THE JOURNAL OF BEHAVIORAL FINANCE, 11: 31–49, 2010

ISSN: 1542-7560 print / 1542-7579 online
DOI: 10.1080/15427561003590100

Financial Engineering and Rationality: Experimental Evidence Based on the Monty Hall Problem

Brian Kluger
University of Cincinnati

Daniel Friedman
University of California at Santa Cruz

Financial engineering often involves reconfiguring existing financial assets to create new financial products. This article investigates whether financial engineering can alter the environment so that irrational agents can quickly learn to be rational. We design two financial assets that embed the Monty Hall problem, a well-studied choice anomaly. Our experiment requires each subject to value one of these assets. Although these assets are equivalent in terms of standard choice theory, valuation experience with one of the assets lowers the subjects' cognitive error rates more than valuation experience with the other asset. We conclude that financial engineering can create learning opportunities and reduce cognitive errors.

Keywords: Experimental finance, Financial engineering, Framing, Choice anomalies

Psychologists and experimental economists have collected convincing evidence that many agents regularly violate the rationality assumptions usually made by financial economists. Most recent research in behavioral finance investigates the theoretical and empirical consequences. This article, however, explores a rather different behavioral question: can financial engineering ever reduce or eliminate irrationality?

Financial engineering can be defined as "combining or carving up existing financial assets to create new financial products" (Harvey [2005]). Such products allow agents to trade positions that are otherwise more costly or even unavailable. Perhaps financial engineering has additional impact, altering the environment so that agents can learn to behave more or perhaps less rationally. For instance, some investigators believe that "portfolio insurance," engineered in the mid 1980s, encouraged irrationality associated with the 1987 stock market crash[1].

To investigate such questions, we conduct a controlled laboratory experiment based on the Monty Hall problem, one of the most persistent and best documented examples of irrational behavior. Using methods adapted from earlier studies, we first verify the presence of erroneous beliefs and choices. Next we engineer two financial assets that embed the Monty Hall problem and require individual subjects to value one of these assets. Although the assets are equivalent in terms of standard choice theory, they are constructed to offer different learning opportunities. One of the assets is designed to make the Monty Hall problem more transparent.

We do not conduct an actual market, so subjects cannot learn from competitive prices or from observation of others' trading behavior. Nevertheless, by the end of the experiment, many subjects have learned to avoid the error. Although valuing either of the assets reduces the error rate, valuing one of the engineered assets is more effective than the other. We conclude that asset design can affect the learning environment and consequently affect the prevalence of cognitive errors.

The rest of the article is organized as follows. Section 2 discusses relevant previous research, and Section 3 presents the experimental design. The experimental results are reported in Section 4. Section 5 presents a summary. The Appendix includes the instructions to subjects.

Address correspondence to Brian Kluger, Department of Finance, College of Business, University of Cincinnati, Cincinnati, OH 45221-0195. E-mail: brian.kluger@uc.edu

PREVIOUS RESEARCH

Financial engineering and behavioral finance are two of the most currently popular topics in Finance, but there is not much prior research linking the two. The most relevant previous studies are concerned separately with framing effects in market experiments and with the Monty Hall problem. We begin with the former topic.

Framing in Markets

Framing effects refer to the possibility that alternative ways of posing an identical problem may affect agents' choices. Several sorts of framing effects are well documented in individual choice experiments (see Camerer [1995] for a review). Financial engineering involves the creation of new financial assets from existing assets. As such, it can present investors with a reframed version of the underlying decision problem and may lead to different valuations.

Two prior studies examine framing in experimental asset markets. Kirchler, Maciejovsky, and Weber [2005] study an asset market where the end of period payoff on the traded asset has a normal distribution with announced mean and variance. Positively framed subjects are given the redundant information that there is a 5% chance that the next payoff will be higher than the corresponding .95 value, while negatively framed subjects are told that there is a 5% chance the next payoff will be lower than the corresponding .05 value. The authors report that positively framed subjects are more likely to be buyers and negatively framed subjects are more often sellers. Prices, however, are unaffected.

Weber, Keppe, and Meyer-Delius [2000] study framing in an experimental asset market with a risky asset whose payoff depends on a drawing from an urn containing yellow and white balls. In positive frame treatments, some subjects are endowed with cash and shares of a white asset (W), which pays 100 if a white ball is drawn from the urn at the end of the period (and zero otherwise). In negative frame treatments, these subjects begin with a short position in yellow assets (Y), which pay 100 only if a yellow ball is drawn. Since a portfolio of one white share and one yellow share pays 100 for sure ($W + Y = 100$), a share of one asset is equivalent to cash and a short position in the other asset ($W = 100 - Y$). Negatively framed endowments substitute $100 - Y$ for each white share in the corresponding positively framed endowment. Although Weber, Keppe, and Meyer-Delius use the term "endowment frame," they are clearly practicing financial engineering when changing from the positive frame (endowments with only long positions) to the negative frame (endowment containing a short position). The authors report higher asset prices in the negative endowment frame; subjects with short positions were willing to pay a higher price to buy assets to cover their short positions. Evidently, subjects are not always maximizing expected utility, but the design cannot tell us whether the divergence from rationality is occurring in the positive frame, the negative frame, or both.

The Monty Hall Problem

The Monty Hall problem is a stylized version of a game from the classic TV show *Let's Make a Deal*. Game show host Monty Hall asks a contestant to choose one of three doors. One of these doors conceals a valuable prize such as a new car, while the other two doors conceal worthless prizes. After the contestant picks a door, Monty always opens one of the remaining doors and reveals one of the worthless prizes. Then Monty gives the contestant a chance to switch doors, that is, to choose the remaining door. The probability that the valuable prize is behind the original door is one-third, so switching to the remaining door has a two-thirds probability of winning. Thus the rational strategy is to switch. The contestant, however, refuses to switch in the belief that his strategy will win with probability (at least) one-half[2].

The Monty Hall problem has been extensively studied in the laboratory, and the error is common and persistent. Indeed, even after having the error explained, many people cling to the belief that winning is equally likely whether or not the contestant switches. Such people include several professors, including a mathematician (e.g., Haddon [2003], pp. 61–65). Friedman [1998] finds an initial error rate of almost 90%, and even in his most intense learning environments the error rate seldom drops much below 50%; the overall error rate was about 70%. Page [1998] finds that even subjects trained in a rather transparent version (with 100 doors) typically revert to the error in the standard three-door version. Slembeck and Tyran [2002] and Palacios-Huerta [2003] show that social learning (e.g., with group decisions) can be effective in overcoming the error but confirm that the error persists in individual learning environments.

Krauss and Wang [2003] show that variations in the problem can decrease the Monty Hall error rate. Based on psychology studies hypothesizing that subjects will make fewer errors in general when working with frequencies as opposed to probabilities, they design a variation of the Monty Hall problem called the guided intuition treatment. Subjects are given a form with the Monty Hall problem at the top. They are then told that the contestant chooses Door 1. Lower on the form they are asked intermediate questions about how many arrangements (of doors and prizes) are possible in which the contestant would win if he or she switches doors, and how many arrangements are possible in which the contestant would win if he or she does not switch. Finally, subjects are asked whether the contestant should stay or switch. In this treatment, they report a 59% switch rate. They also consider other treatments that also decrease error rates, although none is as effective as the guided intuition treatment.

Kluger and Wyatt [2004] embed the Monty Hall problem into a financial asset in order to study whether the Monty Hall error aggregates into market prices. The asset features a conversion option that corresponds to switching doors. They find that asset prices do not reflect the Monty Hall error in sessions where two or more subjects are identified as understanding the problem based on their performance in the individual experiments.

Several results from these studies are especially pertinent to our experiment. First, Friedman's [1998] experiments demonstrate that repetition alone does not quickly eliminate the error. Friedman's control group repeated the Monty Hall exercise 25 times. The switch rate over the first three repetitions was only 17%. The final switch rate, based on the last three repetitions, was only 37%. A one-tailed paired t-test rejects the null hypothesis that the final and initial switch rates are equal only at the 10% level. The Wilcoxon signed-rank test also rejects this null hypothesis at the 10% significance level. Absent an enhanced learning environment, subjects learn to avoid the error very slowly, if at all.

Second, the Krauss and Wang [2003] results raise the possibility that markets, or market-like framing, might serve to "guide intuition." When subjects value a financial asset derived from the Monty Hall task, they are implicitly asked not only whether they should switch doors but also to find the monetary value of their action. Such leading questions could reduce error rates. However, in Kluger and Wyatt's [2004] experimental markets for a convertible Monty Hall asset, prices did not reflect the error when there were at least 2 subjects who understood the Monty Hall problem. Simply trading the asset in a market did not seen to enhance individual learning. In markets with fewer than 2 subjects who already understood the task, errors persisted. Might some other engineered asset do better?

TABLE 1
Experimental Design.
A session of the experiment consists of five blocks, with each block consisting of one or more periods. The choice-task periods required subjects to choose between the set-aside card and the remaining card. The valuation-task periods required subjects to value either the seta or the rem financial asset using a simplified version of the Becker-DeGroot-Marschak method.

Block	Task	Number of Periods	Treatment
A	Choice	8	A red remaining card is always revealed.
B	Valuation	16	In R (odd-numbered) periods, a red remaining card is always revealed. In U (even-numbered) periods, both remaining cards are face-down.
C	Valuation	8	The valuation task is performed both before and after a red remaining card is revealed.
D	Choice	8	A red remaining card is always revealed.
E	Choice	1	A red remaining card is always revealed. Payoffs are times ten.

EXPERIMENTAL DESIGN

We conducted an individual choice experiment with 78 subjects recruited from the undergraduate population at the University of California at Santa Cruz. Each of the 9 sessions lasted approximately 90 minutes, including instructions, with average payouts of about $20 per subject, paid in cash at the end of the session.

Table 1 presents the experimental design. Each session consists of 5 separate blocks, with each block containing 1–16 periods of a given task. There are 2 types of tasks, choice tasks and valuation tasks, which we now describe.

Choice Task

Our choice task is a modified version of the Monty Hall problem. As in Friedman [1998] and subsequent laboratory studies, each period the subjects see 3 ordinary playing cards, placed face-down on a mat. Subjects are informed that 2 of the cards are red (hearts or diamonds) and 1 is black (clubs or spades). One of the subjects (selected on a rotating basis) chooses 1 of 3 face-down cards to be the set-aside card, and the card is moved to the marked position on the mat. Then, the person conducting the experiment looks privately at the 2 remaining cards and always reveals one of them to be a red card. Finally, subjects are asked to choose either the set-aside card or the remaining card. All subjects privately mark their choice on a form. After collecting the form, the conductor turns over both of the face-down cards. If a subject correctly chose the black card, he or she earns 60 cents. If incorrect, the subject earns nothing. The sequence of events for a choice task period is presented in Figure 1.

Choosing the remaining card in this choice task corresponds to switching doors in the Monty Hall problem. The remaining card has a two-thirds probability of winning, while the set-aside card has only a one-third chance of winning. Therefore, a subject who correctly assesses the probabilities should always choose the remaining card. The common judgment error is to believe that each card is equally likely to win. Subjects with this erroneous belief would regard all choices as having the same expected payoff, and so might indulge in any choice pattern[3].

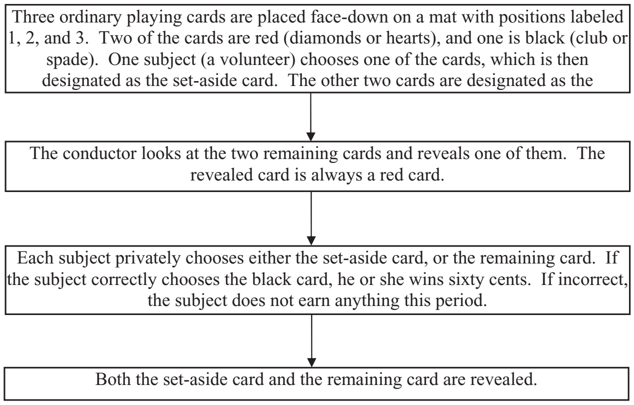


FIGURE 1 The sequence of events for a period of the choice task.

Valuation Task

The choice task requires subjects to decide whether or not to switch cards. The valuation task alters the Monty Hall problem, no longer requiring subjects to choose between the set-aside and the remaining card, but instead requiring subjects to determine a price at which they will sell a claim that pays cash if one of the unpicked cards is black. We design 2 financial assets based on the position of the black card. Define the "rem" asset as a claim that pays the bearer 60 cents if the remaining card is black and pays nothing otherwise. The "seta" asset pays the bearer 60 cents if the set-aside card is black. These claims are redundant because the seta asset always pays 60 cents minus the rem payoff. Although equivalent in terms of standard choice theory, the assets may not be equivalent in terms of susceptibility to the Monty Hall probability error.

We designed the rem asset to make the Monty Hall error more transparent. An individual who makes the error incorrectly believes that revealing the red card changes the probability that the set-aside card is black. After the set-aside card is designated but before the red card is revealed, the rem asset will pay 60 cents if either of the remaining cards is black. This feature may help subjects to solve the Monty Hall problem. A subject will win if either of the 2 remaining cards are black, which is twice as likely as the set-aside card being black.

The seta asset was designed as a control. Even though the payoffs between the seta and rem are perfectly correlated (rem = 60 cents – seta), the seta does not make the choice between 1 set-aside and 2 remaining cards as clear. For this reason, we predict that subjects who value the rem asset will learn how solve the Monty Hall problem more quickly.

Five sessions with a total of 40 subjects were conducted using the rem asset, and 4 sessions with 38 subjects were conducted using the seta asset. We first describe the rem valuation task.

Rem Valuation Task

We use a choice menu procedure that can be regarded as a simplified version of the Becker-DeGroot-Marschak [1964] procedure for eliciting subjects' valuations. The task has 3 variants, which we call R (revealed), U (unrevealed), and U+R (both).

At the start of each R period, each subject is given 1 share of the rem asset, which pays the bearer 60 cents if the remaining card that period is black and pays nothing otherwise. As in the choice task just described, 3 cards are placed face-down on the mat, one of the subjects chooses the set-aside card, and the conductor reveals a red remaining card. Each subject is then given the chance to sell his or her share. The set of possible prices is 27, 29, 31, 33, 35, 37, 39, 41, or 43 cents, with the actual price determined by a random drawing from a bingo cage. Subjects fill out a form asking them to choose whether or not to sell their share at each of the possible prices. The random drawing determines the share price for the period. Finally, as before, the face-down cards are turned over. Subjects who chose to sell at the price drawn receive that amount. Subjects who decided to keep the rem share will receive 60 cents only if the remaining card is black.

If a subject correctly assesses the probabilities, then the expected value of the share is 40 cents; it is the 60-cent payoff if the remaining card is black times the two-thirds probability of that event. An incorrect belief that the black card is equally likely to be either the set-aside card or the remaining card leads to the incorrect expected value of 30 cents.

The U (unrevealed) periods are identical to the R periods, except that both remaining cards stay face-down until the last step; U periods skip the step where the conductor reveals a red set aside card. Therefore both remaining cards are face down when the subject is asked to value the rem asset, which will in effect pay 60 cents if either of the 2 remaining face down cards is black. Of course, determining value while both remaining cards are face down does not affect the true valuation of the share, because revealing a red card is always feasible whether or not one of the remaining cards is black.

The U+R (both) periods require the subjects to value the shares twice. Exactly as in the other periods, one of the subjects chooses the set-aside card. Subjects then value their shares by circling either "keep" or "sell" at each of the possible prices. Next, one of the remaining cards is turned over, always revealing a red card. Subjects again value their shares by circling "keep" or "sell" but on a second form. However, only one of the forms will count. A subject rolls a six-sided die to determine whether the earlier form (a roll of , 2 or 3) or the later form (4, 5, or 6) will be active. Finally the price is determined according to a bingo drawing. Subjects who circled sell at that price on the active form will then sell their share. The sequences of events for the R, U, and U+R periods are diagrammed in Figure 2.

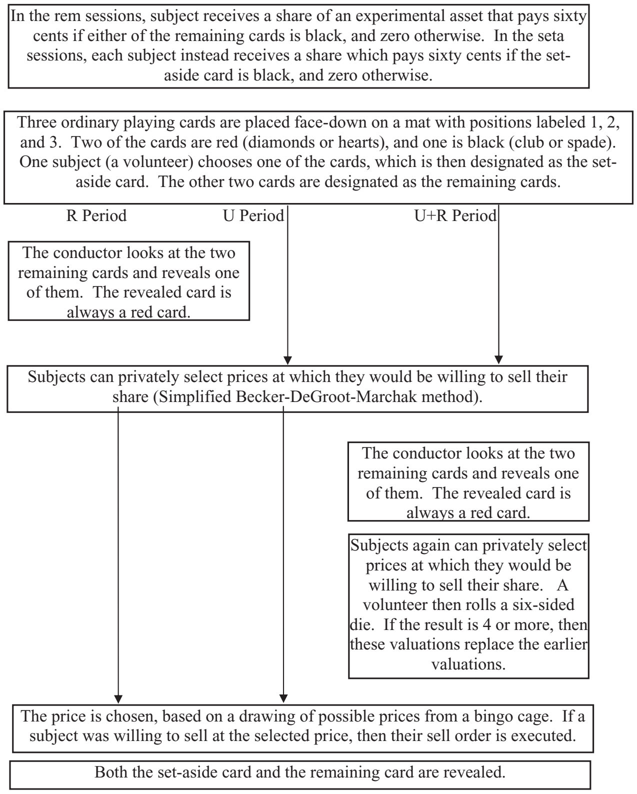


FIGURE 2 The sequence of events for a period of the valuation task.

Seta Valuation Task

The procedures for the seta valuation task are similar to those for the rem task. The choice tasks for both were identical. The valuation task still contains R periods, U periods, and U+R (both) periods, and these are also identical to the rem procedures except for the possible sale prices for the asset as described below.

The seta asset pays the bearer 60 cents only if the set-aside card is black. Since one-third is the correct probability that the set-aside card is black, the seta expected value is 20 cents. If an individual makes the Monty Hall probability error, he or she believes that after the red card is revealed, the set-aside and remaining cards are equally likely to be black. Therefore, the seta expected value is 30 cents for an individual who makes the error. Accordingly, when each subject is given the opportunity to sell his or her seta share, the possible prices are 17, 19, 21, 23, 25, 27, 29, 31, or 33 cents. Again, the actual price determined by a random drawing from a bingo cage. All other procedures are identical to those for the rem valuation task and are shown in Figure 2.

RESULTS

The results for each block of the experiment are presented in sequence. Since we are interested in how quickly subjects learn to avoid the Monty Hall problem, our analysis does not include 11 subjects who chose the remaining card every time in both Block A and Block D. These subjects almost certainly knew the correct solution from the outset.

Descriptive data for all blocks are presented in Table 2. We will see that the Monty Hall probability error is prevalent in the beginning but declines considerably by the end of the session.

Initial Choice Task

In Block A, subjects chose either the set-aside card or the remaining card. The remaining card is the optimal choice, giving the subject twice the chance of picking the black card and earning the 60-cent payoff. The results are presented in the column labeled Block A in Table 2. R% represents the percentage of the time (out of 8 periods) that a subject chose the remaining card, the optimal choice. Across subjects, the average R% was 50.4%. Five of the 67 subjects picked the remaining card every time (R% = 100%). Five subjects had an R% of zero. The rest of the subjects sometimes chose the set-aside card and other times chose the remaining card. As well, there are no obvious time trends within Block A; by period the average R% were 54%, 49%, 43%, 45%, 48%, 69%, 52%, and 51%.

The average R% for the rem subjects is 53.8%, and the average for the seta subjects is 46.4%. Hypothesis tests of the null that the R% for the subjects who will subsequently value the rem asset is equal to the R% for subjects who will subsequently value the seta asset cannot be rejected. This is not too surprising because there is no difference in experimental procedures across these subjects until Block B.

Valuation Tasks

Block B consists of 16 periods of the valuation task, alternating between R periods (where 1 of the remaining cards is revealed before eliciting values) and U periods (where both remaining cards are left face down). Of course, each subject's response on the menu determines a range of values, not an exact value. For our analysis, we assigned the midpoint of the range for intermediate choices. For example, if a subject kept the share at 33 cents but sold at 35 cents and above, then the assigned value is 34 cents. For extreme choices the value is conservatively assigned to be a penny past the endpoint. Thus if the subject sold at every price, his or her value is between 0 and 27 cents, and we assigned the value of 26 cents. Likewise, a subject who kept at every price is assigned the value of 44 cents.

Recall that the rational expected value for the rem asset is 40 cents and that the Monty Hall error implies an expected value of 30 cents. In U periods, the error should not arise because both of the remaining cards are face down. Table 3, Panel A shows that indeed the average rem valuation for the U periods in Block B is 39.27 cents, very close to the expected value of 40 cents. The table also reports the results of two Wilcoxon signed-rank tests. The "L40" tests the null hypothesis that the subject's valuation is 40 against the one-sided alternative hypothesis that the subject's valuation is less than 40. The null hypothesis is rejected at a p-value of .05 in U periods for only 10 of the 36 subjects. The "G30" tests the null that the subject's valuation is 30 against the one-sided alternative hypothesis that the subject's valuation is greater than 30. For the U periods, the null is rejected for 35 of 36 subjects at a p-value of .05. Thus the evidence indicates that subjects value rem shares correctly in U periods of Block B.

In the R periods, some subjects are making the Monty Hall error, but others are not. The average valuation is 37.26 cents. The rational null hypothesis in the "L40" test is rejected for 20 of the subjects in the direction of the Monty Hall error. However, the irrational null hypothesis in the "G30" test is rejected for 31 of 36 subjects in the rational direction. Apparently the error is present in Block B but in diluted form.

Table 3, Panel B reports similar results for subjects valuing the seta asset. The expected value of the seta asset is 20 cents based on the correct probabilities but 30 cents based on the incorrect probabilities associated with the Monty Hall error.

TABLE 2
Responses by Block.

Panel A Responses by block for the rem subjects. R% is the average rate (out of eight periods) of a subject choosing the remaining card. Block B valuations are for the R periods only (when one of the remaining cards is revealed to be red). Block C valuations are the after (the red remaining card is revealed) valuations. Block E is a single period of the choice task. "Yes" signifies that the subject chose the remaining card. "No" signifies he or she chose the set-aside card.

	Block A	Block B	Block B	Block C	Block C	Block D	Block E
Subject	R%	Initial Valuation	Final Valuation	Initial Valuation	Final Valuation	R%	R
rem-1	62.5%	34	36	38	40	75.0%	YES
rem-2	75.0%	40	40	38	40	87.5%	YES
rem-3	37.5%	26	40	40	40	75.0%	YES
rem-4	50.0%	32	44	44	36	75.0%	YES
rem-5	25.0%	34	44	44	44	87.5%	YES
rem-6	50.0%	44	44	44	44	87.5%	YES
rem-7	37.5%	32	32	36	30	62.5%	NO
rem-8	75.0%	30	40	40	42	87.5%	NO
rem-9	62.5%	40	44	44	44	50.0%	YES
rem-10	25.0%	38	44	44	44	75.0%	YES
rem-11	87.5%	34	40	44	44	100.0%	YES
rem-12	0.0%	44	36	36	38	100.0%	YES
rem-13	12.5%	34	34	32	30	25.0%	YES
rem-14	87.5%	34	36	36	36	87.5%	YES
rem-15	75.0%	38	36	36	36	87.5%	YES
rem-16	62.5%	44	44	44	26	87.5%	YES
rem-17	37.5%	34	44	44	44	75.0%	YES
rem-18	50.0%	44	32	32	44	75.0%	YES
rem-19	37.5%	30	42	42	42	50.0%	YES
rem-20	75.0%	40	36	38	42	87.5%	YES
rem-21	25.0%	44	40	36	38	12.5%	NO
rem-22	0.0%	36	38	38	40	0.0%	YES
rem-23	62.5%	32	36	36	36	50.0%	NO
rem-24	37.5%	34	36	44	44	50.0%	NO
rem-25	62.5%	32	34	28	26	75.0%	YES
rem-26	87.5%	36	44	40	38	62.5%	NO
rem-27	100.0%	30	38	44	38	62.5%	NO
rem-28	62.5%	26	44	26	44	75.0%	NO
rem-29	50.0%	40	38	38	38	100.0%	YES
rem-30	100.0%	34	34	36	36	37.5%	NO
rem-31	62.5%	30	34	36	38	87.5%	YES
rem-32	0.0%	40	40	40	38	100.0%	YES
rem-33	100.0%	44	44	44	44	87.5%	YES
rem-34	37.5%	38	40	40	44	50.0%	YES
rem-35	62.5%	36	34	36	40	37.5%	YES
rem-36	62.5%	30	38	36	44	62.5%	YES
Avg. rem	53.8%	35.78	38.89	38.72	39.22	69.1%	75.0%

(Continued on next page)

TABLE 2

Panel B Responses by block for the seta subjects. R% is the average rate (out of eight periods) of a subject choosing the remaining card. Block B valuations are for the R periods only (when one of the remaining cards is revealed to be red). Block C valuations are the after (the red remaining card is revealed) valuations. Block E is a single period of the choice task. "Yes" signifies that the subject chose the remaining card. "No" signifies he or she chose the set-aside card. *(Continued)*

Subject	Block A R%	Block B Initial Valuation	Block B Final Valuation	Block C Initial Valuation	Block C Final Valuation	Block D R%	Block E R
seta-1	62.5%	32	22	30	20	50.0%	YES
seta-2	37.5%	34	30	28	24	37.5%	YES
seta-3	100.0%	30	30	26	28	75.0%	NO
seta-4	37.5%	32	28	34	34	62.5%	YES
seta-5	37.5%	28	26	26	24	87.5%	YES
seta-6	50.0%	24	26	24	34	62.5%	YES
seta-7	25.0%	34	30	34	30	62.5%	NO
seta-8	62.5%	22	24	22	30	100.0%	YES
seta-9	50.0%	24	24	26	20	75.0%	YES
seta-10	25.0%	34	20	24	34	62.5%	YES
seta-11	100.0%	22	22	22	22	87.5%	YES
seta-12	50.0%	24	26	26	22	87.5%	YES
seta-13	50.0%	24	20	28	26	37.5%	NO
seta-14	25.0%	30	30	30	30	12.5%	NO
seta-15	37.5%	34	16	34	34	50.0%	NO
seta-16	37.5%	28	20	22	18	25.0%	NO
seta-17	62.5%	26	24	26	26	62.5%	YES
seta-18	87.5%	16	16	16	34	100.0%	YES
seta-19	50.0%	24	24	30	30	50.0%	YES
seta-20	75.0%	34	34	34	16	12.5%	YES
seta-21	0.0%	30	30	34	34	0.0%	NO
seta-22	0.0%	24	16	16	34	75.0%	NO
seta-23	50.0%	22	34	34	16	75.0%	YES
seta-24	12.5%	22	24	24	26	62.5%	NO
seta-25	75.0%	34	20	16	22	62.5%	YES
seta-26	50.0%	34	34	16	28	75.0%	YES
seta-27	12.5%	34	34	34	34	75.0%	NO
seta-28	37.5%	24	24	34	28	37.5%	NO
seta-29	37.5%	30	26	16	26	62.5%	YES
seta-30	37.5%	34	16	16	34	37.5%	NO
seta-31	62.5%	34	34	34	34	37.5%	YES
Avg. seta	46.4%	28.32	25.29	26.32	27.48	58.1%	61.9%

The average valuation is 23.92 cents for the U periods and 26.10 cents for the R periods. The corresponding hypothesis tests are labeled "L30" and "G20." The "L30" tests the null that the subject's valuation is 30 against the one-sided alternative that the subject's valuation is less than 30 cents. For the U periods the "L30" null is rejected for 24 of 31 subjects. The "G20" tests the null that the subject's valuation equals 20 against the greater than 20 alternative hypothesis. This is rejected for 19 of 31 subjects. Subjects appear to believe that the seta asset is worth somewhere between 20 and 30 cents in the U periods. In the R periods, the average seta valuation is 26.10 cents. Most, 21 of 31, subjects reject the "G20" null, but only 15 of 31 reject the "L30" null. Many of the seta subjects appear to be making the Monty Hall error in Block B.

The experimental design permits another diagnostic test in Block B, comparing each subject's valuations in the R periods to his or her valuation in the U periods. The null hypothesis, that the values are the same, corresponds to rational beliefs. Table 4 shows that the null hypothesis is rejected using either the paired t-test, or the Wilcoxon signed-rank test for both the rem and the seta subjects. Once again we conclude that the Monty Hall error is present in this block, at least to some degree.

In the next Block, each subject's valuation was elicited twice per period, both before and after one of the remaining cards was revealed to be red. Table 5, Panel A shows that for the rem subjects, the averages are almost the same: 39.12 cents before and 39.35 after. The averages are very close to 40, the true expected payoff value. The rational L40 null hypothesis is rejected for 13 rem subjects in the before data and for 16 in the after data, fewer than in the R periods of Block B but more often than in the U periods.[4] Overall, there is less evidence of the Monty Hall error in Block C. Indeed, the irrational G30 null hypothesis that the asset value equals

30 is rejected for 34 of 36 rem subjects before, and 35 of 36 after the remaining card is revealed to be red. Virtually all subjects have learned that the shares are worth more than 30.

Table 5, Panel B contains the corresponding results for the seta subjects. Their average valuation was 26.36 cents before and 24.95 cents after the red card was shown. Sixteen of 31 subjects reject the "L30" null and 22 of 31 reject the "G20" null after the red card is revealed. These results are quite similar to the performance of the seta subjects for the R periods in Block B. Many of the seta subjects are still making the Monty Hall error in Block C.

The experimental design permits another diagnostic test in Block C, comparing each subject's before and after valuations. Table 6 shows that we cannot reject the null hypothesis for the rem subjects using either the paired-t or the Wilcoxon test. In conjunction with the result that average valuations are near 40, as well as the L40 and G30 results, this result confirms that the incidence of the Monty Hall error has declined further by Block C. However, similar tests performed on the seta subjects do reject the null that before

TABLE 3
Average Valuations by Subject in Block B.

Panel A Average valuations for the rem subjects. Valuations are equal to the midpoint of the interval on the valuation forms, except for the endpoints, which are 26 (low) and 44 (high). In R periods, one of the remaining cards was revealed to be red prior to valuation. In U periods, both remaining cards were face-down. The L40 column reports a Wilcoxon signed-rank test that the subject's valuation equals 40, against the alternative that the valuation is less than 40. G30 tests the null that the subject's valuation is 30 against the alternative that the valuation is greater than 30. One asterisk (or two) rejects the null at $p = .05$ (or $p = .01$).

Subject	R Periods Average Valuation	R Periods Standard Deviation	L40	G30	U Periods Average Valuation	U Periods Standard Deviation	L40	G30
rem-1	35.25	1.04	**	**	35.50	0.87	**	**
rem-2	39.25	2.60		**	36.75	3.99	*	*
rem-3	38.25	4.95		**	40.00	0.00		**
rem-4	38.75	6.98		*	36.75	4.79		**
rem-5	39.50	5.10		**	40.75	4.35		**
rem-6	44.00	0.00		**	44.00	0.00		**
rem-7	31.50	2.33	**		32.75	7.07	*	
rem-8	36.50	4.50	*	**	39.25	2.63		**
rem-9	42.00	1.51		**	44.00	0.00		**
rem-10	39.00	4.41		**	42.00	3.87		**
rem-11	34.75	2.12	**	**	40.50	2.18		**
rem-12	36.00	3.55	*	**	44.00	0.00		**
rem-13	34.50	4.24	*	**	31.50	1.32	**	*
rem-14	35.00	4.94	*	*	35.50	0.87	**	**
rem-15	37.50	2.78	*	**	44.00	0.00		**
rem-16	41.75	6.36		**	44.00	0.00		**
rem-17	42.75	3.54		**	41.50	4.33		**
rem-18	39.25	6.58		**	40.50	5.17		**
rem-19	37.75	6.45		*	37.50	5.36	**	*
rem-20	37.00	3.70	*	**	33.25	3.60	**	*
rem-21	39.75	3.77		**	40.00	3.46		**
rem-22	37.75	0.71	**	**	38.25	0.66		**
rem-23	35.75	2.49	**	**	39.00	3.32		**
rem-24	41.25	4.13		**	39.50	4.77		**
rem-25	30.75	2.38	**		38.50	4.77		**
rem-26	39.25	3.54		**	38.25	3.38		**
rem-27	32.25	2.92	**		39.25	1.98		**
rem-28	31.00	6.41	**		44.00	0.00		**
rem-29	38.50	0.93	*	**	38.50	0.87	*	**
rem-30	36.00	3.55	*	**	38.75	2.99		**
rem-31	34.13	2.03	**	**	35.50	5.55	*	*
rem-32	39.75	3.77		**	39.25	1.39		**
rem-33	42.25	4.95		**	44.00	0.00		**
rem-34	35.50	6.02	*	*	41.50	2.18		**
rem-35	35.25	4.89	*	*	41.50	6.61		**
rem-36	32.00	3.70	**		34.00	4.00	**	**
All rem	37.26		20	31	39.27		10	35

(Continued on next page)

TABLE 3

Panel B Average valuations for the seta subjects. Valuations are equal to the midpoint of the interval on the valuation forms, except for the endpoints, which are 16 (low) and 34 (high). In R periods, one of the remaining cards was revealed to be red prior to valuation. In U periods, both remaining cards were face-down. The L30 column reports a Wilcoxon signed-rank test that the subject's valuation equals 30, against the alternative that the valuation is less than 30. G20 tests the null that the subject's valuation is 20 against the alternative that the valuation is greater than 20. One asterisk (or two) rejects the null at p = .05 (or p = .01). *(Continued)*

Subject	R Periods Average Valuation	R Periods Standard Deviation	L30	G20	U Periods Average Valuation	U Periods Standard Deviation	L30	G20
seta-1	26.75	4.53		**	24.00	3.85	**	*
seta-2	30.25	2.49		**	27.00	2.62	*	**
seta-3	30.00	0.00		**	20.25	0.71	**	
seta-4	28.50	6.39		*	27.00	6.05		*
seta-5	27.25	1.49	**	**	22.75	2.12	**	*
seta-6	26.25	2.49	*	**	27.75	3.11		**
seta-7	31.25	1.83		**	30.75	1.49		**
seta-8	22.25	3.11	**		24.25	4.71	*	*
seta-9	24.00	1.07	**	**	24.00	0.00	**	**
seta-10	28.50	6.30		*	20.75	4.53	**	
seta-11	22.00	0.00	**	**	22.00	0.00	**	**
seta-12	24.75	3.85	**	*	24.50	2.78	**	**
seta-13	27.00	6.59		*	24.50	3.82	**	*
seta-14	30.00	0.00		**	20.00	0.00	**	
seta-15	26.00	8.94			27.25	9.31		
seta-16	23.00	5.12	**		25.50	4.63	*	*
seta-17	23.25	3.69	**	*	22.50	3.51	**	
seta-18	16.00	0.00	**		16.00	0.00	**	
seta-19	26.75	3.54	*	**	28.75	1.49		**
seta-20	25.00	9.62			16.00	0.00	**	
seta-21	30.00	0.00		**	30.00	0.00		**
seta-22	24.50	6.82	*		21.50	4.75	**	
seta-23	20.75	6.32	**		29.75	6.63		**
seta-24	23.75	1.67	**	**	25.50	6.02	*	*
seta-25	23.75	8.65	*		23.75	7.04	*	
seta-26	25.00	8.35			18.25	6.36	**	
seta-27	34.00	0.00		**	21.50	3.51	**	
seta-28	26.25	3.28	**	**	24.00	3.02	**	*
seta-29	28.00	3.02		**	24.50	0.93	**	**
seta-30	25.00	9.62			20.50	3.82	**	
seta-31	29.50	6.21		**	26.75	6.04	*	**
All seta	26.10		15	21	23.92		24	19

TABLE 4

Comparing R and U Period Valuations in Block B.

Paired t-test and Wilcoxon Signed rank test comparing a subject's average valuation in R periods to his or her average valuation in U periods. In R periods, one of the remaining cards was revealed to be red prior to valuation. In U periods, both remaining cards were face down.

	N	Paired t	Prob	Signed rank	Prob
H_O Subject average valuations of the rem asset in the R period EQUAL their average valuations in the U periods. H_A Subject average valuations of the rem asset in the R period are LESS THAN their average valuations in the U periods.	36	3.37	<.001	198.0	0.001
H_O Subject average valuations of the seta asset in the R period EQUAL their average valuations in the U periods. H_A Subject average valuations of the seta asset in the R period are GREATER THAN their average valuations in the U periods.	31	2.73	.005	108.0	0.002

valuations are equal to after valuations in Block C. This result is consistent with our earlier claim that the Monty Hall error is still present for seta subjects in Block C.

Solving the Monty Hall Problem

In Block D, subjects return to the choice task of choosing either the remaining or the set-aside card. The column labeled R% Block D in Panel A of Table 2 shows that 4 rem subjects are now choosing the remaining card every time (R% = 100%), and only 1 rem subject is choosing the set-aside every time (R% = 0). The average R% has increased to 69.1%, well above the 53.8% rate in Block A.

Table 2, Panel B also shows that the average R% for seta subjects in Block D has increased from 46.4% to 61.9%.

Figure 3 compares each subject's R% in Block A with their corresponding R% in Block D. The relation for rem subjects is plotted in Panel A. Subjects above the shaded cells in Figure 3 chose the remaining card more often in Block D than they did in Block A. Twenty-five rem subjects are in this category. Three subjects had the same R% in Block

TABLE 5

Valuations by Subject in Block C.

Panel A Average valuations for the rem subjects. Valuations are equal to the midpoint of the interval on the valuation forms, except for the endpoints, which are 26 (low) and 44 (high). Valuations were elicited first before, and then after, one of the remaining cards was revealed. The L40 column reports a Wilcoxon signed-rank test that the subject's valuation equals 40, against the alternative that the valuation is less than 40. G30 tests the null that the subject's valuation is 30 against the alternative that the valuation is greater than 30. One asterisk (or two) rejects the null at p = .05 (or p = .01).

Subject	After Average Valuation	After Standard Deviation	L40	G30	Before Average Valuation	Before Standard Deviation	L40	G30
rem-1	39.75	0.71		**	39.50	1.41		**
rem-2	39.75	0.71		**	39.25	1.49		*
rem-3	40.00	0.00		**	40.00	0.00		**
rem-4	41.50	3.51		**	38.25	1.28	*	**
rem-5	44.00	0.00		**	44.00	0.00		**
rem-6	44.00	0.00		**	44.00	0.00		**
rem-7	39.25	5.44		**	35.75	7.13	*	*
rem-8	39.25	5.55		**	39.50	3.34		**
rem-9	43.75	0.71		**	44.00	0.00		**
rem-10	44.00	0.00		**	44.00	0.00		**
rem-11	43.50	1.41		**	43.50	1.41		**
rem-12	37.50	0.93	**	**	44.00	0.00		**
rem-13	31.25	1.49	**	**	30.75	1.49	**	
rem-14	36.00	0.00	**	**	35.75	0.71	**	**
rem-15	36.00	0.00	**	**	44.00	0.00		**
rem-16	41.75	6.36		**	44.00	0.00		**
rem-17	42.50	4.24		**	44.00	0.00		**
rem-18	38.25	6.36		**	44.00	0.00		**
rem-19	41.75	0.71		**	41.75	0.71		**
rem-20	36.50	2.56	*	**	34.50	2.33	**	**
rem-21	35.00	5.01	**	*	38.00	0.00	**	**
rem-22	38.25	0.71	**	**	37.75	0.71	**	**
rem-23	36.25	1.98	**	**	37.00	1.51	**	**
rem-24	44.00	0.00		**	42.50	4.24		**
rem-25	33.25	5.12	*		34.50	5.42	*	*
rem-26	38.25	3.92		**	35.75	1.98	**	**
rem-27	38.50	6.30		**	31.75	0.71	**	**
rem-28	36.00	8.94			44.00	0.00		**
rem-29	38.00	0.00	**	**	38.00	0.00	**	**
rem-30	37.75	3.45		**	37.00	3.70	*	**
rem-31	36.25	0.71	**	**	34.00	0.00	**	**
rem-32	38.25	0.71	**	**	37.38	3.50	*	**
rem-33	44.00	0.00		**	44.00	0.00		**
rem-34	40.75	3.20		**	38.75	2.60		**
rem-35	34.50	5.43	**	*	37.00	4.66		**
rem-36	39.00	6.41		**	34.75	1.83	**	**
All rem	39.12		13	34	39.35		16	35

(Continued on next page)

TABLE 5

Panel B Average valuations for the seta subjects. Valuations are equal to the midpoint of the interval on the valuation forms, except for the endpoints, which are 16 (low) and 34 (high). Valuations were elicited first before, and then after, one of the remaining cards was revealed. The L30 column reports a Wilcoxon signed-rank test that the subject's valuation equals 30, against the alternative that the valuation is less than 30. G20 tests the null that the subject's valuation is 20 against the alternative that the valuation is greater than 20. One asterisk (or two) rejects the null at p = .05 (or p = .01). *(Continued)*

Subject	After Average Valuation	After Standard Deviation	L40	G30	Before Average Valuation	Before Standard Deviation	L40	G30
seta-1	26.00	4.14	*	**	25.75	4.20	*	**
seta-2	27.75	1.67	**	**	25.75	2.49	**	**
seta-3	29.00	1.51		**	28.75	2.12		**
seta-4	30.25	3.92		**	28.50	4.24		**
seta-5	24.50	2.07	**	**	23.00	2.39	**	*
seta-6	26.25	7.59		*	25.50	3.51	*	**
seta-7	30.00	1.85		**	30.00	1.85		**
seta-8	23.75	3.45	**	*	23.25	2.38	**	**
seta-9	20.75	3.53	**		24.00	0.00	**	**
seta-10	25.50	7.69	*		22.75	7.55	*	
seta-11	22.00	0.00	**	**	22.00	0.00	**	**
seta-12	27.25	5.95		**	25.00	3.70	**	**
seta-13	25.75	3.62	**	**	22.25	1.67	**	*
seta-14	30.00	0.00		**	20.00	0.00	**	
seta-15	24.75	8.34	*		23.75	8.91	*	
seta-16	24.75	5.85	*	*	27.50	2.56	*	**
seta-17	28.52	3.92		**	22.50	4.50	**	
seta-18	22.25	9.32			22.75	9.32		
seta-19	28.25	2.92		**	27.00	3.38	*	**
seta-20	25.00	9.62			16.00	0.00	**	
seta-21	34.00	0.00		**	34.00	0.00		**
seta-22	23.00	8.07	*		24.25	7.67		
seta-23	22.50	8.19	*		28.25	5.18		**
seta-24	26.50	4.87	*	**	24.00	1.07	**	**
seta-25	21.25	8.14	*		25.75	9.04		
seta-26	22.00	6.41	**		24.00	0.00	**	**
seta-27	34.00	0.00		**	23.75	0.71	**	**
seta-28	28.00	3.02		**	24.50	4.24	*	*
seta-29	24.50	3.51	**	*	26.75	3.01	**	**
seta-30	29.50	8.33		*	22.75	9.32		
seta-31	29.50	6.21		**	29.50	6.21		**
All seta	26.36		16	22	24.95		21	22

TABLE 6

Comparing Before and After Period Valuations in Block C.

Values are elicited both before and after one of the remaining cards is revealed to be red. Paired t-test and Wilcoxon signed-rank tests compare averages across subjects.

	N	Paired t	Prob	Signed rank	Prob
H_O Subject average valuations of the rem asset after the red card is revealed EQUAL their average valuations before the card is revealed. H_A Subject average valuations of the rem asset after the red card is revealed are LESS THAN their average valuations before the card is revealed.	36	0.45	0.33	7.0	0.56
H_O Subject average valuations of the seta asset after the red card is revealed EQUAL their average valuations before the card is revealed. H_A Subject average valuations of the seta asset after the red card is revealed are GREATER THAN their average valuations before the card is revealed.	31	2.03	0.03	75.5	0.03

TABLE 7
Block D Choices for Rem and Seta Subjects.
Panel A Paired t-test and Wilcoxon signed rank test compare a subject's R% in Block A (at the start of the session) to his or her R% in Block D (at the end of the session). R% is the average rate (out of eight periods) of a subject choosing the remaining card.

	N	Paired t	Prob	Wilcoxon	Prob
H_O A subject's R% in Block D EQUALS his or her R% in Block A					
H_A A subject's R% in Block D is GREATER THAN his/her R% in Block A					
rem	36	2.82	0.004	150.5	0.002
seta	31	2.23	0.017	83.0	0.011

Panel B R% is the average rate (out of eight periods) of a subject choosing the remaining card. Rem subjects value the rem asset in Blocks B and C, while seta subjects value the seta asset. The hypothesis test is performed twice, once for Block A and again for Block D. Procedures for both sessions are exactly the same until the start of the valuation tasks in Block B.

	N	Pooled t	Prob	Wilcoxon	Prob
H_O R% for a rem subject EQUALS the R% for a seta subject					
H_A R% for a rem subject IS GREATER THAN the R% for a seta subject					
Block A	rem 36 seta 31	1.41	0.255	1.32	0.188
Block D	rem 36 seta 31	1.81	0.030	1.99	0.047

D and Block A, and only 8 subjects had a lower R% in Block D than they did in Block A. Statistical tests confirming the increase in R% are shown in Table 7, Panel A.

Figure 3, Panel B plots the correspondence between Block A and Block D R% for seta subjects. The Block D R% is higher for 16 of the seta subjects, lower for 9 subjects, and constant for 6 of the seta subjects. Table 7, Panel A presents statistical tests confirming the increase in R% for seta subjects as well.

We now compare rem and seta error rates in Block D. Recall that for Block A, the null hypothesis that the R% for rem subjects equaled the R% for seta subjects could not be rejected at standard significance levels. Panel B of Table 7 tests the same null for Block D. However, in Block D the null is rejected in favor of the alternative that the R% is greater for the rem subjects. Rem subjects make the rational choice more often than seta subjects in Block D.

Finally, Block E consists of a single period of the choice task, identical to earlier choice task periods except that the payoff for correctly choosing the black card is multiplied by 10. Seventy-five percent of rem subjects and almost 65% of seta subjects chose the remaining card in Block E. The incidence of the Monty Hall error is significantly diminished by the end of the session, and the reduction is more pronounced for the subjects who valued the rem asset in[5] Blocks B and C.

SUMMARY

Subjects in our experiment learn to overcome the Monty Hall probability error, and the key learning experience appears to be practice in valuing an engineered financial asset. Before this learning experience, subjects in the Monty Hall choice task made the irrational choice (the "set-aside" card) about 50% of the time overall. After the learning experience with the rem asset, the irrational choice rate fell to 31% overall and 25% in final choices. Of the 36 subjects, 13 made the irrational choice more than half of the time before the learning experience and only 5 after. Many studies have demonstrated the amazing strength and persistence of the Monty Hall error, and we are not aware of any individual learning treatment that reduced the error rate as much as our rem valuation task.

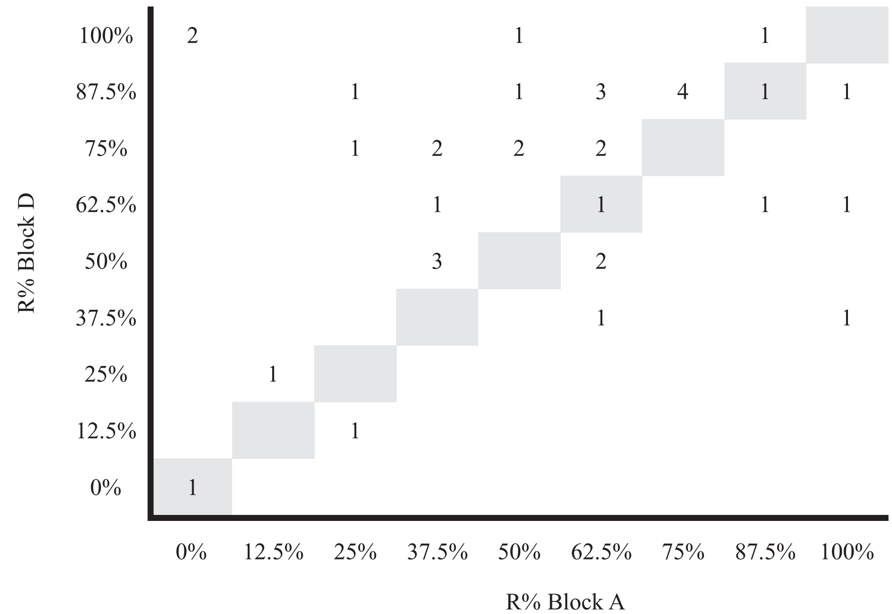
We also found that valuation of the seta asset lowered the error rate, but the reduction was not as dramatic as for the rem asset. Before the valuation task, error rates did not significantly differ from 50%, and there was no significant difference between the error rates for rem and seta subjects.After their learning experience, seta subjects' irrational choice rate fell to 42% in Block D and 38% in Block E. Of the 31 subjects, 15 made the irrational choice more than half of the time before the valuation experience and 9 did so after the learning experience. The Block D error rate for the rem subjects was lower than the error rate for the seta subjects, and the difference was statistically significant.

We conclude that appropriate financial engineering can promote learning and benefit market participants above and beyond providing a wider span of securities at lower prices. Would other financial asset designs be even more effective than the rem asset? The Kluger and Wyatt [2004] study suggests that designing a convertible asset based on the Monty Hall problem would not. Their subjects traded a convertible asset, where the conversion feature allowed selection of either the set-aside or the remaining card to pay the bearer one dollar. This more complex asset is equivalent to ours in terms of the uncertainty space spanned, and trading it helped to aggregate information. However, it did not noticeably reduce individuals' tendency to commit the Monty Hall error.

Would subjects have learned to solve the Monty Hall problem without the experience of valuing any financial asset? Our results indicate that the majority of rem subjects no longer made the Monty Hall error by the end of Block B. By

Panel A

Error rates for subjects who valued the rem asset in Blocks B and C. R% is the average rate (out of eight periods) of a subject choosing the remaining card. The number represents the number of subjects with the corresponding values for R% in Blocks A and D.



Panel B

Error rates for subjects who valued the seta asset in Blocks B and C. R% is the average rate (out of eight periods) of a subject choosing the remaining card. The number represents the number of subjects with the corresponding values for R% in Blocks A and D.

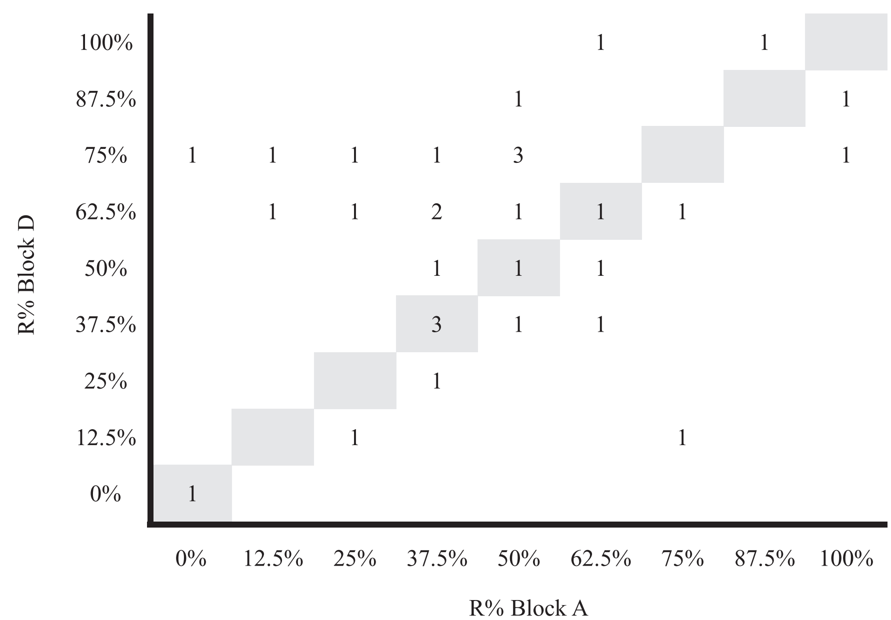


FIGURE 3 The Monty Hall error in Block A and Block D.

this point subjects had performed a total of 24 repetitions (8 repetitions of the choice task, 8 U-period valuations, and 8 R-period valuations). In Friedman [1998], most of the control group subjects made the Monty Hall error throughout 25 repetitions of the choice task. Although subjects in some of his learning treatments showed improvement, our rem valuation task seems more effective.

Although our experiment shows that a particular asset design lowers the Monty Hall error rate, it does not explain why this design is effective. Specifically, why is the rem design more effective than the seta design? We only observe subjects' choices and valuations, not their reasoning. Nonetheless, the evidence is consistent with the following explanation. While all cards are still face down, the majority of subjects probably believe that there is a one-third chance that the set-aside card is black. Subjects who are prone to the error likely believe that when the red card is revealed, there is an equal chance of either the remaining or set-aside card being black. Subjects who make this error therefore mistakenly believe that revealing the red card affects the chance that the set-aside card is black. We conjecture that designing the asset to pay based on the color of the remaining card makes it easier to see that revealing a red card has no effect on the probability. Once subjects realize this, they can correctly value the experimental asset. With the seta asset, it is more difficult to see that revealing the red card provides no information. Therefore, the seta valuation task would be less effective than the rem task in reducing the Monty Hall error rate.

This interpretation of the learning process in our experiment may also be of interest for researchers studying the mechanisms that give rise to cognitive errors. Krauss and Wang ([2003], p. 20) suggest that "a remarkable proportion of naive participants can gain full insight into the Monty Hall problem when elements from the cognitive psychologists' toolbox are applied." Our interpretation also suggests an additional element not considered by Krauss and Wang. In particular, asking subjects to value our experimental asset both before and after the red card is revealed highlights the error. Subjects may well realize that something is wrong if they think the asset value is altered when the red card is revealed. This suggests that pointing out inconsistencies generated by cognitive errors can effectively promote learning.

Although our results demonstrate that valuation tasks can reduce the Monty Hall error rate, it would be interesting to further investigate whether subjects could verbally explain the solution to the Monty Hall problem and if they could generalize their acquired skills to other probability problems. Maciejovsky and Budescu [2007] study the Wason selection task, another well-known problem in which subjects are prone to a reasoning error. After participating in a market for an asset that embeds the Wason selection task, subjects were better able to solve other versions of the problem. In Maciejovsky and Budescu's study, subjects were able to generalize learning acquired during the market. Page [1998], however, reports that subjects trained in a 100-door version of the Monty Hall problem were unable to subsequently solve the standard 3-door version. Future research could address the issue of generalization of learning acquired through valuation of Monty Hall assets.

Our results illustrate that security design can help subjects learn to avoid the Monty Hall error. Of course, the connection between financial engineering and learning may be a two-way street. If breaking down or combining assets to create new ones can promote rationality, the reverse must also be true. Recombining assets can also potentially promote irrationality.

The extent to which cognitive errors affect financial decisions and asset prices is an important question. Even though the Monty Hall anomaly is not a typical financial decision-making problem, it is a useful tool for studying cognitive errors because the Monty Hall error is common, and it is very easy to detect. Our results suggest that in at least this setting, financial engineering can help foster individual rationality. Whether or not financial engineering has a similar effect in other laboratory or field financial markets requires further study. However, it no longer seems safe to assume that financial engineering has no effect on market biases.

ACKNOWLEDGMENTS

We are grateful for financial support from NSF grant SBR-0351801, and we appreciate helpful comments from an anonymous *Journal of Behavioral Finance* reviewer, Lucy Ackert, Richard Deaves, Darren Duxbury, Andreas Ortmann, David Stolin, participants at the Federal Reserve Bank of Atlanta conference on Experimental Finance: Individuals, Firms, and Financial Institutions, and participants at the University of Siena IV Workshop LABSI on Behavioral Finance: Theory and Experimental Evidence. We also thank Todd Feldman, Carrie Kluger, James Pettit, and Tomera Ten for assistance in running experimental sessions.

NOTES

1. After the 1987 stock market crash, the government commissioned a presidential task force (the Brady Commission) to investigate causes of the crash, and to recommend measures to reduce the likelihood of future crashes. Although portfolio insurance was not the only cause of the crash, it was identified as a contributing factor (Fabozzi and Modigliani [2003], pp. 269–270). As well, the press (e.g., Anderson and Duhigg [2008]) has pointed to CDOs and other engineered mortgage derivatives as culprits in the financial market distress of 2008.

2. Friedman [1998] notes some gaps between this stylized version and the actual game show. Dan Friedman and Aadil Nakhoda's "The Learning and Experimental Economics Projects of Santa Cruz! Monty Hall Problem" Web site (http://leeps.ucsc.edu/misc/page/monty-hall-puzzle/) contains material and additional references pertaining to the Monty Hall problem.
3. Friedman [1998] points out that the Monty Hall error is an amalgam of several separate cognitive errors. Our implementation of the Monty Hall problem modifies Friedman's 1998 version eliminating some of these cognitive errors. Our experiment focuses solely on the probability judgment error associated with the Monty Hall problem, that is whether subjects believe that the probability of the remaining card being black is one half or two thirds. We use the term "Monty Hall error" throughout to mean this probability judgment error.
4. Perhaps some subjects who make the Monty Hall error in Block B realize in Block C that the U and R valuations are inconsistent but make the incorrect adjustment of decreasing the before value toward 30. Evidently other subjects resolve the inconsistency correctly, adjusting the after value toward 40.
5. In the Friedman [1998] data and some other published data, there are unexplained and puzzling tendencies for subjects to backslide toward irrationality in the last trial. Thus the 75% rationality rate for rem subjects in Block E is especially impressive.

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APPENDIX: INSTRUCTIONS FOR REM SUBJECTS

Seta instructions are identical except for the asset description and the possible prices on the valuation form.

Part 1

You are about to participate in an experiment in financial decision making. If you follow these instructions carefully and make good decisions, you may earn a considerable amount of money. Today's session will consist of three parts. Your overall earnings will be the total of your earnings in each part. At the end of the experiment, you will receive your overall earnings in cash.

This part of the experiment will consist of several separate periods. At the start of each period, three playing cards will be placed face down in random order in the 1, 2, and 3 spot on a mat. The face-down cards are ordinary playing cards. Two of the cards will be red (diamonds or hearts), and one of the cards will be black (clubs or spades). A volunteer will then choose a number: "1," "2," or "3." The number chosen will be used to designate a card as the "set-aside" card. For example, if the volunteer chooses "3" the mat would appear as shown in Figure 1:

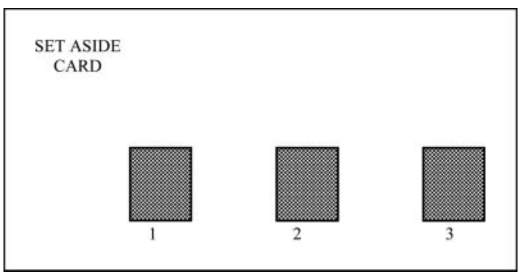


FIGURE 1

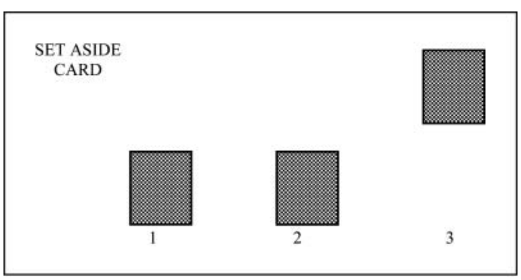


FIGURE 2

The next step will be to reveal one of the two remaining cards. We will not reveal the set-aside card. The conductor will look at the other two remaining cards and always reveal a red card. Continuing the example in Figure 2, the conductor will look at cards 1 and 2 and reveal one of them. The revealed card will always be a red card. Suppose the conductor turns over card 2 as shown in Figure 3.

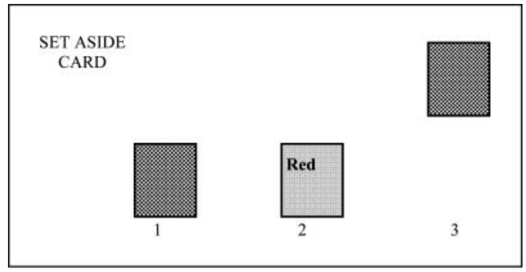


FIGURE 3

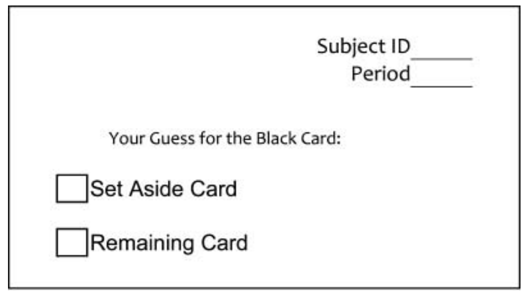


FIGURE 4

At this point, you will be asked to choose a card. Your goal will be to choose the black card. If you choose the black card, you will win 60 cents, but if you choose the red card you will not win any money this period.

Fill in the form by checking the appropriate box (see Figure 4). If you check "set aside," then you will win 60 cents if the "set-aside" card is black and nothing otherwise. If you check "remaining," then you will win 60 cents if the "set aside" card is red, and nothing otherwise. Continuing the example from Figure 3, if you choose "set aside," you will win if card 3 is black. If you choose "remaining" you will win if card 1 is black.

The conductor will then collect the forms and reveal both of the cards. If you correctly chose the black card, your winnings will be added to your earnings for this part of the experiment.

Frequently Asked Questions

Q: Is this some kind of psychology experiment with an agenda you have not told us?

A: No. It is an economics experiment. If we do anything deceptive, or do not pay you cash as described, then you can complain to the campus Human Subjects Committee and we will be in serious trouble. These instructions are on the level and our interest is in seeing how people make decisions in certain situations.

Q: Is my performance in any way linked to that of other people in the room?

A: No, this is an experiment in individual decision making. Your actions do not in any way affect the payoffs of other subjects, nor do their actions affect yours.

Q: Is it possible to lose money in this experiment? Will I have to pay you?

A: No, you cannot lose money. Each time you can correctly choose the black card, you will earn money. Conversely, each time you guess incorrectly, you will not earn any money.

Part 2

This part of the experiment will consist of several periods, and each period will have several steps. The sequence of events for a period is listed and explained below.

1. Receive new share
2. Card placement
3. Selection of the set-aside card
4. Sometimes a red card is revealed
5. Chance to sell your share
6. All cards are revealed and earnings are calculated

1. Receive New Share

You will receive one new share of an experimental asset. The share will be redeemed at the end of each period. The value of the shares will depend on whether or not the set-aside card is a black card (this will be explained further below). The share will pay 60 cents if the set-aside card is black and will pay 0 cents otherwise.

2. Card Placement

As in Part 1, three playing cards will be placed face down in random order in their position on a mat. The face-down cards are ordinary playing cards. Two of the cards will be red (diamonds or hearts), and one of the cards will be black (clubs or spades). There are three positions on the mat, labeled “1,” “2,” and “3.”

3. Selection of the Set-aside Card

Just as in Part 1, a volunteer will pick a number in order to designate a card as the “set-aside” card. The other two cards are designated as the remaining cards.

4. Sometimes a Red Card Is Revealed

In some of the periods, the conductor will look at the two remaining cards and reveal one of them. The conductor will not reveal the set-aside card and will always reveal a red card. In some of the periods, this step will be skipped; the conductor will not look at or reveal any of the remaining cards.

id ______
period ______

Circle the choices you prefer:

	Sell your share for:
Keep your share	27 cents
Keep your share	29 cents
Keep your share	31 cents
Keep your share	33 cents
Keep your share	35 cents
Keep your share	39 cents
Keep your share	41 cents
Keep your share	43 cents

FIGURE 1

5. Chance to Sell Your Share

In this step, you may make an offer to sell your share. The offer may or may not be accepted. The offer is made by filling out the form in Figure 1.

Fill out the form by circling your preferred choices. If you are willing to sell your share for 27 cents, then circle the 27 cents in the first row. If not, circle “Keep your share.” Similarly, if you are willing to sell for 29 cents, then circle 29. If not, circle “Keep your share” and so on for each row of the form. For example, if you are willing to sell your share for a price of 33 cents or higher, fill in your form as in Figure 2.

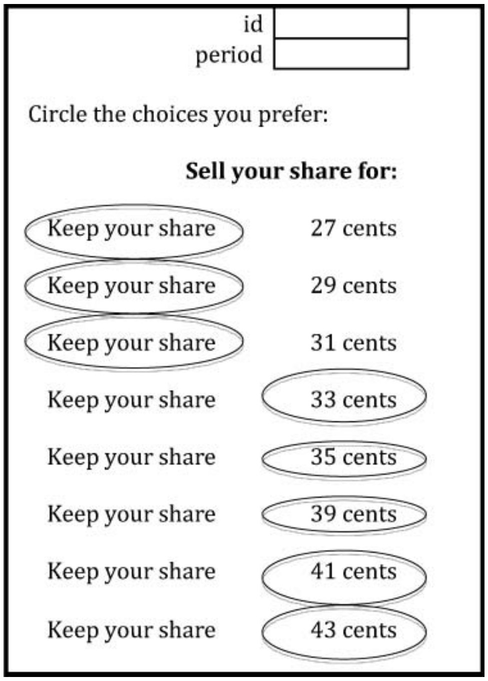
The actual price is decided by a drawing from a bingo cage containing a distribution of balls, labeled 27, 29, 31, 33, 35, 37, 39, 41, and 43. A volunteer will spin a bingo cage and randomly choose a ball. The number on the ball chosen will represent the price for this period.

Continuing the example, suppose the volunteer randomly selects a “41.” Since you circled 41, you will sell your share for 41 cents. If instead a “27” was selected, you do not sell because you circled “Keep you share” if the price is 27 cents.

6. All Cards Revealed and Earnings Calculated

The face-down cards are turned over. Each share of the asset will pay the bearer 60 cents if the set-aside card was black and pays nothing if the set-aside card is red.

If you sold your share, then your earnings for the period will simply be the sale price. For example, if you sold your share in step 5 for 41 cents, then your earnings for the period


id
period

Circle the choices you prefer:

Sell your share for:

Keep your share	27 cents
Keep your share	29 cents
Keep your share	31 cents
Keep your share	33 cents
Keep your share	35 cents
Keep your share	39 cents
Keep your share	41 cents
Keep your share	43 cents

FIGURE 2

will be 41 cents, regardless of whether or not the set-aside card is black. If you did not sell your share, then you will earn 60 cents for the period if the set-aside card is black or nothing if the set-aside card is red.

After the cards are revealed, your share is liquidated, so it does not carry over to the next period. You will receive a new share at the start of the next period. Your earnings for the period will be added to your overall earnings, and the next period will start.

Frequently Asked Questions

Q: Can I affect the share price?

A: No. Remember that the share price is determined by a drawing from a bingo cage. The price you circle will not affect which ball is drawn from the cage. The prices you circle will only affect whether or not you will sell if one of those prices are chosen.

Q: Is it ever profitable to circle "sell" at a price that is lower than the amount I think the share is worth?

A: No. Suppose your value for a share is 36 cents. If so, you should circle "keep your share" at 27, 29, 31, 33, or 35, and you should circle "sell your share" at 37, 39, 41, and 43 cents. Let us call this the original strategy. To see why this is best, consider an alternate strategy, where you make a single change. Now you select "sell your share" at 35 cents. If the price (determined by the bingo drawing is 27, 29, 31, or 33, you will keep your share regardless of whether you choose the original or the alternate strategy. Similarly, if the price is 37, 39, 41, or 43, you will sell you share regardless which strategy you choose. The only time there will be a difference is when the price is 35 cents. With the original strategy you keep the share, but with the alternate strategy you will sell. Keeping the share is better because if it is worth 36 to you, you would rather keep the share than sell it for 35 cents.

Q: Is it ever profitable to circle "keep your share" at a price that is higher than the amount I think the share is worth?

A: No. A similar example will show you why. Suppose your value for a share is 36 cents. If so, you should circle "keep your share" at 27, 29, 31, 33, or 35, and you should circle "sell your share" at 37, 39, 41, and 43 cents. Let us call this the original strategy. Now consider an alternate strategy where you now change your response to "keep your share" at 37 cents. The only time there will be a difference is when the price is 37 cents. With the original strategy you sell the share, but with the alternate strategy you will keep your share. Keeping the share is worse because if it is worth 36 to you, you would rather sell the share for 37 cents than keep it.

Part 3

Just as in the previous part, the experiment will consist of several periods, and each period will have several steps. The sequence of events for a period is modified from the sequence that you have just completed as shown below.

1. Receive new share
2. Card placement
3. Selection of the set-aside card
4. 4a Chance to sell your share
5. A red card is revealed
6. 4b Chance to sell your share
7. All cards are revealed and earnings are calculated

1. Receive New Share

You will receive one new share of an experimental asset. The shares will be redeemed at the end of each period. The value of the shares will depend on whether or not the set-aside card is a black card. As in part 2, each share you own will pay 60 cents if the set card is black, and will pay 0 otherwise.

2. Card Placement

Three playing cards will be placed face down in random order in their position on a mat. The face-down cards are ordinary playing cards. Two of the cards will be red (diamonds or hearts), and one of the cards will be black (clubs or spades). There are three positions on the mat, labeled "1," "2," and "3."

3. Selection of the Set-aside Card

A volunteer will choose a number to designate a card as the "set-aside" card. The other two cards are the designated as the remaining cards.

4a. Chance to Sell Your Share

Just as in part 1, you may now make an offer to sell your share. However, in this part of the experiment, you will make two offers to sell. The first offer is made in this step, and the second offer will be in step 4b (see below). Only one of these offers will be used to determine whether or not you sell your share. Exactly as before, the first offer is made by circling your preferred choices. The actual price will be determined in step 4b.

5. A Red Card Is Revealed

The conductor will look at the two remaining cards and reveal one of them. The conductor will not reveal the set-aside card and will always reveal a red card.

4b. Chance to Sell Your Share

In this step, you may make another offer to sell your share. Fill out a second form by circling your preferred choices.

Before the price is determined, a volunteer will roll an ordinary six-sided die. If a "1," "2," or "3" is rolled, then the first form (from step 4a) will be used, and the second form (from step 4b) will be discarded. If a "4," "5," or "6" is rolled, then the second form will be used and the first form will be discarded.

The actual price is now decided by a drawing from a bingo cage containing a distribution of balls, labeled 27, 29, 31, 33, 35, 37, 39, 41, and 43. A volunteer will spin a bingo cage and randomly choose a ball. The number on the ball chosen will represent the price for this period.

6. All Cards Revealed and Earnings Calculated

The face-down card is now turned over. Each share of the asset will pay the bearer 60 cents if the set-aside card is black and pays nothing if the set-aside card is red.

After the cards are revealed, your share is liquidated, so it does not carry over to the next period. You will receive a new share at the start of the next period. Your earnings for the period will be added to your overall earnings, and the next period will start.