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Authors
Song, Reo
Jang, Sungha
Wang, Yingdi
et al.

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Reinforcement learning and risk preference in equity linked notes markets

Reo Song [a], Sungha Jang [b,*], Yingdi Wang [c], Dominique M. Hanssens [d], Jaebeom Suh [e]

[a] Department of Marketing, California State University, Long Beach, CA 92840, United States of America
[b] Department of Marketing, College of Business, San Francisco State University, San Francisco, CA 94132, United States of America
[c] Department of Finance, Mihaylo College of Business and Economics, California State University Fullerton, Fullerton, CA 92834, United States of America
[d] Department of Marketing, UCLA Anderson School of Management, Los Angeles, CA, 90095, United States of America
[e] Department of Marketing, Kansas State University, Manhattan, KS 66503, United States of America

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ABSTRACT

Individuals who follow a reinforcement learning heuristic put too much weight on recent failures or successes in placing their next bets. Using a large sample of equity-linked notes (ELNs) investments in South Korea, we find evidence showing a negative effect of reinforcement learning on future investments that lasts longer than one investment period. After losses, investors are less likely to repurchase equity-linked notes and spend less on their repurchases. This behavior also results in reinforcement learners underperforming rational agents. The difference in returns received by reinforcement and non-reinforcement groups is economically large at approximately 10.7%. However, these negative effects of reinforcement learning are mitigated by investors' higher risk attitudes. We find that more risk-seeking investors are less likely to shun ELNs after undesirable prior returns and that this effect persists for more than one period. The underperformance of reinforcement learners is also reduced with high risk-taking. Overall, our findings highlight how combining different psychological traits can diagnose and improve biases in investor decision-making.

1. Introduction

Individuals' total financial assets in the U.S. amounted to $221,199 per capita in 2015, and over 55% of those assets were in the form of securities (OECD Data[1]). These individuals' investment decisions have far-reaching consequences, as they affect not only the individual investors but also the greater economy. However, various studies have documented behavioral biases that can adversely affect decision-making. One such bias is naive reinforcement learning, which refers to people's tendency to repeat choices that have produced favorable outcomes in the past. It can be referred to as a "win-stay, lose-shift" heuristic and leads investors to disproportionally favor investments with successful historical outcomes. Kaustia and Knüpfer (2008), Choi et al. (2009), and Chiang et al. (2011) all show that, consistent with reinforcement learning, investors over-extrapolate their own investment experience. Outside of finance, a rich body of evidence in economics, marketing, and psychology also support that reinforcement learning affects peoples' decision-making (e.g., Cross (1973), Charness and Levin (2005), Roth and Erev (1995), Chen et al. (2009))

Despite the potential impact of reinforcement learning on our investment decisions, our understanding of this bias is limited. For example, we do not know how other well-documented psychological traits interact with reinforcement learning. Our sensitivity to

* Corresponding author.
E-mail addresses: reo.song@csulb.edu (R. Song), shjang@sfsu.edu (S. Jang), yingdiwang@fullerton.edu (Y. Wang), dominique.hanssens@anderson.ucla.edu (D.M. Hanssens), jsuh@ksu.edu (J. Suh).

[1] OECD Data: https://data.oecd.org/hha/household-financial-assets.htm#indicator-chart.

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risk, in particular, influences our decisions and returns, and undesirable outcomes increase our risk aversion (Barberis et al., 2001; Guiso et al., 2018). Barberis et al. (2001) also point out that undesirable events such as negative investment returns increase fear and psychological pains from potential losses. Increased fear, in turn, leads to higher risk aversion and reduces subsequent investments in risky assets (Guiso et al., 2018). These studies suggest that risk aversion could magnify the effects of reinforcement learning on investment decisions. In this paper, we study how reinforcement learning affects investors' future decisions, their returns, and how these effects change with risk preferences.

We use a sample of equity-linked notes (ELNs) in South Korea and examine the changes in investors' subsequent repurchase decisions after observing undesirable outcomes.[2] There are two main reasons for studying ELNs in South Korea. First, this market offers unique insights into the measurement of risk. South Korea requires all ELN investors to fill out a risk survey that categorizes their risk preferences on a numerical scale (referred to as risk preference score hereon). This allows us to directly measure these investors' risk preferences as opposed to inferring them from a model of their choices. Second, each ELN is based on a unique basket of securities. That is, each ELN return is independent of the previous one, making it irrational to base repurchase decisions on prior outcomes.

Since ELNs can be structured as either principal-protected or unprotected, we define undesirable outcomes as negative returns from unprotected ELNs and zero returns from the protected ones, respectively. As past ELN returns cannot predict future success, withholding repurchases after undesirable outcomes would be irrational. However, using a Probit selection model and a Heckman selection model, we first find that undesirable outcomes of both protected and unprotected ELNs are associated with a lower likelihood of repurchasing and a lower repurchase amount, a pattern consistent with reinforcement learning. The reduction in repurchase amount is also economically large in both cases but higher after losses from unprotected ELNs. Conditional on repurchases being made, zero returns of principal-protected ELNs are associated with a reduction of $7,566 for subsequent purchases, and negative returns of unprotected ELNs are associated with a reduction of $16,549 in repurchases. We also analyze the effect of percentage returns (as opposed to categorical undesirable outcomes) on investors' repurchase decisions. The results show the same "win stay, lose shift" pattern: higher returns are associated with more repurchases and a higher repurchase amount.

While our results show that investors exhibit naive reinforcement learning, these patterns are attenuated by higher risk preference scores. We find that the likelihood to repurchase increases with investors' risk preference scores. Moreover, after undesirable outcomes, more risk-seeking investors are more likely to repurchase. This effect is even stronger for those who previously purchased principal-protected ELNs. The same pattern holds for repurchase amount as well.

Next, we investigate the dynamic effect of reinforcement learning and risk on repurchase decisions. We find that the negative effects of reinforcement learning last longer than one period. Our results show that undesirable outcomes from the prior investment period, measured by lagged negative returns, continue to be significantly associated with a lower likelihood to repurchase and a lower repurchase amount. However, this effect is smaller than the most recent experience. In contrast, we also find that the mitigating effect of higher risk preference scores persists longer than one period.

Finally, we investigate how reinforcement learning combined with risk preferences affects investors' returns. To test whether reducing repurchases negatively affect returns, we classify investors as reinforcement learners and non-reinforcement learners based on their repurchase patterns after their first investments, then compare returns in subsequent periods. We find that reinforcement learners earn an approximately 10.7% lower average return than non-reinforcement learners do. We also find that reinforcement learners who are not risk-takers show the lowest average return of 6.0% while risk-taking non-reinforcement learners earn 17.9%, the highest average return. Regression results also show that average returns for non-reinforcement learners are significantly higher than those of reinforcement learners. The results do not change meaningfully when we examine recession and non-recession periods separately. Overall, our results show that reinforcement learning has a sizeable negative effect on returns and that risk aversion seems to magnify this negative effect.

Our paper contributes to the literature in several ways. First, our results provide additional insights into reinforcement learning and its impact. Several studies document empirical results consistent with reinforcement learning. Kaustia and Knüpfer (2008) find that Finnish investors are more likely to subscribe to initial public offerings (IPOs) if their IPO investments have been profitable. Chiang et al. (2011) also show that individuals over-extrapolate from their prior experience when participating in IPOs. Choi et al. (2009) find that individual investors' 401(k) savings decisions are influenced by their personal experience, and Strahilevitz et al. (2011) show that investors' willingness to repurchase a stock is affected by their previous experience with that stock. Our results complement these studies by showing that reinforcement learning biases individuals' ELN repurchase decisions and has a large negative effect on returns. Second, our results add to the larger literature on investor learning. Studies have shown that individual investors' learning is affected by a number of behavioral biases and individual characteristics such as overconfidence and habits (e.g., Odean (1998), Hirshleifer and Welch (2002), Madrian and Shea (2011)). However, most research focuses on a single psychological trait or bias. Our results on the interaction between risk preference and reinforcement learning indicate that it is important to study individuals' financial decision-making in a combined framework. These findings also have practical implications on improving investor welfare after experiencing losses.

The remainder of the paper is organized as follows. Section 2 summarizes the ELN market. Section 3 introduces the data and descriptive statistics on our sample. Section 4 and Section 5 present the empirical methodology and results, respectively. Section 6 compares the returns of different investor types, and Section 7 concludes.

[2] Previous studies have shown that negative information is less ambiguous and more diagnostic than positive information (Herr et al., 1991) and that reinforcement learning is more salient when people experience negative events (Strahilevitz et al., 2011). Therefore, our analyses focus on undesirable investment outcomes.

Table 1
ELN market in South Korea.

Year	Protected ELN		Unprotected ELN		Total
	Amount	Percentage (%)	Amount	Percentage (%)	amount
2003	1,626,726	56.0%	1,280,341	44.0%	3,465,462
2004	1,066,923	21.8%	3,818,939	78.2%	5,595,465
2005	857,836	6.2%	13,041,600	93.8%	14,229,534
2006	2,222,816	9.5%	21,125,838	90.5%	22,282,111
2007	4,658,121	16.9%	22,899,494	83.1%	25,600,245
2008	2,242,306	12.1%	16,339,526	87.9%	20,415,970
2009	2,600,493	27.7%	6,785,723	72.3%	11,963,906
2010	4,982,728	22.8%	16,883,006	77.2%	25,271,082
2011	8,930,035	28.8%	22,119,804	71.2%	34,370,309
2012	12,646,013	30.8%	28,369,198	69.2%	46,189,772
2013	12,928,994	33.1%	26,132,882	66.9%	42,760,059
2014	17,726,316	28.1%	45,329,829	71.9%	66,353,477
2015	12,945,131	20.3%	50,888,976	79.7%	72,193,821
2016	12,683,455	31.1%	28,069,219	68.9%	47,246,286
2017	14,187,549	20.6%	54,743,487	79.4%	77,826,172

This table reports the market size of protected and unprotected ELN from 2003 to 2011. Column *Amount* shows the dollar amount (in $1,000) of ELNs in each year. The dollar amount is adjusted using the yearly Korean won to US dollars exchange rate. The percentage is the ratio of protected (unprotected) ELN amount to the total ELN amount each year. The source is Korea Financial Investment Association (KOFIA).

2. ELN market in South Korea

ELNs are hybrid debt instruments. Unlike traditional debt, ELNs' final payouts depend on the underlying equity value, and each ELN has its unique base assets and return. Appendix A provides detailed explanations on ELNs. The market for ELNs evolved in the early 1990s, and its size has rapidly increased since 2004 (Henderson and Pearson, 2011).

ELNs are structured to provide either protection or no protection of principal. These two types of ELNs then determine the lower bound of returns: negative returns from unprotected ELNs and zero returns from protected ELNs. These two return structures can help us identify and compare the extent to which reinforcement learning affects future investment decisions. As reinforcement learning is more salient when people experience negative events, we expect a greater reduction in ELN repurchases after observing higher losses from unprotected ELNs.

One distinct feature of the ELN market in South Korea is that all investors are required to fill out a risk preference survey. This allows us to directly measure individual risk preferences and how they affect the decision-making process.[3] The ELN market in South Korea also grew dramatically over time. The initial market size was $3.5 billion in 2003 and grew to $34.3 billion in 2011. Individual investors make up a significant portion of the Korean ELN market. Table 1 shows the evolution in market size of ELNs (in $1,000) from 2003 to 2011. With the exception of 2003, the majority of the ELNs are unprotected. However, protected ELNs have been growing in size. Investors gradually move to unprotected ELNs following higher past returns. However, the proportion of protected ELNs purchased increased in 2007, coinciding with investors suffering losses from unprotected ELNs due to the financial crisis. These patterns are consistent with reinforcement learning.

3. Data

3.1. Sample construction

Our data on ELNs are provided by one of the largest security brokerage firms in South Korea. Market data such as a stock price index and the 3-year government bond rate are obtained from the *Korea Financial Investment Association*. The firm's market share in brokering ELNs in 2016 was 11.9%. The largest brokerage firm's market share in that year was 13.1%. The original data contain 163,588 ELN purchases made by 60,138 unique individual investors over the period of February 2006 to April 2011.

Information included in the transactions are individual purchase records (e.g., purchase date, amount, and type), returns, advertising amount, and investors' demographics such as gender, age, and risk preferences. Risk preferences, in particular, are obtained from the mandatory surveys. Sample questions used by the survey are provided in Appendix B. Based on the survey questions, the brokerage firm then measures investors' risk preference on a one-to-five scale with five being the most risk-seeking. Individual answers from the survey are confidential. Our data only show the final summary of individuals' risk preferences.

We follow several steps in preparing the data. First, we keep only transactions with realized returns (129,372 transactions), as we cannot determine investors' behavior without return data. We then restrict our sample to investors who repurchased ELNs at least

[3] Inferring individuals' risk preferences using actual financial market data is challenging (Cohn et al., 2015). Self-reported risk preference measured in a survey has been shown to be more useful in predicting real world risk-taking behavior than risk attitude derived from an expected utility-model (Harrison et al., 2005).

Table 2
Summary statistics.

Panel A: Repurchase decisions				
Variable	N	Mean	Median	SD
Repurchase (dummy)	27,336	0.37	0.00	0.48
Purchase of Unprotected ELN (dummy)	10,188	0.91	1.00	0.29
Repurchase Amount ($ thousand)	10,188	33.65	20.00	36.19
Zero Return (dummy)	27,336	0.12	0.00	0.32
Negative Return (dummy)	27,336	0.19	0.00	0.40
Panel B: Investor and market characteristics				
Risk Preference (1–5)	6103	3.50	4.00	1.09
Investment Experience in ELN	27,336	4.50	3.00	4.58
Advertising ($ thousand)	27,336	1.93	1.81	1.75
Annual Return Rate (%)	27,336	6.89	13.79	19.74
Principal Amount ($ thousand)	27,336	27.22	20.00	52.12
Amount of Investment Tools ($1,000)	27,336	309.54	195.48	440.64
Number of Investment Tools	27,336	4.36	4.25	1.48
Age	6103	55.00	54.00	12.65
Male (dummy)	6103	0.37	0.00	0.48
Stock Price Index ($ thousand)	27,336	1.68	1.65	0.23
Government Bond Rates (%)	27,336	4.39	4.29	0.72

This table reports summary statistics of major variables in the paper. Panel A reports the mean, median, standard deviation (SD), and the number of observations (N) for variables that capture repurchase decisions. Except for *Repurchase Amount*, which is the dollar amount of repurchase measured in $1,000, all variables in this panel are indicator variables. *Repurchase* equals 1 if an investor repurchases within 91 days of observing an investment outcome, and 0 otherwise. *Purchase of Unprotected ELN* equals 1 if an investor repurchases an unprotected ELN, and 0 if the investor repurchases a protected ELN within the decision period. *Zero Return* takes the value of 1 if the observed return from the previous principal-protected ELN purchase is 0 and 1 if it is positive. *Negative Return* takes the value of 1 if the return of previous unprotected ELN is negative and 0 if it is positive. The sample does not show any zero return in unprotected ELNs. Panel B presents characteristics of investors in the sample and the market. *Risk preference* measures investors' risk preference on a scale of one to five, with five being the most risk-loving. *Investment experience* is the number of ELN purchases with realized returns that investors have made. *Advertising* is the dollar amount of ELN advisement measured by $ thousand. *Annual Return Rate (%)* and *Principal Amount* are the actual annualized percentage returns and the amount of principal received, respectively. *Amount (Number) of investment tools* is the dollar amount, measured in $ thousand, (number) of non-ELN investments (i.e., stocks, bonds) in investors' portfolios. *Age* and *Male* show investors' age and gender. *Male* takes on the value of one for male investors, and zero for female. *Stock price index* and *Government bond rates* are the Korean stock market index and three-year government bond's rate, respectively.

twice (69,928 transactions) with observed returns.[4] Investors who did not experience a negative return from unprotected ELNs or a zero return from protected ELNs are removed as well. The final database consists of 6103 unique investors with 27,336 transactions.

3.2. Sample statistics

If an investor makes a repurchase within 91 days after observing a past investment return, we classify *Repurchase* as one, and zero otherwise. We chose this 91-day decision window based on both patterns in the data and theoretical reasoning. Our data show that more than 75% of investors repurchase within 79 days after they observe prior returns and that the average time gap between an observed return and a repurchase is 84.2 days. Therefore, this window captures most repurchases. Theoretically, a shorter window may also be more suitable for testing reinforcement learning, for two reasons. First, prior literature shows that investor behavior tends to be affected by most recent and salient experience (e.g., Frydman and Wang (2020)). As a result, a recent return may have a significant effect on repurchase behavior compared to a return from over three months ago. Second, a short event window such as 91 days is less noisy compared to a long event window as it allows for fewer intervening events. Table 2 shows the summary statistics of purchase records and characteristics of investors in our final sample. Panel A of Table 2 shows that 37.3% of investors made repurchases and, among repurchases, the proportions of unprotected and protected ELNs repurchased are 90.6% and 9.4%, respectively. 11.5% of the sample has zero returns from protected ELNs, and 19.4% of the sample has negative returns from unprotected ELNs.

Panel B shows that the average investor in our sample has a risk preference score of 3.5 and has observed returns from more than 4.5 ELNs prior to making a repurchase decision. There are also more female investors as the male indicator is 0.37. The average return of ELNs is approximately 6.9%. However, there is a wide variation in these returns.

Table 3 shows how the repurchase decisions vary with investment outcomes. Since protected and unprotected ELNs have distinct patterns of returns, in this and the following tables, we separate repurchase decisions by whether investors purchased unprotected or protected ELNs. To determine whether the differences in proportions are statistically significant, we use a proportional difference test.

[4] Because we later also study the dynamics of reinforcement learning and analyze how the frequency of showing reinforcement learning behavior is related to returns, we restrict our sample to investors with at least two repurchases instead of one.

Table 3
Purchase decisions by investment outcome.

Prior investment type	Prior investment results		Repurchase		Repurchase of unprotected ELN		Repurchase amount ($1,000)	
	N	Return type	N	Percent	N	Percent	N	Amount
Unprotected	5,293	Negative (1)	724	13.67%	658	90.88%	724	$23.23
	18,151	Positive (2)	8787	48.41%	8020	91.27%	8787	$34.80
		Diff (1–2)		−34.74%***		−0.39%		−$11.56***
Protected	3156	Zero (1)	472	14.95%	408	86.44%	472	$30.03
	736	Positive (2)	205	27.85%	144	70.24%	205	$29.53
		Diff (1–2)		−12.90%***		16.20%***		$0.50

This table reports statistics on investors' repurchase decisions by prior investment outcome. Returns of unprotected ELNs are either negative or positive while those of protected products are either zero or positive. Repurchase decisions are measured by: 1. whether the investor repurchased ELNs, 2. whether the repurchase is for unprotected ELNs, and 3. the repurchase amount. Columns *Percent* and *N* show the percentage and number of observations in each group, respectively. We use t-tests to determine whether the percentages between the two groups are significantly different. *** reports significance levels at 1%.

Table 4
Purchase decisions after undesirable outcomes by risk preference level.

Risk preference	Repurchase		Repurchase of unprotected ELNs	
	Negative returns	Zero returns	Negative returns	Zero returns
1	11.19% (15)	5.08% (6)	93.3% (14)	66.7% (4)
2	8.49% (83)	10.33% (65)	74.70% (62)	61.54% (40)
3	11.40% (105)	13.45% (78)	86.67% (91)	76.92% (60)
4	15.40% (347)	16.44% (210)	94.24% (327)	92.86% (195)
5	17.28% (174)	20.47% (113)	94.25% (164)	96.46% (109)
Total	13.68% (724)	14.96% (472)	90.88% (658)	86.44% (408)
Difference	$\chi^2 = 43.79$	$\chi^2 = 36.06$	$\chi^2 = 35.69$	$\chi^2 = 59.47$

This table reports ELN and unprotected ELN repurchase decisions by investors' risk preference. The percentages of ELN investments that are followed by repurchases (repurchase of unprotected ELNs) within 91 days of observing undesirable investment outcomes are reported for each risk preference level. Risk preference is measured on a scale of 1 to 5, where 1 is the most risk averse. The numbers in parenthesis represent the number of unique investors. *Total* indicates the total percentage of repurchases regardless of risk preference. Column *Negative Returns* and *Zero Returns* report repurchase results for prior investments of unprotected and protected ELNs, respectively. Chi-squared tests are used to determine whether investors in each group are equally likely to repurchase or repurchase unprotected ELNs (All tests are significant at 1% level).

For unprotected ELNs, prior negative returns result in a repurchase rate of 13.67%, compared to a repurchase rate of 48.41% for prior positive returns. The difference is statistically significant at the 1% level. Similarly, protected ELNs also show a significantly higher repurchase rate after positive returns compared to zero returns (i.e., 27.85% vs. 14.95%). The same pattern holds for the repurchase amount as well. Overall, the difference in repurchase decisions is much higher when the ELNs are unprotected than when they are protected. This pattern is consistent with reinforcement learning, as investor losses are limited in protected ELNs.

Conditioning on a repurchase made, there is no significant difference in repurchasing of unprotected ELNs between prior negative and positive returns of unprotected ELNs. The repurchase rate is 90.88% for negative returns versus 91.27% for positive returns. However, investors who experience zero returns of protected ELNs are significantly more likely to purchase unprotected products than those who experience positive returns.[5] These different patterns demonstrate that how returns affect repurchase decisions depends on prior investment types.

Table 4 summarizes the effects of undesirable outcomes (i.e., negative returns of unprotected ELNs and zero returns of protected ELNs) on repurchase decisions by investors' risk preference scores. We find that as the degree of risk-taking increases, investors show a higher repurchase rate. For unprotected ELNs, investors in the risk level 2 category have a 8.49% repurchase rate whereas those in risk level 5 category have a 17.28% repurchase rate. Similarly, investors who observe zero returns from protected ELNs exhibit a significantly higher repurchase rate with increasing risk preference scores (e.g., 13.33% for level 2 but 20.47% for level 5). Repurchases of unprotected ELNs show a similar pattern. The percentage of unprotected ELNs repurchased increases with the degree of risk-taking. These results suggest that investors with higher risk preference levels are less sensitive to prior investment losses. In the next section, we formally test these results in decision models.

[5] Regression results in Table 5 show that investors with undesirable zero-returns are not significantly more likely to repurchase unprotected ELNs than those with positive returns.

Table 5
Estimation results of repurchase and repurchase type.

	Previous investment: Unprotected ELNs		Previous investment: Protected ELNs	
	Choice	Type (Unprotected)	Choice	Type (Unprotected)
Neg/Zero Return	−0.812***	−0.339	−0.727**	0.805
	(0.102)	(0.234)	(0.369)	(1.902)
Risk Preference	0.044***	0.038**	0.048	0.457
	(0.011)	(0.018)	(0.045)	(0.397)
Neg/Zero Return × Risk	0.088***	0.071	0.102**	0.010
	(0.024)	(0.057)	(0.052)	(0.173)
Investment Experience	0.012***	0.049***	0.032***	0.102
	(0.003)	(0.011)	(0.012)	(0.076)
Neg/Zero Return × Investment Experience	−0.004	−0.011	−0.011	−0.078
	(0.007)	(0.022)	(0.015)	(0.087)
Advertising ($1,000)	0.102***		−0.084	
	(0.013)		(0.058)	
Neg/Zero Return × Advertising	−0.121***		0.039	
	(0.028)		(0.111)	
Principal Amount ($1000)	0.002***		0.001**	
	(0.000)		(0.000)	
Amount of Investment Tools ($1,000)	−0.0001***		−0.0003***	
	(0.000)		(0.000)	
Number of Investment Tools	0.031***	−0.001	0.094***	0.003
	(0.008)	(0.012)	(0.019)	(0.128)
Age	0.003***	0.001	0.003	−0.004
	(0.001)	(0.001)	(0.002)	(0.011)
Male	−0.009	0.059	0.002	0.005
	(0.022)	(0.038)	(0.051)	(0.129)
Stock Price Index ($1,000)	0.143	−2.140***	1.313**	1.343**
	(0.103)	(0.206)	(0.589)	(0.634)
Government Bond Rate	0.044	−0.342**	0.012	0.300
	(0.042)	(0.172)	(0.206)	(0.430)
Intercept	−0.673***	6.193***	−4.378***	−6.607***
	(0.237)	(0.754)	(0.873)	(1.410)
Year dummies	Yes	Yes	Yes	Yes
Number of observations	23,444		3892	
Log Pseudo-likelihood	−16,453.88		−1,946.21	

This table reports results of repurchase decisions measured by the probability of repurchasing ELNs in general and the probability of repurchasing *unprotected* ELNs. A probit model with sample selection is used to estimate the two stages for investors who previously invested in unprotected ELNs (Column *Unprotected ELNs*) and those invested in principal-protected ones (Column *Protected ELNs*). Stage 1 estimates the probability of repurchasing ELNs. The dependent variable equals one if the investors repurchased ELNs within 91 days after observing prior ELN investment returns, and zero otherwise. Stage 2 estimates the probability of purchasing only unprotected ELNs. The dependent variable equals one if investors purchased unprotected ELNs within our observation window of 91 days post-return, and zero otherwise. *Neg/Zero Return* is a dummy variable, which takes the value of 1 if unprotected (protected) ELNs yield negative (zero) return, and 0 otherwise. All other variables are defined in Table 2. Year dummies are included in all regressions. Robust standard errors clustered by investor are reported in parentheses. *, **, and *** report significance levels at 10%, 5%, and 1%, respectively.

4. Empirical methodology

4.1. Models

Our goal is to determine the relationship between investment outcomes and repurchase decisions and how this relationship is moderated by higher risk preferences. We measure several dimensions of repurchase decisions: the probability of repurchasing, the probability of purchasing unprotected ELNs, and the repurchasing amount. Because the purchase type and amount are observed only after a repurchase is made, we use a probit model with sample selection to estimate the repurchase type and a Heckman selection model to estimate the repurchase amount.

As previously noted, protected and unprotected ELNs have very different investment outcomes. While the returns of protected ELNs have a lower bound of zero, returns of unprotected ELNs can be negative and are rarely zero.[6] As a result, the degree of reinforcement learning can depend on the type of ELNs (i.e., protected and unprotected) that investors previously purchased. Therefore, we separately model repurchase decisions following investment outcomes of unprotected and protected ELNs.

After observing prior returns, investors first decide whether to make additional investments and the type of ELNs to repurchase. Eqs. (1a) and (1b) represent these repurchase decisions at time *t+1* when investor *i* observes returns at time *t*.

$$y^{*}_{repurchase,it+1} = \alpha_0 + \alpha_1 Neg/ZeroReturn_{it} + \alpha_2 Risk_i + \alpha_3 Neg/ZeroReturn_{it} \times Risk_i + \sum \alpha_k X_{k,it} + u_{it+1} \quad (1a)$$

[6] Our sample does not include any zero returns from unprotected ELNs.

$$y^*_{type,it+1} = \beta_0 + \beta_1 Neg/ZeroReturn_{it} + \beta_2 Risk_i + \beta_3 Neg/ZeroReturn_{it} \times Risk_i + \sum \beta_k W_{k,it} + \varepsilon_{type,it+1} \quad (1b)$$

$y^*_{repurchase}$ is the utility of repurchasing a product. If the utility is above a threshold utility, scaled to zero, we observe repurchase (i.e., $y_{repurchase} = 1$). Otherwise, we observe no purchase (i.e., $y_{repurchase} = 0$). y^*_{type} is the utility of repurchasing an unprotected product over a protected product. If the utility is above a threshold utility, scaled to zero, we observe an unprotected product repurchase (i.e., $y_{type} = 1$). Otherwise, we observe a protected product repurchase (i.e., $y_{type} = 0$). Note that we observe y_{type} when $y^*_{repurchase}$ is greater than zero, or equivalently when the customer decides to repurchase (i.e., $y_{repurchase} = 1$). The error terms follow the standard bivariate normal distribution with a correlation coefficient of ρ_1.

Second, investors decide how much they repurchase after making reinvestment decisions. Eqs. (2a) and (2b) represent the repurchase decision and the repurchase amount at time *t+1* when investor *i* observes returns at *t*.

$$y^*_{repurchase,it+1} = \gamma_0 + \gamma_1 Neg/ZeroReturn_{it} + \gamma_2 Risk_i + \gamma_3 Neg/ZeroReturn_{it} \times Risk_i + \sum \gamma_k X_{k,it} + \nu_{it+1} \quad (2a)$$

$$y_{amount,it+1} = \delta_0 + \delta_1 Neg/ZeroReturn_{it} + \delta_2 Risk_i + \delta_3 Neg/ZeroReturn_{it} \times Risk_i + \sum \delta_k Z_{k,it} + \varepsilon_{amount,it+1} \quad (2b)$$

$y^*_{repurchase}$ is the utility of repurchasing a product as described above. y_{amount} is the amount of repurchase given that $y_{repurchase} = 1$. Note that we can observe y_{amount} when $y^*_{repurchase}$ is greater than zero, or equivalently when the investor decides to repurchase (i.e., $y_{repurchase} = 1$). The error terms follow the standard bivariate normal distribution with a correlation coefficient of ρ_2.

4.2. Independent variables

Neg/Zero Return represents a dummy variable indicating the undesirable investment outcome (i.e., negative returns for unprotected ELNs and zero returns for protected ELNs). We also provide results using actual percentage returns (indicated by variable *Return (%))* in Section 5.3. If multiple returns are observed within two weeks of time *t*, we calculate a principal-weighted return rate for investor *i*. Negative coefficient estimates of *Neg/Zero Return* would be consistent with reinforcement learning behavior, as they show that investors' repurchase decisions are negatively affected by unsuccessful outcomes.

Risk is individual risk preference. This variable is measured on a scale of one to five, with five being the most risk-seeking. *Neg/Zero Return* × *Risk* represents the interaction term between either negative returns of unprotected ELNs and risk preference or zero return of protected ELNs and risk preference. Positive coefficient estimates of this term would suggest that a higher risk preference mitigates the negative impact of reinforcement learning on repurchase decisions.

X in Eq. (1a) is a vector of control variables in the selection stage. It includes a proxy for ELN investment experience, firm's advertising amount, funds available for reinvestment, the amount and the number of different investment tools (e.g., stock, bond, and futures) in investors' portfolios during their decision periods, and demographic information. *X* also includes controls for other investment opportunities and macroeconomic conditions measured by the average stock price index, the 3-year government bond rate during the decision period, and year dummies.

ELN investment experience is the total number of ELNs with observed returns that investor *i* experienced at time *t*. We control for the effect of investment experience because it can confound the effect of risk preference on repurchase decisions. Studies have demonstrated that experience reduces psychological biases. Market experience plays a significant role in eliminating the endowment effect (List, 2003), stock return expectations (Kaustia et al., 2008), and reduces violations of consistent preferences, known as the Generalized Axiom of Revealed Preference (List and Millimet, 2008).

We calculate the firm's *advertising amount* two months before (to reflect a possible carry-over effect), during, and two months after time *t*, when investment outcomes are observed. We also interact ELN investment experience and advertising amount with risk preference to separate the effects of risk preference from the effects of experience and advertising.

We use the *principal amount* from recent investments to measure funds available for reinvestment. During our sample period, the focal firm offered 19 different types of investment tools. We include both the amount and the number of different investment tools (e.g., stock, bond, and futures) in investors' portfolios during their decision periods to control for the effects of the investment portfolio allocation and diversification. Investors' demographic information included are their age and gender. Younger and older investors are likely to invest differently as their incomes evolve with age. Men and women also have different risk attitudes and show different investment patterns (Barber and Odean, 2001; Soll and Klayman, 2004).

W in Eq. (1b) and *Z* in Eq. (2b) are vectors of control variables for ELN repurchase type and repurchase amount model, respectively. *W* and *Z* omit *Advertising* and its interaction with *Neg/Zero Return* from *X* because advertising is to promote the purchase of ELNs instead of promoting specific types of ELNs or investment amounts. Thus, these two variables serve as exclusion restrictions in the selection models.

5. Estimation results

Tables 5 and 6 show the estimation results of the three repurchase decisions separately for prior investments in unprotected and protected ELNs. Tables 7 and 8 present the results when we use percentage returns instead of the indicators for undesirable outcomes. Because we observe multiple repurchases for the same investor, we cluster standard errors by investors.

Table 6
Estimation results of repurchase amount.

	Previous investment: Unprotected ELNs		Previous investment: Protected ELNs	
	Choice	Amount	Choice	Amount
Neg/Zero Return	−0.970***	−43.994***	−0.600***	−30.133***
	(0.096)	(3.997)	(0.182)	(8.829)
Risk Preference	0.041***	1.317***	0.085*	2.743
	(0.010)	(0.370)	(0.044)	(2.198)
Neg/Zero Return × Risk	0.085***	4.014***	0.074	4.652*
	(0.024)	(0.985)	(0.051)	(2.509)
Investment Experience	0.008***	0.093	0.016**	0.536
	(0.002)	(0.089)	(0.007)	(0.351)
Neg/Zero Return × Investment Experience	−0.003	0.043	−0.000	−0.027
	(0.006)	(0.249)	(0.010)	(0.468)
Advertising ($1,000)	0.012***		0.006	
	(0.005)		(0.012)	
Neg/Zero Return × Advertising	−0.030***		0.017	
	(0.008)		(0.019)	
Principal Amount ($1000)	0.005***	0.508***	0.0003	0.143***
	(0.001)	(0.040)	(0.0003)	(0.016)
Amount of Investment Tools ($1,000)	0.000	0.009***	−0.000	0.013***
	(0.000)	(0.002)	(0.000)	(0.003)
Number of Investment Tools	0.013***		0.017***	
	(0.003)		(0.005)	
Age	0.002**	0.112***	0.003	0.220**
	(0.001)	(0.030)	(0.002)	(0.102)
Male	0.005	0.217	0.006	−1.374
	(0.019)	(0.724)	(0.051)	(2.539)
Stock Price Index ($1,000)	0.570***	22.913***	0.466	26.074**
	(0.076)	(2.737)	(0.296)	(13.279)
Government Bond Rate (%)	0.006	0.640	0.170	4.782
	(0.036)	(1.351)	(0.163)	(7.616)
Intercept	−1.151***	−49.358***	−3.323***	−148.264***
	(0.190)	(6.794)	(0.504)	(28.457)
Year dummies	Yes	Yes	Yes	Yes
Number of observations	23,444		3892	
Log Pseudo-likelihood	−56,094.53		−4,610.27	

This table reports how repurchase amounts vary with prior investment outcomes and prior investment types (i.e., unprotected ELNs and protected ELNs). Heckman's sample selection model is used. Stage 1 (Column *Choice*) estimates the probability of repurchasing ELNs. The dependent variable equals one if the investors repurchased ELNs within 91 days after observing prior ELN investment returns, and zero otherwise. Stage 2 (Column *Amount*) estimates the repurchase amount for both protected and unprotected-ELNs. The amount is measured in $1,000. Column *Unprotected (Protected) ELNs* indicate investors' prior investment types. All other variables are defined in Table 2. Year dummies are included in every regression, and robust standard errors clustered by investor are reported in parentheses. *, **, and *** report significance levels at 10%, 5%, and 1%, respectively.

5.1. Repurchase and repurchase type decisions

Investors' first decision about whether to repurchase ELNs is reported in Column *Choice* in Table 5. The variables of most interest are the indicator variables for undesirable outcomes (i.e., negative returns of unprotected ELNs and zero returns of protected ELNs), risk preference, and *Neg/Zero Return* ×*Risk*, the interaction term between undesirable outcomes and risk preference.[7] The results show that undesirable outcomes significantly reduce the likelihood of a repurchase. The coefficient estimate is −0.812 for investors of unprotected ELNs and −0.727 for those of protected ELNs, respectively. This evidence is consistent with a reinforcement learning pattern. We also find that a higher risk preference score increases the likelihood of a repurchase for investors of unprotected ELNs. The coefficient estimate of 0.044 for risk preferences in the Choice of Unprotected ELNs is statistically significant at the one percent level. In addition, a higher risk preference also mitigates the negative effect of undesirable outcomes on repurchases. The coefficient estimates of *Neg Return* × *Risk* and *Zero Return* × *Risk* are both positive and statistically significant. In other words, among investors who observe undesirable returns, the more risk-seeking ones are more likely to reinvest in ELNs.

The results of the other control variables are in line with our expectations overall. Investment experience is significantly associated with a higher likelihood of a repurchase for both unprotected and protected ELNs. The coefficient estimates are 0.012 and 0.032 for unprotected ELNs and protected ELNs, respectively. However, the interaction effect between undesirable outcomes and ELN investment experience is not significant in either case. While advertising significantly increases the likelihood of a repurchase for investors of unprotected ELNs, its interaction term with negatives returns is significantly negative. This implies that advertising is not effective when investors experience negative outcomes. This result is consistent with Zhao et al. (2011), who show that advertising becomes less effective after a product harm crisis. Interestingly, advertising and the interaction of advertising with zero

[7] In unreported results, we also cluster by year. The magnitude and direction of the coefficient estimates are similar.

Table 7
The effect of returns on repurchase and repurchase type with continuous returns.

	Previous investment: Unprotected ELNs		Previous investment: Protected ELNs	
	Choice	Type (Unprotected)	Choice	Type (Unprotected)
Return (%)	0.010***	0.008	0.039**	0.009
	(0.002)	(0.006)	(0.016)	(0.020)
Risk Preference	0.072***	0.073***	0.139***	0.245***
	(0.011)	(0.024)	(0.026)	(0.055)
Return (%) × Risk	−0.001***	−0.002	−0.007*	−0.001
	(0.001)	(0.001)	(0.004)	(0.005)
Investment Experience	0.008**	0.046***	0.024***	0.025***
	(0.003)	(0.012)	(0.007)	(0.009)
Return × Investment Experience	0.0002	0.0002	0.0001	0.002
	(0.0001)	(0.001)	(0.001)	(0.001)
Advertising ($1,000)	0.033**		−0.071	
	(0.015)		(0.045)	
Return × Advertising	0.005***		0.006***	
	(0.001)		(0.002)	
Principal Amount ($1000)	0.002***		0.001***	
	(0.0004)		(0.0003)	
Amount of Investment Tools ($1,000)	−0.0001***		−0.0002***	
	(0.00003)		(0.0001)	
Number of Investment Tools	0.034***	−0.002	0.088***	0.059***
	(0.008)	(0.012)	(0.018)	(0.020)
Age	0.003***	0.001	0.003	0.001
	(0.001)	(0.001)	(0.002)	(0.002)
Male (dummy)	−0.011	0.058	0.008	−0.043
	(0.022)	(0.038)	(0.052)	(0.066)
Stock Price Index (Unit: 1,000)	0.257**	−2.128***	1.385***	1.102***
	(0.104)	(0.202)	(0.491)	(0.328)
Government Bond Rate (%)	−0.006	−0.332**	−0.078	0.066
	(0.043)	(0.165)	(0.193)	(0.180)
Intercept	−0.782***	6.009***	−4.822***	−5.311***
	(0.235)	(0.739)	(0.596)	(0.622)
Year dummies	Yes	Yes	Yes	Yes
Number of observations	23,444		3892	
Log Pseudo-likelihood	−16,513.3		−1,936.55	

This table reports the estimated effects of returns on repurchase decisions. Returns are measured as percentage returns of prior investments as opposed to indicator variables. Probit models with sample selection are used to estimate the effects. Columns *Unprotected ELNs* and *Protected ELNs* indicate prior investments in unprotected ELNs and protected ELNs, respectively. Stage 1 estimates the probability of repurchasing ELNs (Column *Choice*). The dependent variable equals one if the investors repurchased ELNs within 91 days after observing prior ELN investment returns, and zero otherwise. Stage 2 estimates the probability of purchasing only unprotected ELNs (Column *Type*). The dependent variable equals one if investors purchased unprotected ELNs within our observation window of 91 days post-return, and zero if the repurchase is protected ELNs. All other variables are defined in Table 2. Year dummies are included in all regressions. Robust standard errors clustered by investor are reported in parentheses. *, **, and *** report significance levels at 10%, 5%, and 1%, respectively.

returns are not significant for protected ELNs. These results indicate that negative returns significantly affect individual behavior more than zero returns do.

More available funds are associated with a higher likelihood of a repurchase, as the coefficient estimate for *principal amount* is positive. The amount of other investment tools is negatively related to the repurchase decision, probably because of a budget constraint. The positive relationship between the number of other investment tools and the repurchase decision is consistent with investment portfolio diversification behavior, i.e., those investors who diversify their investments also invest in ELNs. In addition, older investors of unprotected ELNs are more likely to repurchase while investors of protected ELNs are more likely to repurchase when there are more investment opportunities, measured by stock market performance.

After making a repurchase decision, investors' second decision is to choose between investing in principal-unprotected and protected ELNs. This choice also has a significant impact on the expected returns of the repurchase, as unprotected ELNs have a higher propensity to achieve better returns. Column *Type* in Table 5 shows the likelihood of repurchasing unprotected ELNs for investors of both protected and unprotected ELNs.

The results show that negative or zero returns do not affect the purchase type. This lack of a significant association is not particularly surprising as these results are conditioned on making a repurchase decision first. Undesirable outcomes lower the likelihood of a repurchase but do not determine the repurchase type. Our results also show that for investors of unprotected ELNs, a higher risk preference score is positively associated with a higher probability of repurchasing unprotected ELNs. The coefficient estimate of risk preference is 0.038 and statistically significant at the 1% level. We also find that the interaction effects between the negative/zero return and risk preference are both positive but not statistically significant.

Other variables that are significantly associated with a higher likelihood of repurchasing unprotected ELNs include macroeconomic conditions, the investment experience of those who previously invested in unprotected ELNs, and the stock market performance.

Table 8
The effect of returns on repurchase amount with continuous returns.

	Previous investment: Unprotected ELNs		Previous investment: Protected products	
	Choice	Amount	Choice	Amount
Return (%)	0.013***	0.614***	0.040**	−0.563
	(0.002)	(0.085)	(0.016)	(0.612)
Risk Preference	0.065***	2.491***	0.139***	0.601
	(0.010)	(0.416)	(0.026)	(1.065)
Return × Risk	−0.001**	−0.058***	−0.007*	0.172
	(0.001)	(0.021)	(0.004)	(0.168)
Investment Experience	0.002	−0.092	0.023***	−0.560***
	(0.003)	(0.123)	(0.007)	(0.202)
Return × Investment Experience	0.0004***	0.013**	0.0003	0.011
	(0.0001)	(0.005)	(0.001)	(0.019)
Advertising ($1,000)	0.002		−0.099**	
	(0.006)		(0.043)	
Return × Advertising	0.001***		0.005*	
	(0.0002)		(0.002)	
Principal Amount ($1000)	0.005***	0.504***	0.001**	0.438***
	(0.001)	(0.039)	(0.000)	(0.090)
Amount of Investment Tools ($1,000)	0.0001	0.009***	−0.0002**	0.022***
	(0.00005)	(0.002)	(0.0001)	(0.007)
Number of Investment Tools	0.013***		0.093***	
	(0.003)		(0.020)	
Age	0.002**	0.118***	0.003	0.049
	(0.001)	(0.030)	(0.002)	(0.112)
Male (dummy)	0.001	0.067	0.001	−1.790
	(0.019)	(0.729)	(0.052)	(2.397)
Stock Price Index (Unit: 1,000)	0.714***	28.717***	1.704***	−11.475
	(0.076)	(2.737)	(0.484)	(16.883)
Government Bond Rate (%)	−0.074**	−2.279	−0.146	6.926
	(0.038)	(1.410)	(0.182)	(7.879)
Intercept	−1.207***	−54.594***	−5.188***	1.217
	(0.192)	(6.980)	(0.614)	(28.392)
Year dummies	Yes	Yes	Yes	Yes
Number of observations	23,444		3892	
Log Pseudo-likelihood	−56,200.08		−4,862.7	

This table reports the estimated effects of returns on repurchase decisions measured by the repurchase amount. Returns are measured as percentage returns of prior investments. Column *Choice* reports results from Heckman's selection model stage 1: the probability of repurchasing ELNs. The dependent variable equals one if the investors repurchased ELNs within 91 days after observing prior ELN investment returns, and zero otherwise. Column *Amount* reports estimated results from Heckman's selection model stage 2: the effect of returns on repurchase amount. The amount is measured in $1,000. Repurchases are both unprotected- and protected-ELNs are included in the estimates. Column *Unprotected (Protected) ELNs* indicate investors' prior investment types. All independent variables are defined in Table 2. Year dummies are included in every regression, and robust standard errors clustered by investor are reported in parentheses. *, **, and *** report significance levels at 10%, 5%, and 1%, respectively.

In summary, we find that undesirable investment experience negatively affects investors' ELN repurchase decisions, a pattern consistent with reinforcement learning. However, this effect is significantly reduced by a more risk-seeking attitude, as measured by a higher risk preference score.

5.2. Repurchase amount decision

Table 6 shows estimated results on repurchase amount. A Heckman selection model is used to correct for selection bias. In general, results from the selection stage (i.e., the decision to repurchase) show the patterns similar to those reported in Table 5. Thus, we focus on the second stage results (i.e., repurchase amount) only.

Columns *Amount* in Table 6 show that undesirable outcomes significantly reduce the repurchase amount. The coefficient estimates are −43.994 for investors of unprotected ELNs and −30.133 for those of protected ELNs. These magnitudes translate to -$16,549 and -$7,566 for these two ELN types, respectively. These numbers are large compared to the average purchase amount of $33,000. Therefore, the reduction in repurchase amount is both statistically and economically significant. Similar to the results on repurchase types, risk preference is positively associated with the repurchase amount for investors of unprotected ELNs. The coefficient estimate is 1.317, which is equivalent to an increase of $225.

In line with our expectations that risk-seeking can mitigate the negative effect of reinforcement learning, the interaction terms between negative/zero returns and risk preference are positive for the repurchase amount. The coefficient estimates are 4.014 and 4.652 for investors of unprotected and protected ELNs, respectively. That is, a one-point increase in risk preference is associated with a $1,727 increase in the repurchase of unprotected ELNs and $1,782 of protected ELNs. In short, the results on repurchase amounts are consistent with those reported in Table 5. We find that undesirable outcomes have a negative effect on repurchase amount and that this negative effect is mitigated by higher risk preference scores.

Table 9
Estimation results of repurchase and repurchase type with lagged effects.

Panel A: Repurchase and repurchase types with lagged effects				
	Previous investment: Unprotected ELNs		Previous investment: Protected ELNs	
	Choice	Type (Unprotected)	Choice	Type (Unprotected)
Neg/Zero Return	−1.136***	−0.322	−1.456***	1.324**
	(0.124)	(0.327)	(0.259)	(0.556)
Lag Neg/Zero Return	−0.731***	0.293	−0.413	−0.503
	(0.117)	(0.329)	(0.283)	(0.811)
Risk Preference	0.046***	0.047*	0.050	0.403**
	(0.015)	(0.026)	(0.052)	(0.177)
Neg/Zero Return × Risk	0.111***	0.078	0.175***	−0.056
	(0.029)	(0.073)	(0.058)	(0.158)
Lag Neg/Zero Return × Risk	0.123***	−0.009	0.052	0.084
	(0.029)	(0.083)	(0.072)	(0.215)
Other controls	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Number of observations	17,989		3244	
Log Pseudo-likelihood	−11,817.53		−1,465.89	
Panel B: Repurchase amount with lagged effects				
	Previous investment: Unprotected ELNs		Previous investment: Protected ELNs	
	Choice	Amount	Choice	Amount
Neg/Zero Return	−1.333***	−51.720***	−0.846***	−32.101
	(0.115)	(4.235)	(0.189)	(19.591)
Lag Neg/Zero Return	−0.736***	−25.601***	−0.036	−0.926
	(0.109)	(3.966)	(0.253)	(27.944)
Risk Preference	0.041***	1.013**	0.156***	7.744
	(0.013)	(0.462)	(0.049)	(4.885)
Neg/Zero Return × Risk	0.112***	4.199***	0.051	1.647
	(0.028)	(1.016)	(0.055)	(4.929)
Lag Neg/Zero Return × Risk	0.132***	4.630***	−0.046	−1.849
	(0.027)	(0.992)	(0.073)	(6.346)
Other controls	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Number of observations	17,989		3244	
Log Pseudo-likelihood	−39,593.74		−3,557.89	
Panel C: The effect of lagged returns on repurchase decision				
	Previous investment: Unprotected ELNs		Previous investment: Protected ELNs	
	Choice	Type (Unprotected)	Choice	Type (Unprotected)
Return (%)	0.019***	0.001	0.079***	0.051**
	(0.003)	(0.007)	(0.018)	(0.021)
Lag Return (%)	0.013***	−0.001	0.011**	0.024***
	(0.003)	(0.005)	(0.005)	(0.007)
Risk Preference	0.120***	0.074**	0.221***	0.326***
	(0.016)	(0.033)	(0.032)	(0.039)
Return (%) × Risk	−0.002***	−0.001	−0.013***	−0.009
	(0.001)	(0.002)	(0.005)	(0.005)
Lag Return (%) × Risk	−0.002***	−0.000	−0.002	−0.004**
	(0.001)	(0.001)	(0.001)	(0.002)
Other controls	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Number of observations	17,989		3244	
Log Pseudo-likelihood	−11,861.41		−1,453.49	

(*continued on next page*)

5.3. Percentage return results

Thus far, we have focused on binary categories of returns, as reinforcement learning is more salient when people experience negative events (Strahilevitz et al., 2011). In this section, we further investigate the effect of percentage returns instead of the indicator variables for undesirable outcomes. In Tables 7 and 8, the effects of percentage returns show that the higher the return, the more likely investors will repurchase. This result is also consistent with investors showing reinforcement learning behavior as they base their repurchase decisions on past outcomes. The interaction terms between actual return and risk preference are negative on the repurchase decisions, showing that risk-taking alters the effect of returns on repurchase decisions.

Table 9 (*continued*).

Panel D: The effect of lagged returns on repurchase amount				
	Previous investment: Unprotected ELNs		Previous investment: Protected products	
	Choice	Amount	Choice	Amount
Return (%)	0.021***	0.793***	0.082***	3.873***
	(0.003)	(0.098)	(0.016)	(0.941)
Lag Return (%)	0.012***	0.375***	0.010**	0.380
	(0.002)	(0.076)	(0.005)	(0.273)
Risk Preference	0.109***	3.364***	0.202***	9.324***
	(0.014)	(0.518)	(0.031)	(1.535)
Return (%)× Risk	−0.001**	−0.054**	−0.009*	−0.422*
	(0.001)	(0.023)	(0.005)	(0.246)
Lag Return (%)× Risk	−0.002***	−0.062***	−0.002	−0.041
	(0.001)	(0.019)	(0.001)	(0.073)
Other controls	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Number of observations	17,989		3244	
Log Pseudo-likelihood	−39,670.77		−3,555.25	

This table reports results of how repurchase decisions change with lagged negative experience. Panel A reports changes in repurchase and repurchased types with lagged effects. A two-stage probit model with sample selection is used to estimate these effects. *Lag Neg/Zero Return* is the one-period lagged variable of *Neg/zero Return*. It equals one if investors observed negative (zero) returns from unprotected (protected) ELNs prior to their last investments, and zero otherwise. *Lag Neg/Zero Return* × *Risk* is the interaction term between *Lag Neg/Zero Return* and risk preference. Repurchase, repurchase types, and all other variables are defined in previous tables. Other controls included but not shown (for brevity) in this table are identical to the rest of the control variables used in Table 5. Panel B shows how repurchase amount changes with lagged effects. A Heckman's selection model is used to estimate those effects. Other controls included but not reported are identical to those shown in Table 6. Year dummies are included in all regressions. Robust standard errors clustered by investor are reported in parentheses. *, **, and *** report significance levels at 10%, 5%, and 1%, respectively.

Table 10
Reinforcement learning and repurchase returns.

Panel A. Average repurchase returns by investor type			
Investor type	Non-Risk taker	Risk taker	Overall
Reinforcement Learner	5.96% (479)	7.03% (570)	6.54% (1,049)
Non-Reinforcement Learner	16.53% (145)	17.88% (169)	17.26% (314)
	8.42% (624)	9.51% (739)	9.01%(1,363)

Panel B. The effect of reinforcement learning on repurchase returns		
Variables	Coefficient	SE
Non-reinforcement Learner	10.301***	(0.926)
Risk taker	0.847	(0.777)
Number of repurchase decisions	0.478**	(0.195)
Intercept	5.249***	(0.665)
Number of observations	1363	
R^2	0.097	

This table relates investors' repurchase returns to their types. Panel A shows average repurchase returns by investor type. Repurchase returns exclude investors' first investment returns. Investors are classified as reinforcement learners if they do not repurchase after observing negative/zero returns of their first investments. Non-reinforcement learners are those who repurchase after observing negative/zero returns from the first investment. Risk takers are investors whose risk preference level is 4 or 5. The number of investors in each group are shown in parentheses. Panel B reports regression estimates of the effects of reinforcement learning on repurchase decisions. The dependent variable is the average repurchase return for each investor. *Non-reinforcement Learner* is an indicator variable that equals one if the investor is classified as a non-reinforcement learner, and zero otherwise. *Number of repurchase decisions* is the number of repurchase decisions we observe. *Risk Taker* equals one if the investor's risk preference is 4 or 5, and zero otherwise. Year dummies are included. Robust standard errors clustered by investor are reported in parentheses. *** reports significance levels at 1%.

The estimated results also show that actual returns and the interaction terms do not affect the repurchased ELN type while higher returns are associated with a higher repurchase amount. These differences in the patterns from using actual returns and undesirable outcomes highlight the importance of understanding the effect of negative outcomes on investors' repurchase decisions, especially given that negative information is less ambiguous and more diagnostic than positive information (Herr et al., 1991).

To check the robustness of our results, we also redo the main tests using two alternative samples. First, we use alternative windows of one year and six months. Results for using a one-year window are shown in Appendix C Tables A.1–A.4). Results using a 6-month window are similar and therefore are omitted for brevity. Second, we relax our sample restriction of investors with at least two repurchases and allow for investors with only one repurchase. The results are shown in Tables A.5–A.8 of Appendix C. The results from these tables are not meaningfully different from our main results. They show that undesirable outcomes are negatively associated with investors' decision to repurchase ELNs and the repurchase amount.

Table 11
Repurchase returns under different economic conditions.

Panel A: Non-Recession period			
Investor type	Non-Risk taker	Risk taker	Overall
Reinforcement Learner	4.33% (163)	7.94% (190)	6.27% (353)
Non-Reinforcement Learner	12.25% (59)	15.02% (82)	13.86% (141)
Overall	6.44% (222)	10.08% (272)	8.44% (494)
Panel B: Recession period			
Investor type	Non-Risk taker	Risk taker	Overall
Reinforcement Learner	6.80% (316)	6.56% (380)	6.67% (696)
Non-Reinforcement Learner	19.47% (86)	20.57% (87)	20.03% (173)
Overall	9.51% (402)	9.17% (467)	9.33% (869)

This table reports investors' average repurchase returns observed under different economic conditions. Panel A shows results of the first return during the non-recession period, and panel B presents results of the first return from the recession period. The recession period in South Korea spans from the fourth quarter of 2008 to the second quarter of 2009. Investor types are defined in Table 10. The numbers in parentheses represent the number of investors in each group.

Table A.1
Estimation results of repurchase and repurchase type with one year observation period.

	Previous investment: Unprotected ELNs		Previous investment: Protected ELNs	
	Choice	Type (Unprotected)	Choice	Type (Unprotected)
Neg/Zero Return	−0.795***	−0.688***	−0.585**	0.675
	(0.096)	(0.264)	(0.269)	(0.983)
Risk Preference	0.061***	0.062***	0.082*	0.384*
	(0.011)	(0.018)	(0.044)	(0.200)
Neg/Zero Return × Risk	0.109***	0.093*	0.072	0.041
	(0.022)	(0.058)	(0.050)	(0.095)
Investment Experience	0.006**	0.047***	0.023*	0.097
	(0.003)	(0.011)	(0.012)	(0.060)
Neg/Zero Return × Investment Experience	−0.012*	0.028	−0.010	−0.071
	(0.006)	(0.024)	(0.014)	(0.056)
Advertising ($1,000)	0.078***		−0.101*	
	(0.013)		(0.054)	
Neg/Zero Return × Advertising	−0.104***		0.027	
	(0.025)		(0.070)	
Principal Amount ($1000)	0.002***		0.001**	
	(0.000)		(0.000)	
Amount of Investment Tools ($1,000)	−0.000***		−0.000***	
	(0.000)		(0.000)	
Number of Investment Tools	0.048***	0.002	0.098***	0.015
	(0.007)	(0.012)	(0.018)	(0.073)
Age	0.002*	0.001	0.003	−0.000
	(0.001)	(0.001)	(0.002)	(0.005)
Male	−0.001	0.046	−0.008	−0.018
	(0.021)	(0.037)	(0.048)	(0.099)
Stock Price Index (1,000)	0.054	−1.406***	1.129***	0.711
	(0.105)	(0.182)	(0.416)	(0.505)
Government Bond Rate	0.072*	−0.091	0.035	0.549
	(0.041)	(0.126)	(0.167)	(0.364)
Intercept	−0.350	3.589***	−4.119***	−6.368***
	(0.236)	(0.531)	(0.640)	(1.140)
Year dummies	Yes	Yes	Yes	Yes
Number of observations	23,496		3893	
Log Pseudo-likelihood	−17,195.44		−2,328.19	

This table reports results of repurchase decisions measured by the probability of repurchasing ELNs in general and the probability of repurchasing *unprotected* ELNs. A probit model with sample selection is used to estimate the two stages for investors who previously invested in unprotected ELNs (Column *Unprotected ELNs*) and those invested in principal-protected ones (Column *Protected ELNs*). Stage 1 estimates the probability of repurchasing ELNs. The dependent variable equals one if the investors repurchased ELNs within 365 days after observing prior ELN investment returns, and zero otherwise. Stage 2 estimates the probability of purchasing only unprotected ELNs. The dependent variable equals one if investors purchased unprotected ELNs within our observation window of 365 days post-return, and zero otherwise. *Neg/Zero Return* is a dummy variable, which takes the value of 1 if unprotected (protected) ELNs yield negative (zero) return, and 0 otherwise. All other variables are defined in Table 2. Year dummies are included in all regressions. Robust standard errors clustered by investor are reported in parentheses. *, **, and *** report significance levels at 10%, 5%, and 1%, respectively.

Table A.2
Estimation results of repurchase amount with one year observation period.

	Previous investment: Unprotected ELNs		Previous investment: Protected ELNs	
	Choice	Amount	Choice	Amount
Neg/Zero Return	−0.904***	−43.609***	−0.653***	3.894
	(0.087)	(3.899)	(0.209)	(7.724)
Risk Preference	0.063***	2.416***	0.082*	2.262
	(0.009)	(0.390)	(0.044)	(1.895)
Neg/Zero Return × Risk	0.098***	4.907***	0.073	−2.332
	(0.022)	(0.974)	(0.050)	(2.243)
Investment Experience	0.003	−0.087	0.024*	−0.875***
	(0.002)	(0.102)	(0.012)	(0.306)
Neg/Zero Return × Investment Experience	−0.011*	−0.409	−0.012	0.313
	(0.006)	(0.262)	(0.014)	(0.319)
Advertising ($1,000)	0.012		−0.114***	
	(0.007)		(0.040)	
Neg/Zero Return × Advertising	−0.014**		0.052	
	(0.007)		(0.036)	
Principal Amount ($1000)	0.007***	0.520***	0.001**	0.301**
	(0.001)	(0.050)	(0.000)	(0.131)
Amount of Investment Tools ($1,000)	0.000***	0.013***	−0.000**	0.015**
	(0.000)	(0.002)	(0.000)	(0.007)
Number of Investment Tools	0.013***		0.098***	
	(0.003)		(0.018)	
Age	0.001	0.086***	0.003	−0.011
	(0.001)	(0.031)	(0.002)	(0.113)
Male	0.023	0.785	−0.007	−0.230
	(0.017)	(0.746)	(0.048)	(2.455)
Stock Price Index (1,000)	0.296***	16.499***	1.051**	0.077
	(0.087)	(2.927)	(0.409)	(15.385)
Government Bond Rate (%)	0.031	2.463*	0.058	−7.908
	(0.035)	(1.487)	(0.164)	(8.775)
Intercept	−0.675***	−40.446***	−3.997***	42.558*
	(0.195)	(7.306)	(0.611)	(22.218)
Year dummies	Yes	Yes	Yes	Yes
Number of observations	23,496		3893	
Log Pseudo-likelihood	−65,736.95		−6,404.69	

This table reports how repurchase amounts vary with prior investment outcomes and prior investment types (i.e., unprotected ELNs and protected ELNs). Heckman's sample selection model is used. Stage 1 (Column *Choice*) estimates the probability of repurchasing ELNs. The dependent variable equals one if the investors repurchased ELNs within 365 days after observing prior ELN investment returns, and zero otherwise. Stage 2 (Column *Amount*) estimates the repurchase amount for both protected and unprotected-ELNs. The amount is measured in $1,000. Column *Unprotected (Protected) ELNs* indicate investors' prior investment types. All other variables are defined in Table 2. Year dummies are included in every regression, and robust standard errors clustered by investor are reported in parentheses. *, **, and *** report significance levels at 10%, 5%, and 1%, respectively.

5.4. Dynamic effects of undesirable returns

To check whether investors' negative experience has a lasting impact on their investment decisions, we include one-period lagged variables of negative/zero returns and their interaction terms with risk preference.[8] Table 9 presents the estimated results. Panel A reports lagged effects on the decision to repurchase and the repurchase type. The results show that lagged negative returns from unprotected ELNs continue to negatively affect investors' decision to repurchase. However, the magnitude of this effect is smaller than that of the most recent experience. The coefficient estimates for negative returns and lagged negative returns are −1.136 and −0.731, respectively. The interaction terms, *Neg Return* × *Risk* and *Lag Neg Return* × *Risk*, in contrast, show similar magnitude. In other words, the mitigating effect of higher risk preference scores on investors' decisions to repurchase persists for more than one investment period. However, we do not observe the same patterns for those who previously purchased protected ELNs. Neither lagged zero return nor its interaction with risk preference is significant.

We find that similar patterns hold for repurchase amounts as well. Results reported in Panel B of Table 9 show that, for investors who previously purchased unprotected ELNS, lagged prior negative returns reduce their repurchase amount significantly, but that this effect is smaller than the most recent negative returns. However, the interaction effect of lagged negative return and risk preference on repurchase amount is equally strong.

In Panels C and D of Table 9, we also look at the lagged effects of percentage returns on repurchase decisions. For unprotected ELNs, the effect of the most recent returns on the decision to repurchase and the repurchase amount is larger than that of the lagged returns, but the magnitudes of the interaction terms with risk preference are similar. Unlike the results from using indicator variables

[8] We use one-period lagged variables of negative/zero returns because two-period lagged variables reduce the number of customers by 53.8% and the number of observations by 44.6%.

Table A.3
The effect of returns on repurchase and repurchase type with continuous returns and one year observation period.

	Previous investment: Unprotected ELNs		Previous investment: Protected ELNs	
	Choice	Type (Unprotected)	Choice	Type (Unprotected)
Return (%)	0.010***	0.009*	0.044***	0.013
	(0.002)	(0.005)	(0.016)	(0.019)
Risk Preference	0.095***	0.083***	0.150***	0.260***
	(0.011)	(0.020)	(0.024)	(0.064)
Return (%) × Risk	−0.002***	−0.002	−0.007	−0.003
	(0.001)	(0.001)	(0.004)	(0.005)
Investment Experience	−0.001	0.061***	0.016**	0.020**
	(0.003)	(0.012)	(0.007)	(0.010)
Return × Investment Experience	0.000**	−0.001	−0.000	0.002
	(0.000)	(0.000)	(0.001)	(0.001)
Advertising ($1,000)	0.026*		−0.088	
	(0.014)		(0.057)	
Return × Advertising	0.004***		0.005***	
	(0.001)		(0.002)	
Principal Amount ($1000)	0.002***		0.001**	
	(0.000)		(0.000)	
Amount of Investment Tools ($1,000)	−0.000***		−0.000**	
	(0.000)		(0.000)	
Number of Investment Tools	0.051***	0.000	0.092***	0.060***
	(0.007)	(0.011)	(0.018)	(0.020)
Age	0.002**	0.001	0.003	0.002
	(0.001)	(0.001)	(0.002)	(0.002)
Male (dummy)	−0.002	0.046	−0.007	−0.040
	(0.021)	(0.035)	(0.048)	(0.060)
Stock Price Index (Unit: 1,000)	0.144	−1.332***	1.104*	0.561*
	(0.104)	(0.171)	(0.597)	(0.300)
Government Bond Rate (%)	0.011	−0.096	−0.064	0.232
	(0.043)	(0.120)	(0.199)	(0.157)
Intercept	−0.391*	3.388***	−4.251***	−4.845***
	(0.234)	(0.496)	(0.686)	(0.586)
Year dummies	Yes	Yes	Yes	Yes
Number of observations	23,496		3893	
Log Pseudo-likelihood	−17,244.18		−2,316.27	

This table reports the estimated effects of returns on repurchase decisions. Returns are measured as percentage returns of prior investments as opposed to indicator variables. Probit models with sample selection are used to estimate the effects. Columns *Unprotected ELNs* and *Protected ELNs* indicate prior investments in unprotected ELNs and protected ELNs, respectively. Stage 1 estimates the probability of repurchasing ELNs (Column *Choice*). The dependent variable equals one if the investors repurchased ELNs within 365 days after observing prior ELN investment returns, and zero otherwise. Stage 2 estimates the probability of purchasing only unprotected ELNs (Column *Type*). The dependent variable equals one if investors purchased unprotected ELNs within our observation window of 365 days post-return, and zero if the repurchase is protected ELNs. All other variables are defined in Table 2. Year dummies are included in all regressions. Robust standard errors clustered by investor are reported in parentheses. *, **, and *** report significance levels at 10%, 5%, and 1%, respectively.

for zero returns of protected ELNs, we find that lagged percentage returns continue to have a significantly positive relationship with all three repurchase decisions (i.e., the decision to repurchase, repurchase of unprotected ELNs, and the repurchase amount of protected ELNs), while the interaction term, *Lag Return(%) × Risk,* is not significant for the repurchase amount of protected ELNs.

In summary, we find that the negative effect of undesirable returns on repurchase decisions lasts longer than the current period. In other words, reinforcement learning has a lasting impact on investors' decisions. While this effect becomes weaker over time, the mitigating effect from higher risk-taking attitudes does not change for the earlier period.

6. Investment performance among different investor types

The concern with reinforcement learning is that this behavior leads to suboptimal outcomes. The value of ELNs is partly derived from the underlying equity value. The literature generally shows that stock returns are not persistent. Therefore, following the pattern of disproportionally withholding reinvestments after undesirable outcomes should also lead to suboptimal investment returns. In this section, we investigate whether reinforcement learning is associated with lower returns and how the outcome of reinforcement learning changes with different risk preferences.

We divide investors into different groups based on whether they are reinforcement learners or risk takers and compare average returns across the groups. We classify an investor as a reinforcement learner if the investor does not repurchase after observing a negative or zero return from the first investment.[9] Similarly, we classify an investor as a non-reinforcement learner if the investor

[9] Reinforcement learning is not restricted to withholding investments after observing negative/zero returns. However, as our analyses so far focus on repurchase decisions after undesirable outcomes (i.e., negative return for unprotected ELNs and zero return for protected ELNs), we only consider the cases after observing a negative/zero return.

Table A.4
The effect of returns on repurchase amount with continuous returns and one year observation period.

	Previous investment: Unprotected ELNs		Previous investment: Protected products	
	Choice	Amount	Choice	Amount
Return (%)	0.012***	0.606***	0.045***	−1.000*
	(0.002)	(0.082)	(0.016)	(0.619)
Risk Preference	0.091***	3.832***	0.150***	−0.487
	(0.009)	(0.420)	(0.024)	(1.182)
Return × Risk	−0.001***	−0.067***	−0.006	0.273
	(0.000)	(0.020)	(0.004)	(0.176)
Investment Experience	−0.005*	−0.417***	0.015*	−0.662***
	(0.003)	(0.126)	(0.007)	(0.240)
Return × Investment Experience	0.000***	0.020***	−0.000	0.001
	(0.0001)	(0.006)	(0.001)	(0.021)
Advertising ($1,000)	0.005		−0.122***	
	(0.008)		(0.037)	
Return × Advertising	0.0004***		0.004*	
	0.0001***		(0.002)	
Principal Amount ($1000)	0.007***	0.515***	0.001**	0.301**
	(0.001)	(0.049)	(0.000)	(0.131)
Amount of Investment Tools ($1,000)	0.000**	0.013***	−0.000***	0.015
	(0.000)	(0.002)	(0.000)	(0.007)
Number of Investment Tools	0.014***		0.097***	
	(0.003)		(0.018)	
Age	0.001*	0.091***	0.003*	−0.018
	(0.001)	(0.031)	(0.002)	(0.113)
Male (dummy)	0.020	0.649	−0.008	−0.354
	(0.017)	(0.752)	(0.048)	(2.459)
Stock Price Index (Unit: 1,000)	0.426***	22.192***	1.482***	−0.502
	(0.085)	(2.885)	(0.423)	(15.713)
Government Bond Rate (%)	−0.041	−0.766	−0.127	−5.483
	(0.036)	(1.534)	(0.164)	(8.567)
Intercept	−0.739***	−44.207***	−4.751***	43.864
	(0.194)	(7.405)	(0.563)	(22.801)
Year dummies	Yes	Yes	Yes	Yes
Number of observations	23,496		3893	
Log Pseudo-likelihood	−65,810.73		−6,392.32	

This table reports the estimated effects of returns on repurchase decisions measured by the repurchase amount. Returns are measured as percentage returns of prior investments. Column *Choice* reports results from Heckman's selection model stage 1: the probability of repurchasing ELNs. The dependent variable equals one if the investors repurchased ELNs within 365 days after observing prior ELN investment returns, and zero otherwise. Column *Amount* reports estimated results from Heckman's selection model stage 2: the effect of returns on repurchase amount. The amount is measured in $1,000. Repurchases are both unprotected- and protected-ELNs are included in the estimates. Column *Unprotected (Protected) ELNs* indicate investors' prior investment types. All independent variables are defined in Table 2. Year dummies are included in every regression, and robust standard errors clustered by investor are reported in parentheses. *, **, and *** report significance levels at 10%, 5%, and 1%, respectively.

repurchases after observing a negative/zero return from the first investment. We then calculate the investor's average subsequent returns. In other words, we classify investors in the first period and compare average returns in subsequent periods. We also classify investors as risk takers based on their risk preferences. An investor is classified as a risk taker if the investor's risk preference is 4 or 5, on a scale of 1 to 5. We then calculate average returns within each investor group, conditioning on a repurchase made. Panel A of Table 10 presents these averages. Consistent with the notion that reinforcement learning does not result in optimal outcomes, non-reinforcement learners earn a higher average return (17.26%) than reinforcement learners do (6.54%). While it is not surprising that risk takers also earn a higher return compared to non-risk takers, risk-taking non-reinforcement learners earn the highest average returns of 17.88%. The group with the lowest returns is non-risk-taking reinforcement learners (5.96%).

To further test these patterns, we estimate a multiple regression model where the dependent variable is repurchase returns. The independent variables include an indicator variable for non-reinforcement, a risk-taker indicator, the number of repurchase decisions (a proxy for investors' experience in ELNs), and year dummies. We also cluster standard errors by investor. Panel B of Table 10 shows that returns are lower for reinforcement learners (the base group) compared to non-reinforcement learners. This is, consistent with the pattern shown in Panel A.

It is possible that the effect of reinforcement learning and risk on returns is driven by economic conditions, as our data includes the 2008–2009 financial crisis period. In South Korea, the recession lasted from the fourth quarter of 2008 to the second quarter of 2009.[10] To check whether this is the case, we analyze investors' average returns observed during the recession and non-recession periods. Panel A of Table 11 represents average returns by investor types during the non-recession period. The pattern is the same

[10] During this period, the real GDP growth rate was −3.3% (fourth quarter, 2008), −4.2% (first quarter, 2009), and −2.1% (second quarter, 2009).

Table A.5
Estimation results of repurchase and repurchase after first return.

	Previous investment: Unprotected ELNs		Previous investment: Protected ELNs	
	Choice	Type (Unprotected)	Choice	Type (Unprotected)
Neg/Zero Return	−1.345***	−0.223	−0.244	0.150
	(0.344)	(0.575)	(0.270)	(0.319)
Risk Preference	−0.029***	0.083***	−0.031	0.184***
	(0.010)	(0.019)	(0.044)	(0.068)
Neg/Zero Return × Risk	0.081*	0.068	−0.015	0.007
	(0.044)	(0.081)	(0.067)	(0.110)
Investment Experience	0.110**	0.092	−5.237	(dropped)
	(0.049)	(0.109)	(384.232)	
Neg/Zero Return × Investment Experience	0.046	−0.209	(dropped)	(dropped)
	(0.290)	(0.492)		
Advertising ($1,000)	0.076***		−0.049	
	(0.015)		(0.033)	
Neg/Zero Return × Advertising	0.074*		−0.077*	
	(0.042)		(0.043)	
Principal Amount ($1000)	0.001***		0.000	
	(0.000)		(0.001)	
Amount of Investment Tools ($1,000)	−0.000***		−0.000	
	(0.000)		(0.000)	
Number of Investment Tools	−0.032***	0.007	0.010	0.010
	(0.006)	(0.013)	(0.026)	(0.029)
Age	0.005***	−0.002	0.009***	0.002
	(0.001)	(0.001)	(0.003)	(0.004)
Male	−0.075***	0.070*	−0.071	0.058
	(0.019)	(0.040)	(0.077)	(0.100)
Stock Price Index ($1,000)	0.005	−1.571***	0.723	0.663
	(0.113)	(0.205)	(0.516)	(0.483)
Government Bond Rate	−0.103**	−0.703***	0.155	0.644*
	(0.050)	(0.133)	(0.237)	(0.345)
Intercept	0.466*	7.297***	3.354	−4.802***
	(0.255)	(0.601)	(384.233)	(1.457)
Year dummies	Yes	Yes	Yes	Yes
Number of observations	18,931		1388	
Log Pseudo-likelihood	−14,114.95		−1,068.37	

This table reports results of repurchase decisions measured by the probability of repurchasing ELNs in general and the probability of repurchasing *unprotected* ELNs after investors observe their first returns. A probit model with sample selection is used to estimate the two stages for investors who previously invested in unprotected ELNs (Column *Unprotected ELNs*) and those invested in principal-protected ones (Column *Protected ELNs*). Stage 1 estimates the probability of repurchasing ELNs. The dependent variable equals one if the investors repurchased ELNs within 91 days after observing the first ELN investment return, and zero otherwise. Stage 2 estimates the probability of purchasing only unprotected ELNs. The dependent variable equals one if investors purchased unprotected ELNs within our observation window of 91 days post the first return, and zero otherwise. *Neg/Zero Return* is a dummy variable, which takes the value of 1 if unprotected (protected) ELNs yield negative (zero) return, and 0 otherwise. All other variables are defined in Table 2. Year dummies are included in all regressions. Standard errors are reported in parentheses. *, **, and *** report significance levels at 10%, 5%, and 1%, respectively. Some variables are dropped due to collinearity.

as that shown in Table 10. Non-reinforcement learning and risk-taking are associated with higher returns (15.2%), while non-risk-taking reinforcement learners have the lowest returns (4.33%). Panel B of Table 11 shows repurchase returns during the nine-month recession period. Investors in the non-reinforcement learner/risk taker group show the highest average return (20.57%) and those in the reinforcement learner/non-risk taker group (6.8%).

7. Conclusion

This study investigates the impact of reinforcement learning, risk preferences, and their interactions on investors' financial decision-making process and returns. We use a sample of principal-protected and unprotected ELN purchases in South Korea, where all ELN investors are required to report their risk preferences. We find evidence showing that undesirable outcomes disproportionally affect investors' repurchase decisions and their returns and that this negative experience lasts longer than the most recent investment period. We also find that this negative effect is mitigated by higher risk-taking attitudes.

We first document that, after observing undesirable outcomes from the most recent investments, investors are less likely to repurchase ELNs and spend less on their repurchases. This negative effect lasts longer than the most recent investment period for unprotected ELNs with higher losses compared to the protected ones. However, among those who observed undesirable outcomes, investors with higher risk preference scores are more likely to repurchase and repurchase more. We also divide investors into groups based on whether their repurchase patterns are consistent with reinforcement learning and their risk preferences. We find that reinforcement learners who have lower risk preference scores have the lowest average returns from their repurchases and that

Table A.6
Estimation results of repurchase amount after first return.

	Previous investment: Unprotected ELNs		Previous investment: Protected ELNs	
	Choice	Amount	Choice	Amount
Neg/Zero Return	−1.374***	−15.245	−0.354	−24.339**
	(0.344)	(13.209)	(0.240)	(9.957)
Risk Preference	−0.028***	0.617**	−0.048	−2.216
	(0.010)	(0.268)	(0.041)	(1.679)
Neg/Zero Return × Risk	0.079*	2.320	0.002	1.578
	(0.045)	(1.816)	(0.064)	(2.714)
Investment Experience	0.113**	−2.264*	−5.404***	(dropped)
	(0.049)	(1.281)	(0.706)	
Neg/Zero Return × Investment Experience	0.059	3.118	(dropped)	(dropped)
	(0.289)	(11.006)		
Advertising ($1,000)	0.062***		0.036***	
	(0.015)		(0.010)	
Neg/Zero Return × Advertising	0.084*		−0.036**	
	(0.044)		(0.016)	
Principal Amount ($1000)	0.001***	0.695***	−0.000	0.093***
	(0.000)	(0.007)	(0.000)	(0.019)
Amount of Investment Tools ($1,000)	−0.000***	0.015***	0.000	0.005
	(0.000)	(0.001)	(0.000)	(0.006)
Number of Investment Tools	−0.033***		0.015***	
	(0.006)		(0.005)	
Age	0.005***	0.037*	0.009***	0.485***
	(0.001)	(0.021)	(0.003)	(0.116)
Male	−0.074***	1.367**	0.007	0.614
	(0.019)	(0.538)	(0.072)	(3.029)
Stock Price Index ($1,000)	0.106	3.575	−0.198	−4.352
	(0.114)	(2.267)	(0.359)	(14.999)
Government Bond Rate (%)	−0.109**	0.680	0.047	−0.736
	(0.050)	(1.435)	(0.205)	(8.695)
Intercept	0.352	3.365	5.152	−3.466
	(0.256)	(6.989)	(3.741)	(29.937)
Year dummies	Yes	Yes	Yes	Yes
Number of observations	18,931		1388	
Log Pseudo-likelihood	−62,017.02		−2,973.77	

This table reports how repurchase amount vary with investment outcomes and types (i.e. unprotected ELNs and protected ELNs) after investors observe their first returns. Heckman's sample selection model is used. Stage 1 (Column *Choice*) estimates the probability of repurchasing ELNs. The dependent variable equals one if the investors repurchased ELNs within 91 days after observing the first ELN investment return, and zero otherwise. Stage 2 (Column *Amount*) estimates the repurchase amount for both protected and unprotected-ELNs. The amount is measured in $1,000. Column *Unprotected (Protected) ELNs* indicate investors' first investment types. All other variables are defined in Table 2. Year dummies are included in every regression. Standard errors are reported in parentheses. *, **, and *** report significance levels at 10%, 5%, and 1%, respectively.

non-reinforcement learners who take higher risks have the highest returns. These results hold for both recession and non-recession periods.

Our findings are consistent with prior research showing that investors exhibit reinforcement learning behavior in their decision-making. Because past performance does not predict future performance in ELNs, this behavior also leads to lower returns for investors. Furthermore, being able to measure risk preferences allows us to show that risk-taking mitigates the negative effects of reinforcement learning. These findings suggest that offering riskier investment options after undesirable outcomes can improve investors' welfare.

As structured notes, ELNs differ from asset classes such as stocks and bonds. Hence, this raises the questions of whether ELN investors are similar to other investors and whether our findings can generalize to other assets. Though there is some evidence supporting that the demographic and risk preferences of ELN investors are not likely to be different from those of other investors,[11] further research that compares investor characteristics across asset classes is needed.

Overall, our research shows that it is important to study psychological traits in a combined framework to improve our understanding of investors' decision-making process. Going forward, we think it is worthwhile to use long-term data to further investigate the role of risk preferences in reinforcement learning as well as their interactions in different settings and other psychological traits that can reduce the effect of reinforcement learning.

[11] See Shin (2021).

Table A.7
The effect of returns on repurchase and repurchase type with continuous returns after first return.

	Previous investment: Unprotected ELNs		Previous investment: Protected ELNs	
	Choice	Type (Unprotected)	Choice	Type (Unprotected)
Return (%)	0.008	−0.004	0.005	0.005
	(0.006)	(0.013)	(0.016)	(0.016)
Risk Preference	0.001	0.113***	−0.030	−0.030
	(0.014)	(0.028)	(0.044)	(0.044)
Return (%) × Risk	−0.002**	−0.002	−0.001	−0.001
	(0.001)	(0.002)	(0.004)	(0.004)
Investment Experience	0.047	−0.178	−5.786	−5.786
	(0.109)	(0.182)	(276.008)	(276.008)
Return × Investment Experience	0.004	0.019*	(dropped)	(dropped)
	(0.006)	(0.011)		
Advertising ($1,000)	0.048***		−0.264***	−0.264***
	(0.019)		(0.046)	(0.046)
Return × Advertising	0.003***		0.017***	0.017***
	(0.001)		(0.003)	(0.003)
Principal Amount ($1000)	0.001***		0.001	0.001
	(0.000)		(0.001)	(0.001)
Amount of Investment Tools ($1,000)	−0.000***		−0.000*	−0.000*
	(0.000)		(0.000)	(0.000)
Number of Investment Tools	−0.031***	0.006	0.015	0.015
	(0.006)	(0.013)	(0.026)	(0.026)
Age	0.005***	−0.002	0.008***	0.008***
	(0.001)	(0.001)	(0.003)	(0.003)
Male (dummy)	−0.074***	0.066	−0.039	−0.039
	(0.019)	(0.040)	(0.078)	(0.078)
Stock Price Index (Unit: 1,000)	0.101	−1.509***	1.899***	1.899***
	(0.114)	(0.204)	(0.530)	(0.530)
Government Bond Rate (%)	−0.105**	−0.732***	−0.175	−0.175
	(0.049)	(0.132)	(0.238)	(0.238)
Intercept	0.197	7.406***	2.857	2.857
Year dummies	Yes	Yes	Yes	Yes
Number of observations	18,931		1388	
Log Pseudo-likelihood	−14,211.01		−1,042.70	

This table reports the estimated effects of returns on repurchase decisions after investors observe their first returns. Returns are measured as percentage returns of the first investments as opposed to indicator variables. Probit models with sample selection are used to estimate the effects. Columns *Unprotected ELNs* and *Protected ELNs* indicate the first investments in unprotected ELNs and protected ELNs, respectively. Stage 1 estimates the probability of repurchasing ELNs (Column *Choice*). The dependent variable equals one if the investors repurchased ELNs within 91 days after observing the first ELN investment returns, and zero otherwise. Stage 2 estimates the probability of purchasing only unprotected ELNs (Column *Type*). The dependent variable equals one if investors purchased unprotected ELNs within our observation window of 91 days post the first return, and zero if the repurchase is protected ELNs. All other variables are defined in Table 2. Year dummies are included in all regressions. Standard errors are reported in parentheses. *, **, and *** report significance levels at 10%, 5%, and 1%, respectively. Some variables are dropped due to collinearity.

CRediT authorship contribution statement

Reo Song: Conceptualization, Data curation, Writing – original draft, Project administration, Supervision, Investigation. **Sungha Jang:** Formal analysis, Writing – original draft, Methodology, Software, Data curation, Visualization. **Yingdi Wang:** Conceptualization, Methodology, Writing – original draft. **Dominique M. Hanssens:** Conceptualization, Writing – review & editing, Supervision, Project administration. **Jaebeom Suh:** Resources.

Appendix A

A.1. Equity-linked notes

A typical ELN combines a call option on equity with a zero-coupon bond payoff. It allows investors to secure downside protection for their initial investments, while retaining some upside gains from the equity market. The underlying equity an ELN can be linked to the performance of an equity index, an individual stock, or a portfolio of indices and stocks. An ELN can also include interest rate call or put options with lower coupon payments. Recent developments in financial engineering have spawned numerous types of ELNs such that they can be structured to provide full, partial, or no principal protection. In the case of full protection, an ELN investor receives the initial investment, which is designed to equal the par value of the note, plus an additional redemption amount based on the performance of the underlying equity at maturity. An ELN can also be designed to seek more upside potential by giving up protection of some or all of the initial investment.

Table A.8
The effect of returns on repurchase amount with continuous returns after first return.

	Previous investment: Unprotected ELNs		Previous investment: Protected products	
	Choice	Amount	Choice	Amount
Return (%)	0.008	−0.040	0.006	−0.296
	(0.006)	(0.205)	(0.016)	(0.523)
Risk Preference	0.002	1.002**	−0.031	−2.174
	(0.014)	(0.473)	(0.044)	(1.638)
Return × Risk	−0.002**	−0.022	−0.001	0.085
	(0.001)	(0.024)	(0.004)	(0.139)
Investment Experience	0.043	−5.451	−6.507***	(dropped)
	(0.110)	(3.360)	(0.822)	
Return × Investment Experience	0.004	0.183	(dropped)	(dropped)
	(0.006)	(0.179)		
Advertising ($1,000)	0.034*		−0.219***	
	(0.019)		(0.051)	
Return × Advertising	0.003***		0.017***	
	(0.001)		(0.003)	
Principal Amount ($1000)	0.001***	0.695***	0.001*	0.458***
	(0.000)	(0.007)	(0.001)	(0.034)
Amount of Investment Tools ($1,000)	−0.000***	0.015***	−0.000*	0.018***
	(0.000)	(0.001)	(0.000)	(0.005)
Number of Investment Tools	−0.032***		0.013	
	(0.006)		(0.026)	
Age	0.005***	0.038*	0.008***	0.112
	(0.001)	(0.021)	(0.003)	(0.097)
Male (dummy)	−0.074***	1.333**	−0.032	2.830
	(0.019)	(0.538)	(0.078)	(2.393)
Stock Price Index (Unit: 1,000)	0.206*	4.202*	1.474***	−10.640
	(0.114)	(2.300)	(0.571)	(11.748)
Government Bond Rate (%)	−0.111**	0.465	−0.135	−1.183
	(0.049)	(1.441)	(0.240)	(7.010)
Intercept	0.075	4.355	4.102	46.760*
	(0.269)	(7.758)	(14.685)	(27.804)
Year dummies	Yes	Yes	Yes	Yes
Number of observations	18,931		1388	
Log Pseudo-likelihood	−62,116.58		−3,054.65	

This table reports the estimated effects of returns on repurchase decisions measured by the repurchase amount after investors observe their first returns. Returns are measured as percentage returns of the first investments. Column *Choice* reports results from Heckman's selection model stage 1: the probability of repurchasing ELNs. The dependent variable equals one if the investors repurchased ELNs within 91 days after observing the first ELN investment returns, and zero otherwise. Column *Amount* reports estimated results from Heckman's selection model stage 2: the effect of returns on repurchase amount. The amount is measured in $1,000. Repurchases are both unprotected- and protected-ELNs are included in the estimates. Column *Unprotected (Protected) ELNs* indicate investors' first investment types. All independent variables are defined in Table 2. Year dummies are included in every regression. Standard errors are reported in parentheses. *, **, and *** report significance levels at 10%, 5%, and 1%, respectively.

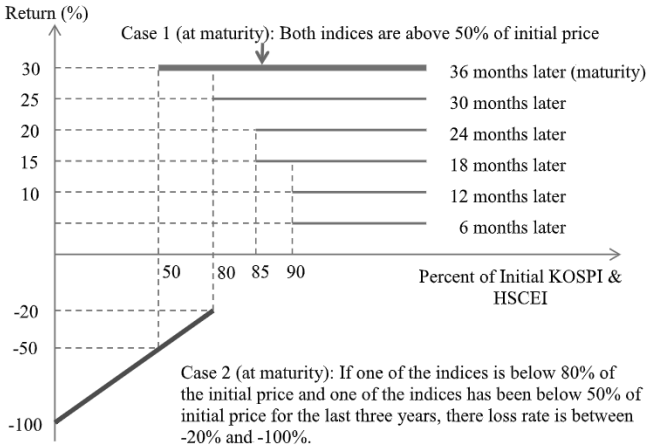
Another feature of ELNs is that there is no market trading for ELNs already issued. Thus, no market prices of ELNs are observed. Each ELN has unique base assets (e.g., stocks) and a return structure. Appendices A.2 and A.3 present examples of ELNs with different base assets. Once investors purchase ELNs, they also have to hold their investments till maturity or wait for an early termination if certain conditions are met (e.g., after six months in the example shown in Appendix II). Therefore, similar to the stock market, which follows a random walk, previous returns of ELNs cannot predict future returns of other ELNs. As such, rational investors should not base their purchase decisions on the prior performance of ELNs.

A.2. Example of principal-unprotected ELN

This section provides an example of a principal-unprotected ELN with terms and conditions. The base assets are the KOSPI (Korea Composite Stock Price Index) and the HSCEI (Hang Seng China Enterprises Index), with a three-year maturity period. This ELN is evaluated every six months. If the specified conditions are met before maturity, an investor will earn the promised annual return of 10%. If early termination conditions have not been met, then there are two possibilities at maturity. If both indices are above 80% of the initial price, the investor earns a 30% (or 10% annualized) return. However, if one of the indices is below 80% of the initial price *and* one of the indices dropped below 50% of its initial price at least once for the last three years, then what the investor receives is computed as 'principal × (price of the lower index at maturity/initial price).' In this case, the investor will experience a (partial) loss of the principal amount. This 50% of the initial price is called a 'knock-in' condition which nullifies the promised return. As this example shows, ELNs can be structured in various ways using options on equities and bonds. In the case of principal protected ELNs, a zero-coupon bond is typically used to guarantee the initial investment amount. Investors *cannot sell* ELNs once they purchase them.

Type	Principal is not protected		
Base asset	KOSPI (Korea Composite Stock Price Index), HSCEI (Hang Seng China Enterprises Index)		
Maturity	Three years		
Evaluation cycle	Every 6 months		
Early termination	Evaluation period	Condition	Return*
	6 months later	Both indices are above 90% of the initial price	5.0%
	12 months later	Both indices are above 90% of the initial price	10.0%
	18 months later	Both indices are above 85% of the initial price	15.0%
	24 months later	Both indices are above 85% of the initial price	20.0%
	30 months later	Both indices are above 80% of the initial price	25.0%
At maturity	Both indices are above 80% of the initial price		30.0%
	One of the indices is below 80% of the initial price and one of the indices has been below 50% of its initial price at least once for the last three years: Return amount = Principal × (Price of the lower index at maturity / Initial price)		Loss

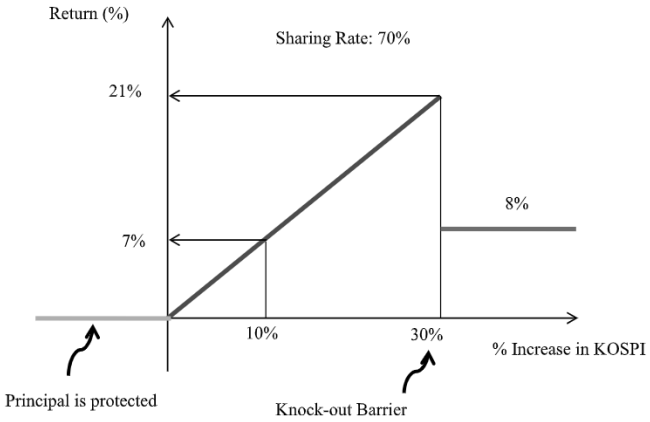
* Annualized returns are all 10%.



A.3. Example of principal-protected ELN with knock-out barrier

Appendix A.3 shows an example of a principal-protected ELN. The base index is KOSPI and the maturity is one year. This ELN has a knock-out barrier of 30% and sharing rate of 70%. If the level of KOSPI at maturity increases by 0 to 30%, the return will be the percentage increase in the base asset multiplied by the sharing rate (70%). If the base asset increases by more than 30% (knock-out barrier), then the return is fixed at 8%. Because the principal is protected, the return will be 0% if KOSPI is below the initial level at maturity.

Type	Principal is protected	
Base asset	KOSPI (Korea Composite Stock Price Index)	
Maturity	One year	
Early termination	Condition	Return
	KOSPI increases more than 30%, even just once (knock-out barrier)	8.00%
At maturity	KOSPI is higher than the initial level	70% x Percent increase in KOSPI
	KOSPI is lower than the initial level	0% (Principal is protected)



Appendix B. Sample questions of the risk preference survey for ELN investors

1. How long do you plan to invest in ELNs?

(1) More than 3 years
(2) More than 2 years, but less than 3 years
(3) More than 1 year, but less than 2 years
(4) More than 6 months, but less than 1 year
(5) Less than 6 months

2. I have investment experience in the following products:

(1) Very high risk product: ELNs, Options, Futures, Exchange rate derivatives, etc.
(2) High risk product: Stocks, Stock mutual funds, Principal-unprotected ELN, etc.
(3) Medium risk product: Mutual funds mixed with stocks and bonds, Principal-protected ELNs, Corporate bonds lower than investment grade, etc.
(4) Low risk product: Bond mutual funds, Principal-protected ELNs, Investment grade corporate bonds, etc.
(5) Very low risk product: Savings accounts, CDs, Government bonds, etc.

3. My experience in derivative products is:

(1) More than 3 years (2) More than 1 year, but less than 3 years (3) Less than 1 year

4. My knowledge in financial products and investment is:

(1) Very high (2) High (3) Medium (4) Low (5) Very low

5. How much loss are you willing to take?

(1) As much as to obtain high return (2) Partial loss (3) Minimum loss (4) No loss

6. My investments purpose is:

(1) Willing to take very high risk including derivatives to obtain much higher returns than the market return
(2) Willing to take some risk to obtain higher returns than the market return
(3) Willing to take minimum risk to obtain higher returns than protected products
(4) Want to minimize risk and expect only reasonable returns
(5) Want to protect principal and do not want to take risk

7. The proportion of investments relative to my total assets is:

(1) More than 70%
(2) More than 50%, but less than 70%
(3) More than 30%, but less than 50%
(4) More than 10%, but less than 30%
(5) Less than 10%

8. My monthly income is:

(1) More than $5,000
(2) More than $3,000, but less than $5,000
(3) More than $2,000, but less than $3,000
(4) More than $1,000, but less than $2,000
(5) Less than $1,000

Appendix C. Robustness checks

This appendix shows robustness checks for the main results using different samples. Tables A.1–A.4 present results using a one-year event window instead of a 91-day window. Tables A.5–A.8 use a 91-day window but include investors who made one repurchase instead of restricting the sample to those making at least two repurchases.

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