\int_{\mathcal{P}} \gamma\left(P(H)\right) d\xi\right)$ are the perceived probability of L and H respectively.

→ $V(X) = Q(H) \times U(H) + Q(L) \times U(L)$

The Arrow-Pratt Premium

✓ coefficient of absolute risk aversion (CARA): $A(w) = -\frac{U''(w)}{U'(w)}$

✓ coefficient of relative risk aversion (CRRA): $\mathrm{R}(w) = \mathrm{A}(w) = -w\frac{U''(w)}{U'(w)}$

- W = current wealth
- z = random gamble payoffs where $E(z) = 0, Var(z) = \sigma_z^2$
- $W + z$ = wealth given gamble
- $\pi(W, z)$ = Arrow-Pratt Premium

- The risk premium is defined by $E[U(W+z)] = U[W + E(z) - \pi(W,z)] = U[W - \pi(W,z)]$.
  LHS: expected utility of the current level of wealth, given the gamble
  RHS: utility of the current level of wealth plus the expected value of the gamble less the risk premium

- By Taylor series expansion (expand at w)
  ✓ LHS $= E\left[U(W) + zU'(W) + \frac{1}{2}z^2U''(W)\right] = U(W) + \frac{1}{2}Var(z)U''(W)$
  ✓ RHS $= U(W) - \pi(W,z)U'(W)$ (Pratt assumes that second order and higher terms are insignificant)
  → $U(W) + \frac{1}{2}Var(z)U''(W) = U(W) - \pi(W,z)U'(W)$, $\pi(W,z) = \frac{1}{2}\left(-\frac{U''(W)}{U'(W)}\right)Var(z)$

- Our utility function is $U = e^{-\beta t} W^{\gamma}, where\ 0 < r \leq 1, 0 < \beta < 1$

  CRRA $= -W \frac{U''(W)}{U'(W)} = -W \frac{e^{-\beta t}\gamma(\gamma-1)W^{\gamma-2}}{e^{-\beta t}\gamma W^{\gamma-1}} = 1 - \gamma$

  → $1-\gamma$愈大(γ愈小)，愈風險趨避

Similarly to Arrow-Pratt’s risk theory, the coefficient of absolute ambiguity aversion (CAAA) can be defined by $-\frac{\gamma''(P(E))}{\gamma'(P(E))}$, and the coefficient of relative ambiguity aversion (CRAA) by $-\frac{\gamma''(P(E))}{\gamma'(P(E))}P(E)$.

02 The Model

- Define the expected probabilities and the variance of probabilities

$$\mathrm{E}[\varphi(x)] \equiv \int_{\mathcal{P}} \varphi(x) d\xi \quad \text{and} \quad \mathrm{E}[\mathrm{P}(x)] \equiv \int_{\mathcal{P}} \mathrm{P}(x) d\xi$$

$$\mathrm{Var}[\varphi(x)] \equiv \int_{\mathcal{P}} \left(\varphi(x) - \mathrm{E}[\varphi(x)]\right)^2 d\xi$$

where $P(x)$ is cumulative probability $P \in \mathcal{P}$ of x, $\varphi(x)$ is the probability density function.

- The value of this asset in terms of expected utility is

$$W(X) \approx \int_{x \leq k} U(x) E[\varphi(x)] \times \left(1 - \frac{\gamma''(1 - E[P(x)])}{\gamma'(1 - E[P(x)])} Var[\varphi(x)]\right) dx + \int_{x \geq k} U(x) E[\varphi(x)] \times \left(1 + \frac{\gamma''(1 - E[P(x)])}{\gamma'(1 - E[P(x)])} Var[\varphi(x)]\right) dx$$

02 The Model

- Consider a binomial asset with low payoff L and high payoff H, in the bad and the good states of nature, respectively.
- Suppose that the reference point k satisfies $L \leq k \leq E[X] < H$.

The value of this asset in terms of expected utility is

$$W(X) \approx U(L)E[\varphi(L)] \times \left(1 - \frac{\gamma''(1 - E[P(L)])}{\gamma'(1 - E[P(L)])} Var[\varphi(L)]\right)$$
$$+U(H)E[\varphi(H)] \times \left(1 - \frac{\gamma''(1 - E[P(H)])}{\gamma'(1 - E[P(H)])} Var[\varphi(H)]\right)$$

where $1 - E[P(L)] = E[P(H)]$, $Var[\varphi(L)] = Var[\varphi(H)]$,

- The degree of ambiguity can be measured by

$$\mho^2[X] = \int E[\varphi(x)] Var[\varphi(x)] dx$$

The measure $\mho^2$ can be used both in the general case of a space with infinitely many outcomes or in a discrete state space with finitely many outcomes.

02 The Model

- Consider now a one-period call option on a binomial asset with one period payoff X and exercise price K with $L - K \leq k \leq H - K$. The value of this option (in terms of expected utility) is

$$C(X) \approx E[\varphi(H)] \times \left(1 + \frac{\gamma''(1 - E[P(H)])}{\gamma'(1 - E[P(H)])} Var[\varphi(H)]\right) U(H - K)$$

- Based on this equation we can make the following claims:
  - ✓ **Claim1** The option value increases with the risk of its underlying equity.

    Since the exercise price K satisfies $k \leq H - K$, the expected utility from this call option is positively affected by the volatility of its underlying equity.

    → value of option increases in the risk of its underlying equity

02 The Model

- ✓ **Claim2** The option value decreases with the aversion to ambiguity.
- ✓ **Claim3** Assuming ambiguity-averse investors, the option value decreases with the ambiguity of its underlying equity.

$$C(X) \approx E[\varphi(H)] \times \left(1 + \frac{\gamma''(1 - E[P(H)])}{\gamma'(1 - E[P(H)])} Var[\varphi(H)]\right) U(H - K)$$

Let $\eta = -\frac{\gamma''(\cdot)}{\gamma'(\cdot)}$ is the coefficient of absolute ambiguity aversion.

Higher aversion to ambiguity implies a greater η. $\eta \uparrow \rightarrow \frac{\gamma''(\cdot)}{\gamma'(\cdot)} \downarrow \rightarrow \; C(X) \downarrow$

e.g. Current price is $1. In the next period its price can be either $H = \$1.1$ or $L = \$0.9$. Assume that reference point is $k = 1$ and the utility function $U(x) = \sqrt{x} - 1$.

$$V(X) = Q(H) \times U(H) + Q(L) \times U(L)$$

- Assume $P(bad\ payoff) = P(good\ payoff) = 50\%$

$$V(X) = 0.5 \times \left(\sqrt{0.9} - 1\right) + 0.5 \times \left(\sqrt{1.1} - 1\right) = -0.0013$$

$$C(X) = 0.5 \times (1.1 - 1) = 0.05$$

02 The Model

- Assume probabilities of the future payoffs of the equity are ambiguous such that outcomes are distributed either $P_1 = (0.4, 0.6)$ or $P_2 = (0.6, 0.4)$.
  - ✓ ambiguity neutral (linear $\gamma(\cdot)$):
    forms perceived probabilities by compounded probabilities
    $Q(H) = 0.5 \times 0.4 + 0.5 \times 0.6 = 0.5 = Q(L)$
  - ✓ ambiguity-averse with $\gamma(P) = -\frac{e^{-\eta P}}{\eta}$, where $\eta = 2$ is the coefficient of (absolute) ambiguity aversion

$$\int_{\mathcal{P}} \gamma\big(P(H)\big) d\xi = 0.5 \times \left(-\frac{e^{-2\times0.4}}{2}\right) + 0.5 \times \left(-\frac{e^{-2\times0.6}}{2}\right) = -\frac{e^{-2\times0.4}+e^{-2\times0.6}}{4}$$

$$Q(H) = \gamma^{-1}\left(-\frac{e^{-2\times0.4}+e^{-2\times0.6}}{4}\right) = -\frac{1}{2}\ln\left(\frac{e^{-2\times0.4}}{2} + \frac{e^{-2\times0.6}}{2}\right) = 0.49$$

$$Q(L) = 1 + \frac{1}{2}\ln\left(\frac{e^{-2\times0.4}}{2} + \frac{e^{-2\times0.6}}{2}\right) = 0.51$$

$$V(X) = 0.51 \times \left(\sqrt{0.9} - 1\right) + 0.49 \times \left(\sqrt{1.1} - 1\right) = -0.0023$$

$$Q(H) = \gamma^{-1}\left(\int_{\mathcal{P}} \gamma\big(P(H)\big) d\xi\right)$$

$$Q(L) = 1 - \gamma^{-1}\left(\int_{\mathcal{P}} \gamma\big(1 - P(L)\big) d\xi\right)$$

$$\gamma^{-1}(\mathrm{P}) = -\frac{1}{\eta}\ln(-\eta P)$$

→ the higher is the aversion to ambiguity, the lower are the perceived probabilities of the good outcomes, the lower is the expected utility.

02 The Model

- $P_1 = (0.4, 0.6)$ or $P_2 = (0.6, 0.4)$
  $E[\varphi(H)] = 0.5 \times 0.4 + 0.5 \times 0.6 = 0.5$, $E[\varphi(L)] = 0.5 \times 0.6 + 0.5 \times 0.4 = 0.5$
  $Var[\varphi(H)] = 0.5 \times (0.4 - 0.5)^2 + 0.5 \times (0.6 - 0.5)^2 = 0.01 = Var[\varphi(L)]$
  → ambiguity $\mho[X]^2 = 0.5 \times 0.01 + 0.5 \times 0.01 = 0.01$

✓ ambiguity neutral (linear $\gamma(\cdot)$):

$$C(X) = 0.5 \times (1.1 - 1) = 0.05$$

✓ ambiguity-averse with $-\frac{\gamma''(\cdot)}{\gamma'(\cdot)} = \eta = 2$

$$C(X) \approx 0.5 \times (1 - 2 \times 0.01) \times (1.1 - 1) = 0.049$$

$$\mho^2[X] = \int E[\varphi(x)]Var[\varphi(x)]dx$$

$$C(X) \approx E[\varphi(H)] \times \left(1 + \frac{\gamma''(1 - E[P(H)])}{\gamma'(1 - E[P(H)])} Var[\varphi(H)]\right) U(H - K)$$

03 Early exercise of executive stock options

dependent variable

- the percentage of an option grant exercised by the option holder in a particular month: $\frac{\#\, vested\ options\ exercised}{\#\, held\ at\ the\ start\ of\ the\ month}$

independent variable

- stock monthly return
- vesting month indicator
- log(1+months to expiration)
- 12-month high price indicator
- dividend yield × dividend month indicator
- log(stock price / exercise price)
- illiquidity
- exercised at highest price in the month
- blackout period indicator
- abnormal accruals
- underlying asset holdings
- overconfidence indicator
- expected ambiguity
- expected volatility

03 Early exercise of executive stock options

independent variable

- expected ambiguity

$$\mho^2[X] = \int E[\varphi(x)]Var[\varphi(x)]dx$$

✓ estimate the degree of ambiguity of each stock j for each month by the discrete form

$$\mho^2[r_j] = \frac{1}{w\ln\left(\frac{1}{w}\right)} \times \begin{pmatrix} E[\phi(r_{j,0};\mu_j,\sigma_j)]Var[\phi(r_{j,0};\mu_j,\sigma_j)] \\ +\sum_{i=1}^{40} E[\phi(r_{j,i};\mu_j,\sigma_j) - \phi(r_{j,i-1};\mu_j,\sigma_j)]Var[\phi(r_{j,i};\mu_j,\sigma_j) - \phi(r_{j,i-1};\mu_j,\sigma_j)] \\ +E[1-\phi(r_{j,40};\mu_j,\sigma_j)]Var[1-\phi(r_{j,40};\mu_j,\sigma_j)] \end{pmatrix}$$

where $\phi(\cdot)$ stands for the cumulative normal probability distribution, $r_{j,0} = -0.1$, $w = r_{j,i} - r_{j,i-1} = 0.005$, and $\frac{1}{w\ln\left(\frac{1}{w}\right)}$ scales the weighted-average volatilities of probabilities to the bins' size.

✓ $ln\widehat{\mho_{j,t+1}}$ is computed by ARMA(p, q) model with the minimal AIC

$$\ln \mho_{j,t} = \psi_0 + \epsilon_{j,t} + \sum_{i=1}^{p} \psi_i \times \ln \mho_{j,t-\mathrm{i}} + \sum_{i=1}^{q} \theta_i \times \epsilon_{j,t-1}$$

✓ The expected volatility is then calculated as

$$\left(\mho_{j,t+1}^2\right)^E = \exp\left(2\ ln\widehat{\mho_{j,t+1}} + 2Var[u_{j,t+1}]\right)$$

where $Var[u_{j,t+1}]$is the minimal predicted variance of the error term.

03 Early exercise of executive stock options

independent variable

- expected volatility
  - ✓ the expected volatility is also estimated with ARMA(p, q) for each equity j with the minimal AIC

$$\ln \mathbb{S}td_{j,t} = \psi_0 + \epsilon_{j,t} + \sum_{i=1}^{p} \psi_i \times \ln \mathbb{S}td_{j,t-i} + \sum_{i=1}^{q} \theta_i \times \epsilon_{j,t-1}$$

  - ✓ The expected volatility is then calculated as

$$\mathbb{V}ar^{E}_{j,t+1} = \exp(2\, ln\widehat{\mathbb{S}td_{j,}}_{t+1} + 2Var[u_{j,t+1}]\,)$$

where $Var\left[u_{j,t+1}\right]$is the minimal predicted variance of the error term.

04 Empirical findings

Data

- from Thomson Reuters Insiders database
- 69,797 option grants (62,422 of which were exercised in 72,182 partial exercises)
- 20,665 employees in 3,222 individual firms
- Time: 1996/1~2014/12
- drop all duplicate records or records that we cannot match with identifiers to the CRSP(Chicago Center for Research in Security Prices) stock price database
- drop all out-of-the-money options, based upon the closing price at the end of the prior month

04 Empirical findings

Table 2
Descriptive statistics.

The full sample includes 2.48 million monthly observations associated with 69,797 option grants, 62,422 of which are fully or partially exercised by 20,665 employees in 3,222 individual firms between 1996 and 2014, using records from the Thomson Reuters Insiders database. For a given option award, the percentage of options exercised equals the number exercised in a given month divided by the number of vested options held at the start of the month. Expected volatility, based on CRSP daily stock price records, and expected ambiguity, based on TAQ intraday stock price records, are calculated according to procedures described in the text. Illiquidity is measured according to Amihud (2002). Abnormal accruals are calculated following the modified Jones (1991) model. The blackout period indicator equals one for the month prior to the month in which the firm announces quarterly earnings. Underlying asset holdings are measured in billions and are cumulated from each manager's trading history. The overconfidence indicator equals one if a manager has ever held a stock option until its final year.

Variable	Mean	Std dev	Minimum	Median	Maximum	N
Percentage of options exercised	0.0247	0.1512	0.0000	0.0000	1.0000	2483877
Expected ambiguity	0.1128	0.0828	0.0194	0.0863	0.6255	2483877
Expected volatility	0.0087	0.0104	0.0003	0.0053	0.0928	2483877
Stock monthly return	0.0197	0.1006	−0.6902	0.0165	2.2747	2483877
Vesting month indicator	0.0090	0.0946	0.0000	0.0000	1.0000	2483877
Log(1+months to expiration)	3.8906	0.7566	0.0317	4.1146	5.8989	2483877
12-month high price indicator	0.0595	0.2366	0.0000	0.0000	1.0000	2483877
Dividend yield × dividend month indicator	0.0002	0.0029	0.0000	0.0000	0.0997	2483877
Log(stock price/exercise price)	0.8657	0.7556	0.0000	0.7035	14.1998	2483877
Illiquidity	0.0054	0.0385	0.0000	0.0008	22.3255	2483877
Exercised at highest price in the month	0.000005	0.0022	0.0000	0.0000	1.0000	2483877
Blackout period indicator	0.3289	0.4698	0.0000	0.0000	1.0000	2483877
Abnormal accruals	−0.0104	0.2795	−1.0607	0.0000	4.7227	2483877
Underlying asset holdings	0.0056	0.0387	0.0000	0.0007	1.0000	2483877
Overconfidence indicator	0.1052	0.3069	0.0000	0.0000	1.0000	2483877

04 Empirical findings

Table 3
Correlation matrix.

The full sample includes 2.48 million monthly observations associated with 69,797 option grants, 62,422 of which are (fully or partially) exercised by 20,665 employees in 3,222 individual firms between 1996 and 2014, using records from the Thomson Reuters Insiders database. Correlation coefficients and *p*-values are computed for each firm separately, and the table reports their average across firms. For a given option award, the percentage of options exercised is the number exercised in a given month divided by the number of vested options held at the start of the month. Expected volatility, based on CRSP daily stock price records, and expected ambiguity, based on TAQ intraday stock price records, are calculated according to procedures described in the text. Illiquidity is measured according to Amihud (2002). Abnormal accruals are calculated following the modified Jones (1991) model. The blackout period indicator equals one for the month prior to the month in which the firm announces quarterly earnings. Underlying asset holdings are measured in billions and are cumulated from each manager's trading history. The overconfidence indicator equals one if a manager has ever held a stock option until its final year. *p*-values appear in parentheses.

#		Percentage of options exercised	Expected ambiguity	Expected volatility	Stock monthly return	Vesting month indicator	Log(1+months to expiration)	12-month high price indicator	Dividend yield × dividend month indicator	Log(stock price/exercise price)	Illiquidity	Exercised at highest price in the month	Blackout period indicator	Abnormal accruals	Underlying asset holdings	Overconfidence indicator
1	Percentage of options exercised	1														
2	Expected ambiguity	0.0127 (0.3200)	1													
3	Expected volatility	−0.0114 (0.3211)	−0.0674 (0.1412)	1												
4	Stock monthly return	0.0333 (0.3273)	0.0234 (0.2728)	0.0318 (0.2246)	1											
5	Vesting month indicator	0.0221 (0.2720)	0.0004 (0.2100)	0.0034 (0.2114)	0.0043 (0.2094)	1										
6	Log(1+months to expiration)	−0.1113 (0.1824)	−0.0225 (0.2068)	0.0717 (0.2080)	0.0146 (0.3810)	0.0485 (0.0727)	1									
7	12-month high price indicator	0.0095 (0.3558)	0.0348 (0.2503)	0.0056 (0.2404)	0.0291 (0.2358)	0.0031 (0.2453)	0.0051 (0.3666)	1								
8	Dividend yield × dividend month indicator	0.0026 (0.0950)	0.0025 (0.0532)	−0.0011 (0.0578)	0.0013 (0.0574)	0.0007 (0.0791)	−0.0060 (0.0536)	0.0006 (0.0691)	1							
9	Log(stock price/exercise price)	0.0616 (0.2711)	0.0432 (0.2055)	−0.0231 (0.2101)	0.1741 (0.1798)	−0.0167 (0.1530)	−0.1088 (0.0996)	0.1130 (0.1652)	−0.0023 (0.0586)	1						
10	Illiquidity	−0.0537 (0.2555)	−0.0466 (0.1558)	0.1895 (0.1498)	−0.0305 (0.3016)	0.0127 (0.1957)	0.1653 (0.1212)	−0.0838 (0.1985)	−0.0009 (0.0533)	−0.2554 (0.1026)	1					
11	Exercised at highest price in the month	0.0004 (0.0003)	0.0001 (0.0006)	0.0000 (0.0010)	0.0001 (0.0008)	0.0000 (0.0014)	0.0000 (0.0004)	0.0000 (0.0013)	0.0000 (0.0003)	0.0000 (0.0003)	0.0000 (0.0006)	1				
12	Blackout period indicator	−0.0520 (0.2498)	−0.0009 (0.3360)	−0.0447 (0.3046)	0.0039 (0.2724)	−0.0059 (0.1307)	0.0125 (0.6355)	0.0069 (0.1881)	−0.0103 (0.0259)	−0.0019 (0.5767)	−0.0183 (0.3950)	0.0000 (0.0006)	1			
13	Abnormal accruals	0.0005 (0.3218)	0.0044 (0.1990)	0.0021 (0.2008)	0.0053 (0.2007)	0.0010 (0.2288)	−0.0069 (0.2436)	0.0050 (0.2410)	0.0003 (0.0573)	0.0039 (0.2393)	−0.0064 (0.1890)	−0.0001 (0.0012)	−0.0336 (0.1166)	1		
14	Underlying asset holdings	−0.0993 (0.2093)	0.0150 (0.3189)	−0.0139 (0.3197)	0.0585 (0.3920)	−0.0036 (0.2258)	−0.0369 (0.1918)	0.0404 (0.3297)	−0.0004 (0.0836)	0.1945 (0.1417)	−0.1186 (0.2070)	0.0000 (0.0011)	0.0197 (0.4577)	0.0021 (0.3057)	1	
15	Overconfidence indicator	−0.0351 (0.4764)	0.0063 (0.1287)	−0.0136 (0.0974)	−0.0002 (0.0892)	−0.0062 (0.1800)	−0.1937 (0.1664)	−0.0024 (0.0106)	0.0013 (0.1631)	−0.0054 (0.0412)	−0.0296 (0.0666)	0.0000 (0.0663)	0.0028 (0.0005)	0.0012 (0.2709)	0.0270 (0.1369)	1

04 Empirical findings

Table 4

GLMX regression estimates of option exercise timing.

Generalized linear mixed model regression estimates of the percentage of an option award that is exercised in a given month. The full sample includes 2.48 million monthly observations associated with 69,797 option grants, 62,422 of which are (fully or partially) exercised by 20,665 employees in 3,222 individual firms between 1996 and 2014, using records from the Thomson Reuters Insiders database. For a given option award, the percentage of options exercised is the number exercised in a given month divided by the number of vested options held at the start of the month. Expected volatility, based on CRSP daily stock price records, and expected ambiguity, based on TAQ intraday stock price records, are calculated according to procedures described in the text. Illiquidity is measured according to Amihud (2002). Abnormal accruals are calculated following the modified Jones (1991) model. The blackout period indicator equals one for the month prior to the month in which the firm announces quarterly earnings. Underlying asset holdings are measured in billions and are cumulated from each manager's trading history. The overconfidence indicator equals one if a manager has ever held a stock option until its final year. *t*-statistics clustered by person, firm, month, and year appear in parentheses below each coefficient estimate.

Intercept	0.021	0.026	0.023	0.150	0.148	0.171	0.196	0.196
	(131.790)	(209.650)	(113.550)	(247.320)	(43.380)	(174.060)	(251.280)	(251.460)
Expected ambiguity	0.030		0.026	0.028	0.009	0.045	0.039	0.039
	(25.840)		(22.010)	(23.200)	(7.740)	(31.410)	(27.460)	(27.650)
Expected volatility		−0.164	−0.110	−0.115	−0.048	−0.190	−0.111	−0.111
		(−17.780)	(−11.540)	(−12.130)	(−4.850)	(−17.680)	(−10.390)	(−10.360)
Stock monthly return				0.058	0.057	0.053	0.046	0.046
				(61.820)	(60.460)	(55.660)	(49.390)	(49.300)
Vesting month indicator				0.063	0.062	0.058	0.047	0.047
				(63.000)	(62.270)	(58.010)	(47.300)	(47.230)
Log(1+months to expiration)				−0.031	−0.029	−0.033	−0.039	−0.039
				(−221.030)	(−196.700)	(−225.760)	(−255.060)	(−255.230)
12-month high price indicator				0.003	0.002	0.002	0.001	0.001
				(6.860)	(5.110)	(3.770)	(1.370)	(1.300)
Dividend yield × dividend month indicator				0.132	0.101	0.194	0.156	0.157
				(4.090)	(3.140)	(4.870)	(4.190)	(4.200)
Log(stock price/exercise price)				0.001	0.001	0.003	0.008	0.008
				(10.320)	(7.010)	(18.060)	(39.720)	(39.830)
Illiquidity				−0.026	−0.024	−0.028	−0.024	−0.024
				(−10.700)	(−9.580)	(−10.780)	(−9.390)	(−9.370)
Exercised at highest price in the month				0.694	0.696	0.695	0.689	0.689
				(16.130)	(16.210)	(16.220)	(15.950)	(15.960)
Blackout period indicator				−0.014	−0.014	−0.014	−0.014	−0.014
				(−70.470)	(−70.910)	(−70.700)	(−70.550)	(−70.550)
Abnormal accruals				0.002	0.002	0.001	0.001	0.001
				(6.050)	(5.870)	(2.700)	(2.610)	(2.630)
Underlying asset holdings				−0.048	−0.047	−0.055	−0.104	−0.104
				(−19.410)	(−19.390)	(−20.580)	(−24.700)	(−24.680)
Overconfidence indicator				−0.057	−0.058	−0.060	−0.065	−0.065
				(−168.730)	(−169.800)	(−169.760)	(−173.760)	(−173.910)
Year fixed effects	No	No	No	No	Yes	No	No	Yes
Firm fixed effects	No	No	No	No	No	Yes	No	Yes
Person fixed effects	No	No	No	No	No	No	Yes	Yes
Observations	2483877	2483877	2483877	2483877	2483877	2483877	2483877	2483877

04 Empirical findings

Table 5
Hazard regression estimates of option exercise timing.

Cox hazard model regression estimates of the exercise of an option award in the current month. The full sample includes 2.48 million monthly observations associated with 69,797 option grants, 62,422 of which are (fully or partially) exercised by 20,665 employees in 3,222 individual firms between 1996 and 2014, using records from the Thomson Reuters Insiders database. For the hazard model, the dependent variable equals one when at least 50% of the options are exercised, which occurs for 57,690 grants. Expected volatility, based on CRSP daily stock price records, and expected ambiguity, based on TAQ intraday stock price records, are calculated according to procedures described in the text. Illiquidity is measured according to Amihud (2002). Abnormal accruals are calculated following the modified Jones (1991) model. The blackout period indicator equals one for the month prior to the month in which the firm announces quarterly earnings. Underlying asset holdings are measured in billions and are cumulated from each manager's trading history. The overconfidence indicator equals one if a manager has ever held a stock option until its final year. *z*-statistics clustered by person, firm, month, and year appear in parentheses below each coefficient estimate.

Expected ambiguity	1.093		0.949	1.012	0.559	2.181	2.154	1.005
	(23.453)		(19.443)	(20.708)	(10.764)	(28.886)	(19.774)	(7.831)
Expected volatility		−7.347	−4.899	−7.996	−3.339	−16.974	−15.476	−6.188
		(−16.146)	(−10.74)	(−16.47)	(−6.769)	(−23.94)	(−15.95)	(−5.838)
Stock monthly return				2.083	2.063	2.029	1.934	1.912
				(58.586)	(56.116)	(39.777)	(26.594)	(24.698)
Vesting month indicator				5.680	5.697	5.617	5.034	5.127
				(50.651)	(50.593)	(23.497)	(12.034)	(11.217)
Log(1+months to expiration)				−0.987	−0.916	−0.895	−0.862	−0.733
				(−215.915)	(−191.734)	(−104.689)	(−59.685)	(−47.352)
12-month high price indicator				0.060	0.034	0.006	0.017	−0.017
				(3.596)	(2.017)	(0.293)	(0.595)	(0.575)
Dividend yield × dividend month indicator				6.104	4.452	10.411	7.369	12.477
				(5.044)	(3.583)	(5.271)	(2.862)	(4.115)
Log(stock price/exercise price)				0.040	0.047	0.162	0.384	0.622
				(8.768)	(11.108)	(18.866)	(26.827)	(36.741)
Illiquidity				−9.083	−7.904	−31.655	−31.651	−14.857
				(−21.93)	(−19.612)	(−28.772)	(−20.7)	(−10.2)
Exercised at highest price in the month				3.116	3.144	2.145	1.077	0.538
				(8.82)	(8.894)	(4.03)	(.922)	(.452)
Blackout period indicator				−0.641	−0.641	−0.821	−0.792	−0.788
				(−60.263)	(−60.282)	(−59.858)	(−41.675)	(−39.187)
Abnormal accruals				0.097	0.095	0.124	0.179	0.193
				(6.228)	(5.916)	(6.178)	(6.535)	(6.614)
Underlying asset holdings				−8.061	−7.850	−7.987	−8.496	−10.155
				(−19.595)	(−19.539)	(−19.)	(−12.148)	(−13.285)
Overconfidence indicator				−4.497	−4.537	−4.866	−4.518	−4.538
				(−67.826)	(−68.418)	(−65.243)	(−48.133)	(−47.813)
Year fixed effects	No	No	No	No	Yes	No	No	Yes
Firm fixed effects	No	No	No	No	No	Yes	No	Yes
Person fixed effects	No	No	No	No	No	No	Yes	Yes
Observations	2291966	2291966	2291966	2291966	2291966	2291966	2291966	2291966

04 Empirical findings

Table 6

Regression estimates of option exercise timing with lags of key explanatory variables.

Panel A presents generalized linear mixed model regression estimates of the percentage of an option award that is exercised in a given month. Panel B presents Cox hazard regression estimates of the exercise of an option award in the current month. The full sample includes 2.48 million monthly observations associated with 69,797 option grants, 62,422 of which are (fully or partially) exercised by 20,665 employees in 3,222 individual firms between 1996 and 2014, using records from the Thomson Reuters Insiders database. For a given option award, the percentage of options exercised is the number exercised in a given month divided by the number of vested options held at the start of the month. For the hazard model, the dependent variable equals one when at least 50% of the options are exercised, which occurs for 57,690 grants. The regression models contain all of the control variables from the model in Tables 4 and 5 above, and the left column in this table reproduces the estimates from the right column of Table 4 for comparison purposes. In Panel A, *t*-statistics clustered by person, firm, month, and year appear in parentheses below each coefficient estimate. In Panel B, *z*-statistics clustered by person, firm, month, and year appear in parentheses below each coefficient estimate.

Panel A: GLMX regressions					
Intercept	0.196	0.194	0.196	0.197	0.194
	(251.460)	(249.800)	(249.470)	(249.720)	(237.960)
Expected ambiguity	0.039				0.022
	(27.650)				(10.340)
Expected volatility	–0.111				–0.039
	(–10.360)				(–2.830)
Expected ambiguity *t*-1		0.042			0.028
		(28.470)			(11.780)
Expected volatility *t*-1		–0.140			–0.091
		(–12.660)			(–6.560)
Expected ambiguity *t*-2			0.034		0.010
			(23.320)		(4.440)
Expected volatility *t*-2			–0.113		–0.035
			(–10.240)		(–2.540)
Expected ambiguity *t*-3				0.026	–0.009
				(17.910)	(–4.280)
Expected volatility *t*-3				–0.085	0.015
				(–7.670)	(1.120)
Controls	All	All	All	All	All
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
Person fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	2483877	2420386	2400045	2383232	2306422

04 Empirical findings

Table 7
Regression estimates of option exercise timing for certain subsamples.

Panel A presents generalized linear mixed model regression estimates of the percentage of an option award that is exercised in a given month. Panel B presents Cox hazard regression estimates of the exercise of an option award in the current month. The full sample includes 2.48 million monthly observations associated with 69,797 option grants, 62,422 of which are (fully or partially) exercised by 20,665 employees in 3,222 individual firms between 1996 and 2014, using records from the Thomson Reuters Insiders database. For a given option award, the percentage of options exercised is the number exercised in a given month divided by the number of vested options held at the start of the month. For the hazard model, the dependent variable equals one when at least 50% of the options are exercised, which occurs for 57,690 grants. In the first column, we show estimates only for those executives identified as chief executive officers (CEO) in the Thomson Reuters database. In the second column, we show estimates only for those executives identified as overconfident (having ever held a stock option until its final year). In the third column, we restrict the analysis to those executives whose holdings in the underlying equity in lie in the top two quartiles of the holdings variable. In the fourth column, we restrict the analysis to those observations in the top two quartiles of the ambiguity variable. In the fifth column, we restrict the estimation to those observations in the top two quartiles of the volatility variable. Expected volatility, based on CRSP daily stock price records, and expected ambiguity, based on TAQ intraday stock price records, are calculated according to procedures described in the text. The regression models contain all of the control variables from the model in Tables 4 and 5 above. In Panel A, *t*-statistics clustered by person, firm, month, and year appear in parentheses below each coefficient estimate. In Panel B, *z*-statistics clustered by person, firm, month, and year appear in parentheses below each coefficient estimate.

Panel A: GLMX regressions

	CEO	Overconfident	Non-diversified (highest 50%)	50% highest Ambiguity	50% highest Volatility
Intercept	0.181	0.109	0.178	0.193	0.190
	(109.040)	(57.280)	(168.430)	(181.000)	(170.600)
Expected ambiguity	0.043	0.018	0.026	0.039	0.036
	(12.580)	(3.970)	(16.190)	(23.690)	(12.750)
Expected volatility	−0.068	−0.099	−0.069	−0.132	−0.096
	(−2.720)	(−2.980)	(−5.210)	(−6.420)	(−7.900)
Controls	All	All	All	All	All
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
Person fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	407252	184222	1241939	1241939	1241939

Panel B: Cox regressions

	CEO	Overconfident	Non-diversified (highest 50%)	50% highest Ambiguity	50% highest Volatility
Expected ambiguity	1.152	0.985	1.139	0.930	0.502
	(3.745)	(2.384)	(4.679)	(6.081)	(2.061)
Expected volatility	−0.624	−11.359	−3.274	−2.223	−3.931
	(−1.969)	(−3.042)	(−1.544)	(−1.996)	(−3.395)
Controls	All	All	All	All	All
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
Person fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	376886	173304	1145984	1145984	1145984

05 Conclusion

- Our contribution involves the introduction of a second measure of uncertainty—ambiguity—alongside the more traditional measure of volatility.

- The empirical estimates of these two quantities exhibit only a modest correlation, and both turn out to be significant predictors of managers' exercise behavior, with volatility causing executives to hold their options longer, and ambiguity increasing the tendency for executives to exercise early.

- Consistent with previous studies, these findings can be explained by the option holder's willingness to preserve remaining option value when volatility is expected to be high. On the other hand, when ambiguity is expected to be high, the holder prefers to exercise early in response to ambiguity aversion.