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ORIGINAL PAPER

Distribution-dependent number preferences

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Abstract

There is existing evidence that many individuals have preferences regarding selection of numbers in lottery games. Lottery data indicate that the percentage of players who choose their numbers, instead of having numbers randomly assigned, varies widely by lottery game. Differences in number selection mechanisms between games and an expected return maximization motive only present for parimutuel games are both reasons that can explain the variation. Differences in the payoff distributions between lottery games could also be contributing to the observed variation, a novel proposition. An experiment is designed to control for differences in number selection mechanisms and remove the expected return maximization motive, to test for the presence of distribution-dependent number preferences. Results indicate that 40% to 50% of subjects may display such preferences. It is therefore possible that distribution-dependent number preferences contribute to the empirical variation in number selection percentages in lottery games.

Keywords: Choice over risk; illusion of control; lotteries; number preferences

JEL Codes: C91; D81; D91

1. Introduction

There is extensive existing evidence that many individuals exhibit number preferences when playing lottery games. Players tend to select meaningful numbers like birthdays, age, and postal code; situationally available numbers like the current date, jackpot draw date, and jackpot amount; numbers in sequence or arranged in spatial patterns on the board (see Wang et al., 2016 for an extensive analysis and list of numerous other studies on number preferences). Some even consult dream books, lottery 'experts,' and astrologers to aid in number selection (Clotfelter & Cook, 1991).

Number preferences are consistent with the established illusion of control phenomenon (Langer, 1975). There is an extensive experimental psychology literature demonstrating the illusion of control (Stefan & David, 2013). Within a lottery context, experimenters assessed subjects with a Desirability of Control scale (Burger & Cooper, 1979) and found that high desire for control subjects were more likely than low desire of control subjects to select their own numbers in the California lotto (Burger, 1991) and bet more money when allowed to throw the dice themselves in a dice game (Burger & Cooper, 1979). Another experiment found that participants were willing to relinquish 60% to 80% of the expected value of low-stakes gambles to maintain control (Bobadilla-Suarez et al., 2017). In an experiment in which subjects could choose winning cards themselves or delegate that task to a computer, choosing resulted in participants subjectively inflating rewards by an average of 30%, and the presence of the ability to exercise control stimulated activity in the ventral striatum (K. S. Wang & Delgado, 2019).

Several studies of choice under risk in the economics literature have struggled to identify an illusion of control effect. While 68% of subjects preferred rolling the dice themselves to determine the outcome of an investment in a low-stakes endowment experiment, only 9% were willing to relinquish 5% of their endowment to actuate that preference (Charness & Gneezy, 2010). In another study, half of subjects demonstrated a preference for control in selecting winning numbers, but only 5% believed that self-selecting increased the chances of winnings, in contradiction with an illusion of control rationalization (Li, 2011). An additional experiment finds no evidence of an illusion of control effect in a risky choice task, and the authors chalk up the divergence in the psychology and economics literatures regarding illusion of control in choice over risk to a lack of incentivization in most psychological studies (Filippin & Crosetto, 2016). A recent study attempts to bridge the gap between the psychology and economics literatures with an incentivized experiment finding some evidence of an illusion of control effect in an ambiguity task but not in a risk task (Berger & Tymula, 2022).

Whether it be due to an illusion of control or a consumption utility of gambling (Conlisk, 1993; von Neumann & Morgenstern, 1944), there are demonstrated number preferences in lotteries, both experimentally and empirically. American lottery draw[1] games provide lottery players the option to choose their own numbers. Alternatively, players can relinquish involvement in lottery resolution by opting to Quick Pick[2] (QP) and receive a random set of numbers. If many players have number preferences then a low aggregate QP percentage would be expected. If players prefer to spend less time generating entries relative to selecting numbers, there could be a high aggregate QP percentage. Preference heterogeneity would allow for essentially any QP percentage to prevail across draw games.

The motivation for this paper is the strong variation in QP percentages between draw games offered in the state of Pennsylvania.[3] There are several competing (and perhaps complementary) explanations for the variation. Games with observed higher QP percentages are also parimutuel: at least one prize is split if there are multiple winners. Since each entry has the same probability of winning, a unique set of numbers maximizes the expected return that is conditional on playing. QP could therefore approximate an expected return maximizing strategy for such games and be inconsequential for non-parimutuel games. Existing differences in number selection mechanisms between games can also explain the variation in QP percentages, since games that allow selection of numbers with replacement may be more amenable to picking personally meaningful or lucky numbers, like 777. The remaining possibility is the primary consequential difference between these games, namely the payoff distributions themselves. The lottery data does not allow for a disambiguation of this newly proposed distribution-dependent number preference rationalization from the other two explanations readily accounted for by the extant literature. There is not a clear, intuitive reason as to why such preferences should exist, so the expectation is that the QP percentage variation in the lottery data is entirely due to parimutuelity and number selection differences. However, results from a simple experimental design controlling for expected return considerations and number selection mechanisms indicate that 40% to 50% of subjects may exhibit distribution-dependent number preferences, suggesting that such preferences may be contributing to the variation in QP percentages in draw games.

[1] Draw games are lottery games in which players need a set of numbers to be eligible for game prizes. Prizes are determined by comparing the entry with the winning numbers drawn by the lottery.

[2] This is the term used in American draw games for receiving randomly generated numbers.

[3] The patterns in Pennsylvania are representative of those in other American states and not somehow unique to Pennsylvania.

Table 1. Pennsylvania Draw Games

	Sales (millions)	QP Percentage	Parimutuel Top Prize	Selection Mechanism	Odds at Top Prize
Pick 2	$1.8	4.8%	No	2 single digits	1 in 100
Pick 3	$79.9	2.4%	No	3 single digits	1 in 1,000
Pick 4	$68.2	1.4%	No	4 single digits	1 in 10,000
Pick 5	$18.2	3.5%	No	5 single digits	1 in 100,000
Treasure Hunt	$8.0	57.0%	Yes	5 from 1 – 30	1 in 142,506
Cash 5	$23.4	69.6%	Yes	5 from 1 – 43	1 in 962,598
Match 6	$44.1	74.8%	Yes	6 from 1 – 49	1 in 4,661,272
Cash 4 Life	$7.9	71.6%	Yes	5 from 1 – 60 and 1 from 1 – 4	1 in 21,846,048
Powerball	$84.5	81.5%	Yes	5 from 1 – 69 and 1 from 1 – 26	1 in 292,201,338
Mega Millions	$87.5	83.5%	Yes	5 from 1 – 70 and 1 from 1 – 25	1 in 302,575,350

Notes: Table 1 presents Sales, QP Percentage – the percent of entries that were randomly generated; Parimutuel Top Prize – if the top prize is shared if there are multiple winners; Selection Mechanism – the required number selections for an entry, and Odds at Top Prize of draw games in the state of Pennsylvania for the first calendar quarter of 2021.

2. Draw game data

Table 1 presents relevant features of draw games offered in Pennsylvania for the first calendar quarter of 2021. The Pick x games require choosing x digits from 0 to 9 with replacement. The other games require selecting several single and double-digit numbers without replacement. It is likely easier to construct personally meaningful, situationally relevant, lucky, and repeating numbers in Pick x games than in the other games. Additionally, some players apparently find it a daunting task to choose six numbers or more (Clotfelter & Cook, 1989). The low QP percentages of Pick x games relative to the other games could be explained by a number selection mechanism that is more conducive to actuating a number preference.

A second explanation for the variation in QP percentages is differences in the prize structure between games. Pick x games yield fixed prize amounts for each eligible prize tier, regardless of the number of winners. The other games are a mix of fixed and parimutuel prizes. Generally, lower tier prizes are fixed but liability is capped with a parimutuel top prize or jackpot. Such games are traditionally called 'lottos.' While QP will not impact the expected payout in Pick x games since all prizes are fixed, the potential to share prizes in lotto games provides an impetus to have as unique a set of numbers as possible. Since manual number selection tends to generate more duplicate number combinations in the aggregate (Wang et al., 2016), the ability of QP to yield a more unique number combination can improve expected returns by a few percent (Parker et al., 2022) or even double expected winnings (Cox et al., 1998). So, high QP percentages in lotto games and low QP percentages in Pick x games could also be due to a number preference that becomes dominated by expected return considerations.

The remaining third possible explanation of the variation in QP percentages is a distribution-dependent number preference. The games in Table 1 are listed in ascending odds for the top prize in each game. There is a clear positive relationship between odds and QP percentage. Admittedly, to the author's knowledge there is no existing evidence of distribution-dependent number preferences. The broader preference for control literature has a single study finding evidence of control preferences varying by payoff distribution. Subjects scoring highly on a Desirability of Control scale (Burger & Cooper, 1979) bet more money than low desire for control subjects in a dice game only when the odds of winning were most favorable (Wolfgang et al., 1984). This implies a distribution-dependent number preference difference between high and low desire for control subjects, identified by the difference

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in betting observed only at the favorable odds. Their experiment was conducted on a small sample of male undergraduates at a limited odds range of 6:1 to 18:1.

Assessing QP variation using the aggregate data assumes that players are not sorting into games by number preferences. For example, players with strong number preferences may play Pick x games for perhaps unobservable reasons, whereas players without number preferences or conditional expected return maximizers may play lotto games.[4] Lower income players tend towards games with lower expected payouts and are more likely to choose their own numbers (Parker et al., 2022). Demonstrating QP variation between games at the individual level would alleviate selection concerns.

Pennsylvania maintains lottery purchase data at the transaction level, so each lottery product purchased within a single transaction can be seen and grouped at the individual level. Compiling this data over a long period can become prohibitively costly very fast, so the transaction level data assessed are statewide purchases on March 31, 2021. There are 34,184 transactions of at least one Pick x purchase and at least one lotto purchase. Of these transactions, 16,277 display manual selection for Pick x and QP for lottos, which is the pattern consistent with the variation at the aggregate level. Just 67 transactions display the opposite trend of QP for Pick x and manual selection for lottos. 9,922 manually select across Pick x and lottos, and 646 consistently QP.[5] Since nearly half the transactions display the QP pattern observed at the aggregate level, it is unlikely that the aggregate patterns are purely resulting from player sorting.

3. Experiment I[6]

The lottery data shows that QP percentage varies strongly by game. It does not reveal which feature(s) of the game are responsible for the variation. The parimutuel prize nature of lottos justifies QP for lottos through a conditional expected return maximization motive. The more conducive number selection mechanism of Pick x games to number preferences could rationalize a lower QP percentage for Pick x games. It could also be that something about the payoff distributions is driving QP percentage variation. Pick x games offer lower prizes, have higher probabilities of winning, and are much less skewed than lottos. Experiment I is designed with the intent to neutralize the expected return motivation by eliminating parimutuelity and controlling for number selection mechanisms by requiring selection of several digits from 0 to 9 with replacement, at odds representative of typical lottery games. This should allow for identifying any possible distribution-dependent number preferences.

Experiment I was conducted during the spring of 2021 on Amazon Mechanical Turk (mTurk), an online workplace that has seen increased usage by experimentalists in recent years. Several classical experimental economics results have been replicated on mTurk (Horton et al., 2011). Experiment I presents subjects with two choices to make, one more closely resembling a Pick x distribution and the other more akin to a lotto's. The within-subject design was chosen to account for unobserved differences between subjects that could possibly be driving any observed effects. For each choice, subjects could choose their preference or state their indifference. Experiment I was incentivized, so subjects opting for indifference would be randomly assigned to one of the two options to play out. The Appendix provides screenshots of Experiment I. The choices are presented below.

[4] Lotto games in which the jackpot gets unusually large will tend to have the best expected return of any lottery product.

[5] $16{,}277 + 9{,}922 + 646 + 67 = 26{,}912 < 34{,}184$. So, over 7,000 transactions either QP and manual pick between Pick x games or QP and manual pick between lottos. This could be due to user error, randomization between QP and manual pick due to indifference, or a transaction consisting of an individual purchasing plays on behalf of multiple individuals with differing QP preferences.

[6] The study was approved by the IRB of the University of Maryland. Four hundred subjects were requested to participate over two sessions capped at 200 participants each. One session presented Option 1 as manual selection, and the other session presented it as the QP option to account for order effects. Responses for subjects who participated in both sessions were excluded from the reported results, along with subjects who did not follow all the directions, yielding 355 subject responses reported. The subject pool was restricted to those located in the United States.

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Table 2. Experiment I Results

		High Skew			
		Manual	Indifferent	QP	Total
Low Skew	Manual	78	18	55	**151**
	Indifferent	9	51	21	**81**
	QP	30	11	82	**123**
	Total	**117**	**80**	**158**	**355**

Notes: Table 2 reports the results of Experiment I by tabulating the number of subjects that chose their own numbers (Manual), opted for random numbers (QP), or indicated Indifference across the two choices. Selections on the diagonal are shaded in Red highlighting consistency as the most frequent response, above the diagonal in Orange as intermediary frequency, and below the diagonal in Yellow as the lowest frequency.

Choice 1:

Low Skew**Option 1.** Letting a computer randomly pick a number between 0 and 999 two separate times. If it picks the same number each time you receive \$10 (Ten dollars); otherwise, you receive \$0.
Option 2. Picking any number you want from 0 to 999 and then letting a computer randomly pick a number from 0 to 999. If the numbers match, you win \$10 (Ten dollars); otherwise you receive \$0.

Choice 2:

High Skew **Option 1.** Letting a computer randomly pick a number between 0 and 999,999 two separate times. If it picks the same number each time you receive \$100 (One hundred dollars); otherwise, you receive \$0.
Option 2. Picking any number you want from 0 to 999,999 and then letting a computer randomly pick a number from 0 to 999,999. If the numbers match, you win \$100 (One hundred dollars); otherwise you receive \$0.

Prizes are not parimutuel, so there is no expected return motive to QP. Notice that the number selection mechanism of **Low Skew** is equivalent to that of Pick 3, choosing three digits from 0 to 9 with replacement. Individuals with a preference for selecting meaningful, lucky, or repeating numbers should be able to do so in **Low Skew. High Skew** would allow for an even larger set of meaningful, lucky, or repeating numbers that subsumes that of **Low Skew**, since the sequence chosen in **Low Skew** could be repeated, or preceded or followed by 000. **High Skew** therefore is effectively a Pick 6 game. The results are presented in Table 2.

Notice that number preferences independent of the payoff distribution means making the same selection in both choices, implying a diagonal matrix. However, only 60% of subjects choose consistently across choice problems (highlighted in Red in Table 2): 14% act in accord with the consequential prediction of consistent indifference, 22% of subjects manually selected consistently, and 23% chose QP consistently. Since there is no explicit Indifference option in American draw games, the experimental QP percentage will be calculated by excluding the Indifference responses and only using strict preference responses. In the **Low Skew** choice, the QP percentage is 45%, whereas it is 58% for the **High Skew** choice. Notice that the QP percentage trend is in line with that of the Pennsylvania lottery games, with a higher QP percentage observed at higher skew. However, the 13% difference is much smaller than the differences in excess of 50% observed in games that further vary by parimutuelity and number selection as listed in Table 1. This is reasonable since the expected return motive and number selection differences are likely (and really should be) contributing to the QP percentage spread observed in the draw games.

One way to assess significance is to see if responses are consistent between **Low Skew** and **High Skew** with some error rate. Essentially, an approximately symmetric matrix in Table 2 (or at least

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one with a similar amount of responses on both sides of the diagonal) could be interpreted as evidence against distribution-dependent number preferences, in which a majority selects consistently between choice problems while the minority would have done so but made some errors (failure to understand the task, input error, etc.). This sets the significance threshold higher than just seeing what percentage of responses are off-diagonal by further requiring sufficient asymmetry. Some 144 subjects made off-diagonal selections, 50 of these below the diagonal (highlighted in Yellow in Table 2), and 94 above (highlighted in Orange in Table 2). Using the binomial test, the probability of 94 or more subjects of 144 lying on either side of the diagonal is $p < .0004$. This suggests that the experimental results are not enough to conclusively reject the existence of distribution-dependent number preferences.

Given that the number selection set of **High Skew** subsumes that of **Low Skew, High Skew** is perhaps more conducive to the selection of meaningful, lucky, or repeating numbers. Absent distribution-dependent number preferences, **High Skew** could have been expected to demonstrate a lower QP percentage because of its more amenable number selection mechanism. However, the results run contrary to the expanded choice set increasing the appeal of manual selection under **High Skew**, which constitutes additional evidence of the existence of distribution-dependent number preferences in light of the results.

4. Experiment II[7]

A second, separate experiment was conducted on mTurk to serve as a robustness check, testing whether distribution-dependent number preferences are a construct of lottery-type games or if they are generalizable to other types of payoff distributions. **High Skew** in Experiment I also did not offer a high enough payoff to justify the lengthened odds that real-world lottos do.[8] Experiment II unequivocally controls for the number selection mechanism by requiring subjects to select a single digit from 0-9 for both choices. Experiment I required selecting three single digits with replacement in the **Low Skew** choice and six single digits with replacement in the **High Skew** choice. The Appendix provides screenshots of Experiment II. The choices are given below.

Choice 1:

Low Probability **Option 1.** Picking a number from 0 to 9 and then letting a computer randomly pick a number from 0 to 9. If the numbers match, you win \$10; otherwise you receive \$0.
Option 2. Letting a computer randomly pick a number between 0 and 9 two separate times. If it picks the same number each time you receive \$10; otherwise you receive \$0.

Choice 2:

High Probability **Option 1.** Picking a number from 0 to 9 and then letting a computer randomly pick a number from 0 to 9. If the numbers do NOT match, you win \$10; otherwise you receive \$0.

[7]The study was approved by the IRB of the University of Maryland. Four hundred subjects were requested to participate over two sessions capped at 200 participants each. One session presented Option 1 as manual selection and the other session presented it as the QP option to account for order effects. Responses for subjects who participated in both sessions were excluded from the reported results, along with subjects who did not follow all the directions, yielding 368 subject responses reported. The subject pool was restricted to those located in the United States. Unlike Experiment I, Experiment II was unincentivized and subjects did not play out their chosen option.

[8]There is a difference of one-hundred-fold in expected payoff between the choices that is not typical of the expected payoff relationship between real-world lottery games. Equating the expected payoffs between **Low Skew** and **High Skew** would have meant offering a \$10,000 payment for a match in **High Skew**. As unlikely as a match would have been, experimental funding would not have been sufficient to cover that high of a payoff.

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Table 3. Experiment II Results

		High Probability			
		Manual	Indifferent	QP	Total
Low Probability	Manual	82	24	89	**195**
	Indifferent	18	75	23	**116**
	QP	26	7	24	**57**
	Total	**126**	**106**	**136**	**368**

Notes: Table 3 reports the results of Experiment I by tabulating the number of subjects that chose their own numbers (Manual), opted for random numbers (QP), or indicated Indifference across the two choices. Selections on the diagonal are shaded in Red highlighting consistency as the most frequent response, above the diagonal in Orange as intermediary frequency, and below the diagonal in Yellow as the lowest frequency.

Option 2. Letting a computer randomly pick a number between 0 and 9 two separate times. If it does NOT pick the same number each time you receive \$10; otherwise you receive \$0.

It is possible that the distribution-dependent number preferences being picked up in Experiment I are due to spillover effects of a social norm. For example, if players QP in actual lottery games, perhaps due to parimutuelity concerns, then even if parimutuelity is removed, the strength of the QP preference could still lead to QP because of the pre-existing behavior and not distribution-dependent number preferences.[9] Essentially, Experiment I may not be sufficiently different from actual lottery games to disqualify norm persistence as a rationalization of the Experiment I results. In Experiment II, the **Low Probability** choice offers a 10% chance of receiving \$10, and the **High Probability** choice offers a 90% chance of receiving \$10. Experiment II should be much less susceptible to any possible norm persistence. The results of Experiment II are presented in Table 3.

It is interesting to note that the most common choice pattern was to manually select for **Low Probability** and to QP for **High Probability**. QP percentage is once again calculated for each choice by excluding indifference responses. **Low Probability** reports a QP percentage of 23%, whereas the QP percentage is 51% for **High Probability**. Once again, a binomial test can assess significance of the results. Fifty-one observations are below the diagonal (highlighted in Yellow in Table 3), and 136 are above the diagonal (highlighted in Orange in Table 3). The asymmetry is starker than in Experiment I, with a lotto-level p-value of $p < .00000001$. Taken in conjunction with the first experimental results, distribution-dependent number preferences do not seem to be simply monotonic with distribution features like probabilities, skewness, or expected payoff. **High Skew** and **High Probability** yielded the minimum and maximum values for probability, skewness, and expected payoff, yet they reported the two highest QP percentages of the four choices across the two experiments.

5. Discussion and conclusion

Empirical evidence from Pennsylvania indicates that the percentage of lottery players who select their own winning numbers varies widely by game. Games with low and high QP percentages differ not only in payoff distributions, but also have different number selection mechanisms, and the parimutuel nature of some games makes QP an expected return maximization strategy. An experimental design controlling for parimutuelity and number selection mechanisms suggests that 40% to 50% of subjects make choices consistent with distribution-dependent number preferences. The results suggest that the observed wide variations in QP percentages in lottery games are not solely due to parimutuelity or number selection mechanism differences, but also to the existence of distribution-dependent number

[9] I would like to thank an anonymous referee for making this point.

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preferences among some subset of lottery players. Unfortunately, it is merely speculative to say what portion of the empirical QP variation is due to each of the three motives.

The experimental results indicative of distribution-dependent number preference are surprising, given there is not a clear rationale justifying them or an existing literature documenting them, unlike parimutuelity and number preferences. The experiments did not allow for determining if the odds, payoff, expected value, or other distributional factors are driving the apparent distribution-dependent number preferences displayed by nearly half the subjects. More comprehensive experimentation could appropriately identify what distributional features or psychological underpinnings are responsible for such preferences. Additional studies could also determine the economic strength of such preferences by assessing how much in payoff or expected return subjects would be willing to relinquish to exact their preference. Research can also be conducted to see if the distribution effects are unique to number selection mechanisms or if they extend to other risk resolution mechanisms like drawing cards, rolling die, and so on. Such research can contribute to the understanding of control and delegation decisions in choices involving risk.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/esa.2025.10026

Data availability statement. The replication material for the study is available at https://doi.org/10.7910/DVN/7YDGTM.

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