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The impact of pressure on performance: Evidence from the PGA TOUR

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ABSTRACT

Do large rewards lead to psychological pressure causing underperformance? Previous studies have tested this 'choking' phenomenon using the world of sports, but such studies often lack an explicit link between performance and reward. This study utilizes a large PGA TOUR dataset to more directly analyze the effect of pressure on individual performance by calculating the potential change in earnings from making or missing a putt on the final hole of a tournament. We find that as the amount of money riding on a shot increases, the likelihood that shot is made is significantly reduced.

1. Introduction

When the result of an activity matters most, psychological pressure may adversely affect performance. This can be the case whether an individual is interviewing for a job, making a sale to receive a commission, or sinking a putt on the final hole of a golf tournament to earn a huge check. These situations have enormous rewards designed to elicit maximum effort (Ehrenberg and Bognanno, 1990; Lazear, 2000). However, these large rewards also create a great deal of pressure, potentially leading to underperformance, a phenomenon that is informally known as 'choking'.

While choking occurs in many settings from business to sports, it is a very difficult effect to measure. Psychologists and kinesiologists have studied choking for several decades. Baumeister (1984) and Baumeister and Steinhilber (1984) were among the first to study choking using athletic performance. Recent studies have examined free throw shooting in basketball (Dandy et al., 2001; Otten, 2009; Worthy et al., 2009) and different aspects of golf performance (Clark, 2002a, 2002b, 2007; Hill et al., 2010; Wells and Skowronski, 2012; Wright et al., 1991).[1] In general, the conclusions of these studies have been mixed, with some finding evidence of choking and others finding no significant effect.

In the past few years, behavioral economists have also begun to study choking, mostly by way of experiments (Ariely et al., 2009) or sports (Apesteguia and Palacios-Huerta, 2010; Cao et al., 2011; Dohmen, 2008). While experiments allow one to control for outside factors and isolate the choking phenomenon, the results may not always be applicable to real-world situations. Sports are often studied as they can offer a wealth of data on actual market participants who repeatedly perform identical tasks under varying degrees of pressure. For example, several recent studies examine performance under pressure

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[1] A psychological review of 'choking' in sports can be found in Beilock and Gray (2007) and Hill et al. (2013).

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using penalty kicks in soccer or shootouts in hockey (Jordet et al., 2007; Kocher et al., 2012; Kolev et al., 2015), while others focus on individual sports such as weightlifting (Genakos and Pagliero, 2012) and tennis (Gonzáles-Díaz et al., 2012).

In this article, we explore the impact of pressure on performance by focusing on PGA TOUR putting from the last hole of a golf tournament. Putting on the final hole of a tournament is our focus because this is the point that allows us to specifically quantify the level of pressure a player faces. In this moment, the make or miss of a putt has a final impact on a player's finish position in the tournament, and his subsequent monetary reward. As the monetary reward for a made or missed putt varies, it creates varying degrees of pressure on each player. Larger rewards equate to facing larger amounts of pressure, and an opportunity to study choking arises by relating the outcome of a player's shot with the size of the monetary reward involved, while controlling for other factors relevant to the shot. This does not mean to imply that players do not face pressure at other points in the tournament, and focusing on the final hole does mean ignoring a great deal of additional data that are available. However, it is much less clear how to associate a particular value for the amount of pressure a player faces with each shot at each stage of the tournament. The abundance of the data available does, fortunately, mean that our focus on the last hole of the final round still allows for a relatively large sample size.

This paper fills an important gap in the literature by directly connecting pressure and monetary reward to performance. To our knowledge, no previous study has examined this relationship directly, with the exception of Ariely et al. (2009), which utilized an experimental setting. The fact that our study involves highly trained athletes who deal with pressure on a regular basis may provide results that are more indicative of how pressure affects performance than those that are derived from an experiment.[2]

The connection of pressure and monetary reward is an important and significant advancement over previous sports-related studies on choking.[3] Most previous studies simply define a single situation as pressure-packed and compare performance in this situation to performance outside of this situation. For example, Cao et al. (2011) examine free throw performance in the NBA. Generally speaking, they define a pressure situation as one in which there is less than a two-point difference between the teams and less than one minute left in the game. While there is no argument that these situations present players with a great deal of pressure, the make or miss of a free throw is not directly tied to a player's earnings or reward, rather, it impacts the team's points and opportunity to win the game. Also, a free throw with less than a minute to play does not have a final impact on the outcome of the game, in almost all cases there will be time left in the game after the free throw attempt. Furthermore, studies performed in this way allow for little variation in the "pressure" variable. Indeed, there are often only two cases examined: a situation with pressure and a situation without. Our ability to link a specific monetary value to an individual's performance allows one to more clearly identify the relationship.

There have been a few previous studies that examine the phenomenon of choking in the sport of golf, specifically. However, these studies tend to suffer from the same limitations as the previous free throw example. These studies also typically define a certain situation as pressure-packed. For example, comparing the performance of a player in the 4th (final) round of a tournament (or the 4th round within a certain number of shots from the lead) with performance in a lower pressure situation, such as the 3rd round (or the 4th round with no chance to win the golf tournament) (Clark, 2002a, 2002b, 2007; Wells and Skowronski, 2012).

In addition to the issues in quantifying the amount of pressure, studies of golf commonly use the score from an entire round to measure performance. Aggregating performance over a large number of shots introduces a significant level of noise when measuring the relationship of interest. For example, Balsdon (2013) has suggested that it is optimal for players to take on riskier strategies in the final round in an attempt to claim larger prizes near the top. If this is the case, then it may be this riskier strategy that results in a higher score, rather than the pressure of the final round. Also, the pressure level may be quite different over a final round. The start of the round may have little to no pressure for those not leading the tournament, while the last few holes may be the time when a disproportionately large amount of pressure is perceived by a relatively large number of players. Such an aggregated measure of performance is susceptible to many other factors of influence besides pressure. It is for this reason we narrow the focus of our study to the last shot (or shots) on the final hole of a tournament.

In order to evaluate the impact of pressure on performance, we use PGA TOUR ShotLink Data from 2004 to 2012[4] that records the exact location of players' golf balls before and after each shot, down to the inch. The ShotLink Data, combined with tournament earnings data, allow us to create a unique dataset of putting on the last hole of a tournament which contains information on the shot, the player taking it, and the tournament in which it is taken. The results of our analysis provide evidence that pressure can indeed lead to significantly reduced performance in a real-world setting. We also find that less experienced players tend to be more affected by pressure than their more experienced counterparts, that recent success in

[2] Genakos and Pagliero (2012) examine the impact of interim rank in a weightlifting competition on the probability of a successful lift. Controlling for weight (the difficulty of the task), they find that higher ranked competitors, those arguably under more psychological pressure than lower ranked competitors, are less likely to complete a successful lift. Their study is similar in thought to ours, but instead of using monetary reward as a measure of pressure, they use rank in a tournament.

[3] In a recent study, Deutscher et al. (2013) links clutch performance by NBA players to increased earnings. While this is an after-the-fact reward in a team game, it does link performance to reward in an indirect manner.

[4] Sponsored by CDW. There are several other studies which have used ShotLink data. Brief summaries of the papers can be found at http://www.pgatour.com/stats/academicdata/institutions.html. One of the most notable contributions is the Pope and Schweitzer (2011) study of loss aversion.

putting may mitigate the effects of pressure, and that the difficulty of the shot (based on distance) factors into the magnitude of the impact caused by high stakes.

2. Data and descriptive statistics

The data used in this study come from the PGA TOUR. In creating the dataset, we combined information on individual shots taken by players (from the ShotLink Data series) with information on player attributes, monetary distributions, and other variables. While ShotLink Data are available beginning in 2002, our sample begins with the tournaments played in 2004 due to the lack of certain variables in prior years. We first collected information on all shots taken for the years 2004–2012. As the focus of our study is putting performance under pressure, we next restricted the sample to putts taken on the 18th hole in the final round of each tournament played over this time period. We then paired the data for each remaining observed putt with information on the player taking the shot, as well as information on the tournament itself. Finally, we focus on tournaments in which all players start on the first hole of the course and finish on the 18th. In many tournaments, some groups of players begin the round on the 10th hole, and finish on the 9th. We eliminate these tournaments from the sample so that we can more clearly identify the impact of pressure by controlling for hole-specific characteristics. Despite this seemingly restrictive sample selection, after dropping observations for which some or all of the variables included in our analysis were missing, we are left with a sample of 23,596 putts. The dataset contains information on a total of 568 unique players and 210 unique tournaments.

After compiling the data, we next created the key variable in our analysis, the value of a putt. Our goal is to determine the amount of money that a player stands to gain (or lose) by making (or missing) a given putt. By doing so, we can use this value as a measure of the amount of pressure facing an individual on a particular shot.[5] The idea behind the creation of this variable is relatively straightforward. The dataset contains only the putts taken by players on the final hole in the final round of the tournament. If, for example, a player is observed taking a putt that is his 280th stroke of the tournament, we calculate the difference in what this player would earn if he makes this putt and finishes the tournament with an overall score of 280, and what he would earn if he misses. Here we assume that, if he misses, the player will make the following shot and finish with a score of 281.[6] We can then use the results of the tournament to determine what position the player would finish the event in, and how much money he would earn, with each score. The difference in these two monetary amounts is considered the value of the putt.

While the idea behind creating the value of the putt variable is simple, there are a few technical issues worth discussing further. First, in order to determine the amount of money earned in each potential finish position, it is necessary to consider the payout structure of each tournament. Luckily, the PGA TOUR uses the same payout structure for nearly all of its tournaments. This means that if you observe the amount of money earned by the tournament winner, you can use this figure to determine the exact payout amount for each finish position in the tournament.

The second, related issue, to deal with is that of ties in the final score. For any position other than first place, the practice of the PGA TOUR is to split the earnings of each position involved in the tie. For example, a two-way tie for second place would mean the individuals split the sum of the second and third place prize money, a three-way tie for second would mean the individuals split second, third, and fourth prizes evenly, and so on. The main point here is that if a player makes a putt and finishes the tournament in second place, assigning a value to this putt is not as simple as calculating the difference between second and third place earnings. It is essential that we also consider the final scores of others in the tournament, and adjust the values accordingly. In order to do this we take the final scores of the other players in the tournament as given when calculating the value of putt for each individual. It is also worth noting that it is possible for the value of a putt to be $0, in the event that a player finishes several strokes ahead of and/or behind the closest competitors.

A third technical issue involves the timing of shots. The data we observe indicates the final score for each player in the tournament, but does not indicate the position of a particular player, or those near him in scoring, at the time a shot is taken. This opens up the possibility for measurement error in the calculation of this key variable. In order to investigate the level of this potential error, we further examined a much smaller sample of putts, those from the final group of players in the 2012 tournaments.[7] This sample is relevant because the entire field is finished (and their scores set) with only two or three players remaining. Using this small sample, we used the timing of shots to create a more accurate calculation of the value a shot holds at the time it is taken. In many cases, this involved creating an expectation for how the other remaining player(s)

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[5] While the dollar value of a putt estimates a value for pressure, it also has its limitations. The result of a tournament may have other outcomes of interest beyond the prize money. These may include earning sponsorships or exemptions into prestigious events, as well as other non-monetary factors such as concern over one's reputation and legacy. Our calculated value is most likely a lower bound for the amount of overall pressure a player faces. These other sources of pressure are likely to vary in a similar manner as the monetary reward with respect to a player's position in the tournament. As a result our value of monetary pressure is a reasonable proxy for the overall amount of pressure on a given shot.

[6] This assumption is made for simplicity, but also reflects the nature of the dataset. More than 94% of the putts observed in the dataset are either the first or second for that particular player.

[7] In addition to checking the calculation of value for this smaller sample, we ran a robustness check of our base empirical model (described in the next section of the paper) in which we focused on the last 25% of putts, based on the time the shot is taken, for each tournament in our dataset. The idea is that this group can likely be more accurate in estimating the value of the putt, given the additional information on the final position of other players. The impact of pressure on performance did not differ significantly from our results for the entire sample.

Table 1
Descriptive statistics.

	Mean	Standard deviation	Minimum	Maximum
Putt made	60.71%	0.49	0	1
Value of putt (tens of thousands of dollars)	1.89	4.38	0	68.40
Distance to pin (feet)	11.78	14.69	0	108.83
Player age	35.48	6.63	18.03	64.38
Money earned in previous year (millions of dollars)	1.22	1.24	0	10.91
Money earned in career (millions of dollars)	7.83	9.57	0	94.82
Total putts gained	0.92	3.35	−14.45	13.84
Uphill	51.00%	0.50	0	1
Number of putts observed	23,596			
Number of players	568			
Number of tournaments	210			
Number of courses	50			
Years	2004–2012			

will perform.[8] In the end, our simple calculation used on the entire sample produced the exact same estimate for value as our detailed method for 118 of the 148 shots in the 2012 final group sample. Overall, the average value for these shots from our detailed method was $96,724, and from our simple method was $96,363, a difference of less than one half of one percent.

As this variable leads to the key contributions of this study, it is worthwhile to work through a recent anecdotal example illustrating how it is constructed. During the 2014 Waste Management Phoenix Open, Bubba Watson lined up for a putt on the final hole from a little over 5 feet away. Making the shot would move Watson into a tie for first place with Kevin Stadler. A tie for first place is unique in that the players involved proceed to a playoff, rather than splitting the prize earnings as is done with ties in other finish positions. However, in our hypothetical valuation of the putt, we assume a playoff between two players would give each a 50% chance of winning and a 50% chance of coming in second. The relevant prizes for this tournament were: $1,116,000 for first place, $669,600 for second place, and $421,600 for third place. Thus, if Watson were to make the putt, we calculate his expected earnings to be $892,800. If Watson were to miss the putt, he would end in a tie for second place with Graham DeLaet. This would mean Watson and DeLaet would split the second and third place prices, and each earn $545,600. According to our methodology, the value of Watson's roughly 5 foot putt on the final hole is the difference in earnings between making and missing the putt, which in this case would be $347,200. Given the fact that 76.8% of the putts in our sample between 5 and 5.5 feet were made, and that Watson's putting in the tournament to that point had been excellent (13th in the field, according to the strokes gained putting statistic), perhaps it was the pressure from this large difference in monetary reward that led Watson to miss the putt.

As one can tell from the discussion and example, the value assigned to a particular putt often ends up being a complex calculation. As such, we are not assuming that each player is calculating this figure in his head before he lines up to take a putt. However, we do assume that a given player is familiar with the level of prizes for a tournament, the general prize structure, and his position and score relative to those in his vicinity on the leaderboard. We interpret this variable as estimating the amount of pressure associated with a particular shot, and assume a player will know which shots have more at stake (and act accordingly), whether or not they have calculated the exact dollar amount. Anecdotal evidence suggests this is the case as well. When asked about putting on the final hole of the 2014 Valspar Championship, John Senden said, "I don't want to leave myself something to make because it is difficult (commenting on his first putt and its impact on the length of his second putt). The biggest challenge is to hit putts or shots out there and try not to think what they're worth." (Rand, 2014). This statement indicates players are aware of the relative value of a putt, no matter how hard they may try to ignore it. If players focus on the dollar amount, it may diminish their ability to complete the task at hand (i.e. lead to choking).[9]

Table 1 presents the summary statistics for the value of the putt, as well as the other variables included in the analysis to follow. The mean for the value of the putt is slightly under $19,000, but there is a great deal of variation in this factor. The maximum value of $684,000 is observed for a shot by Heath Slocum in the 2009 Barclay's, a tournament Slocum won by one stroke. The statistics for the other variables are presented to provide further insight into the nature of the dataset. The discrete variable of whether or not a putt is made is the dependent variable in our empirical analysis, and so the other variables are largely factors that are likely to determine the probability of this occurring. The amount of money earned in the previous year (or over a career), for example, is meant to account for factors such as the experience and ability of the player. The variable "total putts gained" is a statistic calculated by the PGA TOUR to indicate how well a particular player is putting in that specific tournament. This is a cumulative measure for the tournament overall, with negative values indicating poor

[8] For example, suppose Phil Mickelson is attempting a 20 foot putt for birdie on the final hole. The value of this putt may depend not only on whether Mickelson makes this shot, but also on the outcome of the subsequent 12 foot putt from Tiger Woods, whom Mickelson is currently tied with. While calculating the value of Mickelson's shot, we would assume a probability that Woods makes his putt given the average make percentage from our sample at that distance.

[9] DeCaro et al. (2011) refers to this as outcome pressure. A player is distracted away from the task (making the putt) by thinking about the situation and its consequences.

Table 2
Percentage of putts made by value of putt.

Value of putt	Observations	Made (%)
0 to $999	6941	65.06
$1000 to $9999	7181	61.98
$10,000 to $24,999	4895	57.36
$25,000 to $49,999	2993	56.87
$50,000 to $99,999	792	53.41
$100,000 or more	794	53.53
All values	23,596	60.71

putting, and positive indicating strong putting. The putts gained measure is a result of research from Broadie (2008), and has been shown to be an excellent measure of putting ability (Fearing et al., 2011). The "uphill" variable is a dummy equal to one when a player putts from an elevation below the cup, and equal to zero otherwise. The elevation change may factor into the probability that a particular putt is made by allowing a player putting uphill to better control the speed of the ball, for example.

Before estimating with more rigorous empirical methods, we first examine the simple relationship between the pressure an individual faces on a shot and the outcome of that shot. Table 2 presents the probability a putt is made by different levels of the value of the putt variable. The statistics in the table provide some preliminary evidence that player performance is significantly impacted by the amount of pressure. As the monetary value of the putt increases, the likelihood that the putt is made decreases. It is interesting to note that shots with extremely high values ($100,000 and more) actually have a slightly greater probability of being made than those in the next lower range of values. One plausible explanation for this is that the players facing this massive amount of pressure are at the top of the leaderboard, and so may be the best players (and/or putters) with the most experience in pressure situations. It might also be the case that other factors, such as the distance of the putt, are not exactly the same in each of the range of values, which might complicate the relationship. While the findings in Table 2 support the notion that monetary pressure may be causing some players to underperform, in order to more clearly identify the relationship, we proceed to a more formal analysis.

3. Empirical methodology

The goal of our analysis is to isolate the impact of the level of pressure faced by a player, as measured by the monetary value of a putt, on the likelihood that the player makes a putt. In order to accomplish this, we utilize a linear probability model where the dependent variable is whether or not the putt is made.[10] We include a number of control variables, as well as fixed effects, in order to identify the key relationship as cleanly as possible. In addition, we examine a number of alternative specifications in an attempt to test the robustness of the findings in our primary model. Our primary specification of the model is represented by the following equation:

$$\text{Made}_{s,i,j,t} = \beta_0 + \beta_1 \text{Value}_{s,i,j,t} + \gamma \text{X}_{s,i,j,t} + \varphi \text{Z}_{i,j,t} + \alpha_i + \lambda_t + \delta_j + \varepsilon_{s,i,j,t} \tag{1}$$

The dependent variable (Made) is equal to 1 if shot s, taken by player i, playing on course j, during year t, is made, and 0 if not. The key variable in our analysis is the monetary value of the putt (Value). In order for the magnitudes of the coefficients to be more easily interpreted, we scale this variable by tens of thousands of dollars. The X in the equation represents a matrix of shot-level characteristics. These include the distance of the putt, as well as the dummy variable for whether or not the putt is uphill. Distance is an important factor in whether or not a putt is made, and the effect is nonlinear. We follow Pope and Schweitzer (2011) in using a seventh-order polynomial distance model.[11]

The Z matrix represents our set of player-specific attributes that might affect the probability that a putt is made. The first one is the age of the player, which might be related to the likelihood of making a shot for a number of reasons. On the one hand, age is related to a player's experience, and so it may positively influence the likelihood of making a putt.[12] This might be especially true given the fact that we are only observing putting on the final hole of the final round. It is possible that the putting of younger players might be more influenced by nerves then those who are more familiar with that environment. An older player, all else equal, might also be more likely to have played in a particular tournament in past years, and thus might have an advantage in knowledge of a particular course. On the other hand, it is possible that the younger players 'have no fear' and do not fully comprehend the enormous pressure and difficulty of the task. As a result, they may be immune to

[10] We use the linear probability model in order to allow for the inclusion of the various fixed effects used in our different specifications, as well as for ease of interpretation. The use of the linear probability model is also consistent with other similar analysis such as Pope and Schweitzer (2011). The results are of similar significance when utilizing a Logit model specification without fixed effects, as shown later in the paper.

[11] We attempted various other models of distance, such as the fourth-order polynomial plus logged distance used in Fearing et al. (2011). In each case, the significance of the value variable is unchanged.

[12] As experience was one of the main factors we are controlling for here, we tried including a number of different measures, such as the number of events a player had played in over his career, among others. The main results that follow did not change with the inclusion or exclusion of any of these variables. We omit these other experience variables and rely on age due to issues with multicollinearity.

pressure situations which makes sinking a putt more likely. Also, older players may be 'haunted by demons', past failures in pressure situations, which make the current pressure situations more difficult to handle and make sinking a putt less likely.

Next, we include the earnings of the player during the previous year. This variable is meant to control for a given player's general ability level. The more money a player earned in the previous year, the more likely it is that he is a strong player and, all else equal, the more likely he will be to make a given putt. This variable also likely captures other factors relating to how equipped a player is to handle the nerves and excitement of a final round putt. Finally, we feel this is an important variable to control for given our interest in the results for the value of the putt variable. Consider the hypothetical case where two players are each taking a putt from an identical distance, and that this putt is worth $50,000 in value to each player. These players and shots are identical in all aspects, except for the fact that one of the players earned $2 million the year before, and the other earned $200,000. In this case, the amount of pressure felt by the two players, and the impact this has on the ability to make the putt, may differ substantially. Thus, omitting a measure of recent monetary success may bias the coefficient of interest in our study. The final individual variable we include is the total putts gained statistic discussed in the previous section. The idea for this variable is to account for the success a player has had in overall putting during the tournament. It is expected that, all else equal, a player that has been putting more effectively throughout the tournament will be more likely to make a putt on the 18th hole of the final round.

In addition to these variables, we also include fixed effects for the year in which a tournament takes place, and the specific course on which it is played. Including the year effects is meant to control for factors that change over time and affect all players in a particular year in a similar way. This takes into account, for example, the changing values of prize money due to inflation or the popularity of the game, or changes in the rules, among other factors. The inclusion of course fixed effects is to deal with certain features of the various courses, such as the condition of the greens, which might affect the ability of all players to make a given putt.[13] In the results that follow, we estimate the model as specified above, as well as with some variations.

One concern in the model is that unobserved player attributes may bias the relationship between pressure and performance. In this case, one might be concerned that not adequately accounting for player characteristics might violate our key assumption that the value of the putt is exogenous. Fortunately, the large nature of our dataset allows us to implement specifications in which we include player fixed effects to better control for these unobserved variables.[14] In this way, we observe how different amounts of monetary pressure faced by the same player at different points in time affect putting performance. Furthermore, we are able to consider other specifications, including those with course-year and player-year fixed effects. These specifications allow us to better ensure that we have properly isolated the impact of pressure on performance.

When considering the residuals in our analysis, it is our belief that the robust set of control variables as well as our ability to control for player, course, and year fixed effects in various forms give a reasonable expectation of exogeneity. However, it cannot be assumed that there is constant variance across our sample of shots. In particular, it is likely that the residuals are not independent across players in the same tournament, that instead the variances in both putts made and the value of the putt are different for each unique tournament. To account for this we cluster the standard errors at the tournament level in each regression.

4. Results

The results from estimating the model specified in Eq. (1) (with different combinations of fixed effects) are presented in Table 3. In each of these specifications, the coefficient on our key variable is indeed negative and significant at the 1% level, which corresponds to the idea of pressure leading to underperformance. Column 2 displays the results of the model as specified in the equation, with course, year, and player fixed effects. The coefficient indicates that an increase in the estimated value of a putt by $10,000 will, all else equal, reduce the likelihood of the player making that putt by 0.18 percentage points. Another way to interpret this number is to say that a putt worth $56,035 is, all else equal, 1 percentage point less likely to be made than a putt with $0 in value. While this may seem like a substantial sum of money to cause a 1 percentage point change, it is important to keep in mind that the average earnings in the previous year for the players in our sample is over $1 million.[15] Furthermore, a putt value of $50,000 is not that unusual. Just under 7% of the observed putts in our sample have a value of at least this much. In subsequent results we examine situations in which the impact of pressure on performance varies based on player or shot characteristics.

An examination of the coefficients on the other variables in our model show that the results are generally in line with our expectations. Much of the explanatory power of the model comes from the distance variables. While not displayed in the table (for the sake of brevity), each of the seven distance coefficients is significant at the 1% level. The coefficients on the uphill dummy and total putts gained variables are both estimated to be positive and highly significant, as expected. Putting uphill allows a player have better control of the speed of his putt, which increases the likelihood a shot is made. Also, players that have been putting well throughout the tournament are more likely to make a given shot on the final hole

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[13] As mentioned below, we also run a variation of the model where we use the interaction of course and year fixed effects to better control for these factors. These course-year fixed effects are equivalent to tournament-specific fixed effects in our sample.

[14] To give a sense of the sample, 388 of the 568 players in the sample have at least 10 observed putts, and 191 have at least 50.

[15] The median value for previous year's earnings is $935,265.

Table 3
Regression results.

	(1)	(2)	(3)	(4)
Value of putt (tens of thousands of dollars)	−0.0019*** [0.0004]	−0.0018*** [0.0004]	−0.0019*** [0.0004]	−0.0017*** [0.0004]
Player age	−0.0004 [0.0003]	0.0605** [0.0253]	−0.0090*** [0.0017]	
Money earned in previous year (millions of dollars)	0.0026 [0.0018]	−0.0003 [0.0024]	−0.0002 [0.0024]	
Total putts gained	0.0089*** [0.0006]	0.0087*** [0.0007]	0.0088*** [0.0007]	0.0089*** [0.0007]
Uphill	0.0156*** [0.0040]	0.0152*** [0.0039]	0.0164*** [0.0041]	0.0150*** [0.0040]
Constant	1.0708*** [0.0149]	−1.3064 [1.0160]	1.5042*** [0.0734]	1.0523*** [0.0082]
Course fixed effects	X	X		X
Year fixed effects	X	X		
Player fixed effects		X	X	
Course–year fixed effects			X	
Player–year fixed effects				X
Observations	23,596	23,596	23,596	23,596
Adjusted R^2	0.613	0.615	0.615	0.613

Notes: Results from estimating linear probability model where dependent variable is equal to 1 if putt is made and 0 if not. Standard errors, clustered at tournament level, displayed in brackets. Each regression includes a seventh-order polynomial for distance, the estimated coefficients of which are not presented in the table.

** Indicates significance at 5% level.

*** Indicates significance at 1% level.

of the final round than those that have been putting poorly throughout the tournament. The variables on player age and money earned in the previous year are either insignificant or inconsistent across the various models. One explanation for this is that the effects of age on performance may be nonlinear. The money earned in the previous year variable may not be highly correlated with putting performance for this sample. Because of the inability of these and other available variables to precisely capture player attributes, we rely on the inclusion of player or player-year fixed effects in our models to control for these factors, whenever possible.

Given the detail of the data utilized, as well as the size of the sample, we have the opportunity to further examine the link between monetary pressure and player performance by separating the sample based on various characteristics. The difficulty of a putt is largely determined by its distance to the hole (Broadie, 2014). So, we begin by separating the putts in our sample based on distance to investigate the impact of task difficulty and/or uncertainty on performance under pressure.[16] Are there certain distances (difficulties) of putts that are more likely to be impacted by the monetary pressure facing the player?[17] To test this question, we included interactions between our key (value of the putt) variable, and distance. Specifically, we created the following categories for the distance of the putt: under 5 feet, 5–10 feet, 10–15 feet, and over 15 feet.[18] We then interacted each categorical variable with the value variable. As before, we run the distance interactions model with various levels of fixed effects.[19] The results of this specification are displayed in Table 4. The coefficient on the value of the putt variable, alone, represents the impact of pressure on performance for putts from less than 5 feet. Interestingly, despite the fact that as a group these putts have over a 96% chance of being made, we do find a significant negative impact for the pressure variable. The magnitude of the coefficient, is similar to those in our primary model in Table 3. This indicates that it would take a relatively large amount of monetary pressure to have a major impact on performance.

For putts in the 5–10 foot range, the estimated magnitude of the impact of pressure is greatly increased. While the estimates are not precise enough for there to be a statistically significant difference between categories, the effect of a high-value putt is estimated to be more than double for these shots from an intermediate distance.[20] This seems reasonable, given the fact that these putts involve the most uncertainty in terms of accomplishing the task. In our sample, putts from the 5–10 foot range have a 55% probability of being made. The results in these models predict that for the average player putting in the 5–10 foot range, increasing the value associated with the putt by just $20,000 will decrease the probability of making the putt by approximately 1 percentage point, all else equal. As the distance from the hole increases, the impact of pressure on performance begins to decline. Putts in the 10–15 foot range are estimated to experience an almost identical

[16] Typical sports studies using shootouts (e.g., penalty kicks) or tennis involve opponents on the other end of the task, which makes quantifying changes in task difficulty relatively impossible. Other studies in this area examining tasks that do not involve opponents (i.e. free throws in basketball) do not typically have the opportunity to quantify changes in the level of task difficulty.

[17] Panayiotou and Vrana (2004) examine the role of task difficulty on self-focused performance. Due to their lack of sample size, they indicate further research into the impact of task difficulty is warranted. Genakos and Pagliero (2012) discuss the fact that success decreases as the task becomes more difficult, but they do not examine the interaction of pressure and difficulty as we do here. Ariely et al. (2009) perform experiments involving tasks of different difficulties, but these tasks also involve differences in skill (mental vs. physical, for example).

[18] We estimated numerous different variations on these categories, including different distance increments, more categories (up to 20 feet) etc. In each case, the pattern of the results remains similar.

[19] In these models, we include a linear distance variable to control for how distance affects make probability within each category. The results remain similar if we include polynomial distance controls in this model.

[20] The p-value for the significance of this interaction term is between 0.15 and 0.20 in the various models.

Table 4
Regression results with distance interactions.

	(1)	(2)	(3)	(4)
Value of putt (tens of thousands of dollars)	−0.0019*** [0.0004]	−0.0020*** [0.0005]	−0.0022*** [0.0005]	−0.0019*** [0.0005]
(Value of putt)*(5–10 foot putt)	−0.0032 [0.0021]	−0.0028 [0.0022]	−0.0028 [0.0022]	−0.0029 [0.0021]
(Value of putt)*(10–15 foot putt)	−0.0003 [0.0020]	−0.0000 [0.0020]	−0.0001 [0.0020]	−0.0000 [0.0019]
(Value of putt)*(>15 foot putt)	0.0009 [0.0009]	0.0012 [0.0009]	0.0012 [0.0010]	0.0011 [0.0009]
Course fixed effects	X	X		X
Year fixed effects	X	X		
Player fixed effects		X	X	
Course–year fixed effects			X	
Player–year fixed effects				X
Observations	23,596	23,596	23,596	23,596
Adjusted R^2	0.606	0.607	0.607	0.605

Notes: Results from estimating linear probability model where dependent variable is equal to 1 if putt is made and 0 if not. Standard errors, clustered at tournament level, displayed in brackets. Each regression includes dummy variables for distance categories, a linear distance variable, a dummy variable for whether or not the putt was uphill, and the total putts gained statistic for the player in that tournament. Regressions in columns 1, 2, and 3 also include variables for player age and money earned in the previous year. The omitted distance category in each regression is less than 5 feet.
*** Indicates significance at 1% level.

impact from pressure as those from under 5 feet. Putts from longer distances, which have a low probability of being made to begin with, are estimated to be relatively unaffected by pressure.[21]

Thinking more generally about the findings in Table 4, the result suggests that for very easy tasks (putts from less than 5 feet, for example) pressure does have an impact on performance, but it takes a relatively substantial amount of pressure to have a strong effect. One explanation for this finding is that an individual's confidence in successfully completing a task minimizes the psychological impact of the difference in monetary reward. Similarly, our findings suggest no evidence of choking on very difficult tasks (putts from greater than 15 feet, for example). Perhaps the reduced expectations of successfully completing the task frees the individual up to perform without a fear of failure. However, tasks for which there exists a relatively equal expectation of success and failure, such as those from between 5 and 10 feet, lead to the largest amount of underperformance. In these cases players may instinctively focus more on the outcome of their shot, since it is in doubt, instead of focusing on performing the task at hand.[22]

Next, we examine whether the performance of certain players are more impacted by pressure. We begin by exploring how the coefficient on the value of putt variable differs based on the career earnings of the player taking the shot. In theory, players with higher levels of career earnings should be less impacted by the monetary pressure associated with a given putt. First, the fact that they have career earnings, and in many cases, annual earnings, in the multiple millions of dollars means that values of $10,000 or even $50,000 may not be all that influential in terms of financial pressure. Secondly, the players that have more in career earnings have, by definition, been more successful in their careers, and have more experience (and more success) playing under pressure. On the other hand, our strategy in this study is to utilize the amount of money riding on a putt to quantify the level of pressure a player faces. This does not imply that finances are the only source of pressure. Other factors such as concern over one's legacy and the chance to earn endorsements, among others, are additional sources of psychological pressure on a PGA TOUR player as he finishes a particular tournament. These factors are likely to be highly correlated with monetary pressure, but may impact the performance of players with all levels of career earnings more evenly than direct financial pressure would.

To investigate this issue, we include interactions between the value of the putt and the quartile of the player in terms of his career earnings among players in our sample. The omitted category in these models is the bottom quartile of earners. The results of this estimation are presented in Table 5.[23] The estimates support the theory that the performance of those with higher levels of career earnings are less impacted by the pressure of a putt.[24] The point estimate for the coefficient on the pressure variable in the bottom quartile of earnings is −0.0043, more than double the magnitude of the estimate for the sample overall. The point estimate for those in the next quartile is around −0.0025 (in the results shown in the first column), though this is not statistically different from the coefficient for the bottom quartile. The impact of pressure is much lower, and significantly so, for those in the upper half of career earnings. The straightforward interpretation of this

[21] If we estimate the regressions separately for each distance category, the value coefficient is indeed insignificant when restricting the sample to only putts from greater than 15 feet.

[22] This idea that worry about the outcome creates a distraction which leads to underperformance is opposed to the view that choking in golf is due to explicit monitoring. These issues are discussed further in the final section of the paper. See Beilock and Gray (2007) and DeCaro et al. (2011) for a more extensive discussion of the distraction and monitoring theories of the choking phenomenon.

[23] As before, we present the estimates with the inclusion of various combinations of fixed effects. For this specification, player-year fixed effects are not possible, as career earnings in our sample are calculated at the beginning of each year.

[24] Past studies in this area typically find weak to no results for the impact of experience on performance under pressure. Dohmen (2008) indicates that performance improves with experience, but comments that this results may be due to selection bias. Players are chosen to take penalty kicks and players that often miss are frequently removed from taking future penalty kicks. Cao et al. (2011) finds that experience has no effect on free throw performance in pressure situations.

Table 5
Regression results with career earnings interactions.

	(1)	(2)	(3)
Value of putt (tens of thousands of dollars)	−0.0043*** [0.0011]	−0.0043*** [0.0012]	−0.0042*** [0.0012]
(Value of putt)*(25th–50th percentile of career earnings)	0.0018 [0.0015]	0.0024 [0.0016]	0.0021 [0.0016]
(Value of putt)*(50th–75th percentile of career earnings)	0.0028** [0.0014]	0.0031** [0.0015]	0.0029* [0.0015]
(Value of putt)*(top 25% of career earnings)	0.0034** [0.0013]	0.0030** [0.0014]	0.0029** [0.0014]
Course fixed effects	X	X	
Year fixed effects	X	X	
Player fixed effects		X	X
Course–year fixed effects			X
Observations	23,596	23,596	23,596
Adjusted R^2	0.614	0.615	0.615

Notes: Results from estimating linear probability model where dependent variable is equal to 1 if putt is made and 0 if not. Standard errors, clustered at tournament level, displayed in brackets. Each regression includes a seventh-order polynomial for distance, as well as variables for player age, money earned in the previous year, the total putts gained statistic for each player in each tournament, and a dummy variable for whether or not the putt was uphill. The omitted earnings category in each regression is "bottom 25 percent of career earnings".
* Indicates significance at 10% level.
** Indicates significance at 5% level.
*** Indicates significance at 1% level.

Table 6
Regression results with total putts gained interactions.

	(1)	(2)	(3)	(4)
Value of putt (tens of thousands of dollars)	−0.0029*** [0.0007]	−0.0028*** [0.0007]	−0.0028*** [0.0007]	−0.0031*** [0.0006]
(Value of putt)*(total putts gained)	0.0003** [0.0001]	0.0003** [0.0001]	0.0003** [0.0001]	0.0004*** [0.0001]
Total putts gained	0.0085*** [0.0007]	0.0083*** [0.0007]	0.0085*** [0.0007]	0.0085*** [0.0005]
Course fixed effects	X	X		X
Year fixed effects	X	X		
Player fixed effects		X	X	
Course–year fixed effects			X	
Player-year fixed effects				X
Observations	23,596	23,596	23,596	23,596
Adjusted R^2	0.614	0.615	0.615	0.613

Notes: Results from estimating linear probability model where dependent variable is equal to 1 if putt is made and 0 if not. Standard errors, clustered at tournament level, displayed in brackets. Each regression includes a seventh-order polynomial for distance, as well as a dummy variable for whether or not the putt was uphill, and the total putts gained statistic for the player in that tournament. Regressions in columns 1, 2, and 3 also include variables for player age and money earned in the previous year.
** Indicates significance at 5% level.
*** Indicates significance at 1% level.

result is that players with higher earnings are less influenced by pressure. However, another way of thinking about these results is to say that those with more earnings are still influenced by pressure, it just takes a much larger amount to make a difference. In the specification in column 3, for example, we estimate that it would require an increase in value of around $23,810 to decrease the probability a player in the bottom quartile of career earnings makes a putt by 1 percentage point. For players in the top half of career earnings, it would take an increase in value of around $76,923 to cause the same change in performance.

Next we consider whether the impact of pressure differs based on how well the player has been putting in the specific tournament. The basic idea for this model is to test whether recent success in performing similar tasks decreases the negative effects of pressure. This specification may also provide insight into whether those who are generally better putters are able to overcome the choking phenomenon in high-pressure situations. In order to examine this, we interact the value of putt variable with the total putts gained statistic discussed previously. The results are presented in Table 6. As anticipated, the coefficient on the interaction term is positive and significant in each specification. One plausible explanation for this result is that above-average putting performance in the tournament gives a player confidence in his putting ability in the later rounds, which lessens the possibility of the pressure "getting to him".

Let's consider an example illustrating the magnitude of the estimated coefficients in the fourth column of Table 6. Suppose three players are each taking a putt from the same spot on the final hole of the tournament worth $50,000. The first player has been putting poorly in the tournament, and has a total putts gained statistics of −3.3 (the 10th percentile in our sample), the second is putting in the middle of the pack for those in the final round (total putts gained at 0.9, the median in our sample), and the third is putting well, with a total putts gained stat of 5.2 in the tournament so far (90th percentile in our sample). Based on the coefficients, we would say the $50,000 makes it 2.21 percentage points less likely the first player (the one putting poorly in the tournament) makes the putt, as compared to a putt worth $0. For the second and third players, the impacts of the $50,000 are 1.37 percentage points and 0.51 percentage points, respectively. Overall, we see that putting

Table 7
Regression results from alternative specifications.

	(1) Logged value of putt	(2) Excluding values > $250,000	(3) Excluding values < $1,000	(4) Logit (marginal effects)
Value of putt (tens of thousands of dollars)		−0.0037*** [0.0008]	−0.0016*** [0.0004]	−0.0043*** [0.0010]
Ln (value of putt)	−0.0046*** [0.0009]			
Observations	23,596	23,367	16,655	23,596
Adjusted R^2 (pseudo R^2 in Logit model)	0.613	0.614	0.620	0.577

Notes: Results in columns 1 through 3 from estimating linear probability model where dependent variable is equal to 1 if putt is made and 0 if not. These regressions include course and player–year fixed effects. Logged value of putt in column 1 computed as the natural logarithm of calculated value plus $1, so as not to exclude putts with zero estimated value. Results in column 4 present marginal effects (at means) from logistic regression model with same dependent variable. Standard errors, clustered at tournament level, displayed in brackets. Each regression includes a seventh-order polynomial for distance, as well as a dummy variable for whether or not the putt was uphill, and the total putts gained statistic for the player in that tournament. Logit model also includes control variables for player age and money earned in previous year.
*** Indicates significance at 1% level.

performance prior to the last hole, and the level of confidence this instills in a player, can be a major factor in the degree to which performance is affected at the end of the tournament.[25]

5. Alternative specifications

In this section, we present several different variations to our modeling choices in the previous section in order to demonstrate the robustness of our key findings. The results of these models are presented in Table 7. The first variation we implement is to estimate the model with player-year and course fixed effects (as displayed in the fourth column of Table 3), but simply replace the value of the putt with the natural logarithm of the value.[26] This specification was performed out of concern that the skewed nature of the value variable may have driven the results in the previous specifications. While the average value for putts in the sample is around $19,000, there are 10 putts with a value greater than $500,000. The results, presented in the first column of Table 7, indicate that pressure still has a significant negative impact on performance, and that the magnitude is estimated to be similar to that of the previous models.[27]

Another way to deal with concern over the skewed nature of our key variable is to exclude extreme values from the sample. Column 2 of Table 7 presents results of the linear probability model when restricting the sample to exclude putts with estimated values of $250,000 or greater (roughly the top 1% of the sample). The concern here is that these outlying values may be influential in the results. For example, there are a grand total of four observed putts with a value of over $600,000. In each of these cases, the player made the shot associated with these large values. This unique result, and the fact that these values stand apart from the rest of the data, may lead them to substantially alter the findings. When we exclude the values on the high end of the distribution, we find that the magnitude of the coefficient is increased significantly, indicating a more negative impact of pressure on performance. It seems that outlying values on the high end of the distribution may be attenuating our results.[28] Another explanation for this finding is that there may be diminishing effects of pressure on performance. That is to say that a putt worth $100,000, for example, may cause a great deal of stress for the typical player, but perhaps increasing the value to $200,000 does not double the stress level.

In the third column of Table 7, we display results from a model where shots with a value of less than $1000 have been dropped from the sample. This specification was performed to alleviate concerns that the large number of shots with little to no estimated monetary value are in some way driving the key findings of the study. When these low value observations are dropped, the magnitude of the primary coefficient is very similar to those found in the earlier models containing the full sample.

Finally, the fourth column of Table 7 presents the marginal effects from utilizing a Logit model. As mentioned previously, the linear probability model was chosen as our base model so that we might include various fixed effects, based on the models of similar studies on putting performance, and for ease of interpretation. However, the discrete nature of our dependent variable makes the Logit model appealing in its own right. The basic finding of this model again indicates that the amount of pressure associated with a putt significantly reduces the likelihood that the putt is made.

[25] Cao et al. (2011) finds a similar result, players with a lower free throw percentage for the season are more likely to choke in pressure situations as opposed to better free throw shooters.
[26] When creating the logged values, we replaced those shots with a value of 0 to have a value of $1, so that they would remain in the sample.
[27] A $10,000 increase in value from the mean is estimated to reduce the probability a putt is made by 0.0024 percentage points, as opposed to 0.0017 when value is not logged.
[28] As previously mentioned, high value putts are most likely to carry additional benefits, such as sponsorships and exemptions. This specification may also lessen the concern that our results are driven by these benefits that cannot be measured with the data available.

Overall, the results indicating a significant negative influence of pressure on performance are robust to a number of different modeling choices. While the exact magnitude of the effect varies, there does indeed appear to be evidence of choking on the PGA TOUR.

6. Conclusions and discussion of findings

Tournament theory suggests very large rewards elicit maximum effort by competitors to achieve the top positions, in this way large rewards increase performance. Empirical tests of this hypothesis have shown this to be true in many cases. However, our study suggests that an attenuating force, known as choking, does exist in which large rewards lead to a drop in performance due to psychological pressure. This study is intended to provide new evidence on the choking phenomenon by investigating how pressure associated with different monetary prizes influences the putting performance of professional golfers. By making use of an unusually rich dataset, we are able to expand upon previous findings in the literature in several key ways. First, we study the impact of pressure in an environment where those involved have real stakes and are involved in a real-world situation, as opposed to an experimental setting. Second, the large size of the dataset allows us to narrow the focus of the study to the final hole in the final round of a tournament, where psychological pressure is likely to be a significant factor, and where it is possible to specifically quantify this pressure. Unlike many other studies in this area, this research design allows us to observe a great deal of variation in the key pressure variable. Previous studies in this area typically rely on basic high-pressure and low-pressure distinctions, rather than calculating a continuous measure. Finally, the richness of the ShotLink data allows us to test how the impact of pressure varies based on shot and player characteristics.

While we argue that the observed drop in make percentage is due to psychological pressure, there are some alternative explanations which deserve further discussion. One may argue, for instance, that players with high putt values have a greater level of fatigue as compared to players with lower putt values, and that fatigue leads to their underperformance. While possible, this is most likely not the case in golf. All players remaining in the final round of the tournament have played the same number of holes, and players with lower putt values have, on average, taken more strokes than players with high value putts and thus should be more fatigued. Alternatively, we might consider the issue of mental fatigue as opposed to physical. Perhaps the mounting pressure of maintaining a high-level of performance throughout the tournament has eroded the nerves and mental capacity to concentrate on the final putt of a tournament. In that case, the value of a putt represents the overall level of pressure felt throughout the tournament, which still indicates that pressure leads to underperformance.

This result could also be due to the psychological phenomenon known as loss aversion, as opposed to monetary pressure. A player may feel, for instance, that the final putt is a chance to lose money. A traditional view held by many golfers is that taking two putts to achieve par and maintain one's position is the proper course of action. In these cases, the psychological loss from a three-putt is much worse than the gain from a one-putt. The phenomenon of loss aversion is most likely to be present for players very near the top of the standings, who also typically have the highest value of a putt in our calculation. Suppose a player at the top of the leaderboard needs to finish the hole in two shots or less to win the tournament. In this case, a player will often lag his first putt from a relatively short distance so that he will have a very short putt remaining for the win. The concern, in terms of our results, is that this is a case in which a player is missing the putt they are generally expected to make (the first putt) not because of the pressure of winning the tournament, but because of a loss aversion strategy. Fortunately, our measurement of pressure is designed to avoid this issue. Putts that do not change the position of a player (such as the first putt for the player described above) are recorded as having a value of zero, and so the concern for the loss aversion story in which players lag high value putts should be mitigated.

We have argued that putt value represents outcome pressure, which serves to distract the player from the task at hand. In this case, each player is generally aware of his position relative to others in terms of the final standings. Given the large differences in monetary rewards that can result from changing finish position, it is not difficult to imagine a player being unable to focus on making his putt. However, there is a competing theory that our result could be due to explicit monitoring, where a player becomes self-conscious about performing correctly due to a large crowd (or television cameras), which causes him to focus too much on the step-by-step process that usually takes place outside of conscious awareness. While it is not possible to explicitly untangle these two theories with our data (because we do not have information on the size of the crowd following each group), the focus on the final hole may lessen the concern that this result is due to explicit monitoring. During the final day of the tournament, fans tend to accumulate around the 18th hole early in the round, as this is where the tournament will ultimately be decided. As a result, the area around the green is often at maximum capacity for a great number of the playing groups, and the players with the highest value putts do not necessarily have more of an audience than players with lower value putts. While it is definitely possible that explicit monitoring creates pressure for players, it is not likely that players with high value putts are experiencing much more self-consciousness than those players with low value putts based on our empirical strategy.

The findings from our primary model indicate that increasing the value of a putt by around $50,000 will decrease the likelihood of a player making the putt by 1 percentage point. However, for certain shots, such as those taken from 5 to 10 feet away, the magnitude of the effect is substantially greater. We also show that pressure affects less experienced players more than those that have earned more money throughout their careers, and that the impact of pressure on performance varies based on how well the player has been putting in the tournament up to that point. These additional findings are important as there is very little prior work on how task difficulty, experience, and recent success impact performance under pressure in real world settings. Finally, we show that the findings are robust to a number of different modeling choices and specifications.

The unique, individual nature of golf and the availability of a substantial amount of detailed data from the ShotLink system provide ample opportunities for future research into additional topics in behavioral economics.

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