Components of Superior Professional Golf Scoring From 1983 to 2018, With a Focus on Driving Distance and Accuracy

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Abstract

This report examines the contributions of driving distance and driving accuracy to superior scoring on the PGA Tour from 1983 to 2018. The contributions of approach shots, short game and putting over time are also examined using PGA Tour and LPGA Tour data. One main finding is that the contribution of driving distance to superior scoring increased over the period 1983 to 2018. More precise results are possible using the PGA Tour's ShotLink data which has been available since 2004. Analysis of the ShotLink data shows that from 2004 to 2010 the top scorers gained an average of 18% of their strokes from longer driving distance; from 2011 to 2018 it was 23%, a gain of 5%. Another main finding is that the contribution of driving accuracy to superior scoring decreased over the period 1983 to 2003 and has been steady from 2004 to 2018.

1. Introduction

This report examines the relative contributions of various shot and skill categories that distinguish exceptional versus average performance in professional golf. The main questions are: How has the relative importance of driving distance and driving accuracy changed over time? We also examine the roles of approach shots, short game shots and putting through time, using PGA Tour and LPGA Tour data.

One key idea is that importance is defined by performance relative to the field. A player wins by scoring better than the field and that scoring advantage is derived from performing better than the field in various aspects of the game. For example, if every player hit every drive exactly 300 yards in the fairway, then driving distance would not be important because it would not explain any of the variation in player scores. Another key idea is that performances in different shot categories are easier to compare when measured in the same unit of strokes. For example, if one player drives 20 yards further than the field and hits his approach shots five feet closer to the pin than the field, it is hard to say which factor explains more of score differences. But if one player gains 0.2 strokes on the field with his drives and 0.4 strokes with his approach shots, then it is clear that approach shots contribute twice as much to better scores than driving.

For the purposes of this report, driving refers to tee shots on par-4 and par-5 holes. The approach shot category refers to shots starting 100 or more yards from the pin, excluding drives; the short game category refers to shots starting within 100 yards of the pin, excluding putts, and putts are shots starting on the green (excluding the fringe). These categories differ slightly from the ones used by the PGA Tour, where instead of short game they use the term around-the-green which refers to shots starting within 30 yards of the front edge of the green (excluding putts).[1]

Reliable shot tracking data has been available on the PGA Tour since 2004 with their ShotLink system. This shot-level data includes the starting and ending locations of every shot of every player at almost every PGA Tour event.[2] Shot tracking data can be used to measure the quality of each shot using the strokes gained method. Strokes gained measures progress to the hole in units of strokes instead of distance. For example, suppose the PGA Tour average strokes to hole out on a difficult par-4 hole is 4.3. Now suppose a long drive is hit into the fairway where the PGA Tour average strokes to hole out is 3.1. The shot progressed the ball 1.2 strokes closer to the hole, but it took one stroke to do so, so the shot's strokes gained is defined to be +0.2 ($= 4.3 - 3.1 - 1$) strokes. The strokes gained method can be used to measure the quality of every shot relative to an average PGA Tour shot. It can also be used to compare drives, approach shots, short game shots and putts since it uses the same unit of measurement, strokes, for all shots.[3]

The strokes gained (SG) analysis in this report differs in two important ways from the SG stats on the PGA Tour website `pgatour.com`. The first difference is that the average strokes to hole out baselines used in the strokes gained calculations are adjusted for each course and round (while the PGA Tour baselines are the same for every course and round in a season). This is important because the average strokes to hole out varies greatly from one course to the next and one round to the next. Adapting the baselines for each course and round gives more accurate results, in particular, better strokes gained results and a more better estimate of the tradeoff between driving distance and driving accuracy. The second difference is taking into account the strength of the field. This method of analysis is described in more detail in the next section. Section 2 also discusses the method for computing statistical significance (i.e., p values) and for determining a statistically significant break in a trend.

Strokes gained results using PGA Tour ShotLink data from 2004 to 2018 are given in Section 3. Results using traditional driving distance and driving accuracy statistics from the same time period are investigated in Section 4 in order to compare the consistency with the shot tracking data. Analysis of standard statistics on the PGA Tour from 1983 to 2018 is given in Section 5.

The tradeoff between driving distance and driving accuracy is influenced in part by the cost of errant drives. Section 6 examines the cost of missing a fairway (which includes hitting into sand,

[1]So the main difference is that shots starting from around 60 yards to 100 yards from the pin are in the short game category here, but in the PGA Tour's approach category. However, there are only about 1.5 shots per round starting from 60 to 100 yards from the pin.

[2]Exceptions include events played on multiple courses, where shot tracking data is only recorded at one course.

[3]For a more detailed explanation of the strokes gained method, see the book *Every Shot Counts*, Mark Broadie, 2014, Avery Press or the paper Broadie, 2012, "Assessing Golfer Performance on the PGA TOUR," *Interfaces*, Vol.42, No.2, 146-165.

water and other recovery and penalty situations) and Section 7 examines the related cost of hitting out of the rough compared to the fairway. The evolution of hole distances and second shot distances is examined in Section 8. Results with LPGA Tour data are given in Section 9. A summary of the main results is given in Section 10. The Appendix contains additional results with standard statistics and shows the connection between the "top 40" analysis and regression analysis.

No attempt is made to identify the cause of any trends. For example, if putts per round decreased over time it could be due to many factors, including better agronomy, green conditions, player skill, coaching, green maps, or other factors.

All data for this report is provided is courtesy of the USGA, PGA Tour and LPGA Tour.

2. Analysis Methods

This section describes several analysis methods used in the report. The first subsection discusses how scores and other statistics are adjusted to account for course difficulty and the strength of the field. The second subsection describes the test used for statistical significance and how the reported p values are computed. The third subsection describes a procedure to detect a statistically significant break in the time trend of a variable of interest.

2.1. Course Difficulty and Strength of Field Adjustments to Scores and Other Stats

This subsection gives an explanation of the method used to account for course difficulty and the strength of the field. The PGA Tour SG stats are adjusted so that the field average strokes gained each round is zero, i.e., this adjusts for the course difficulty but the strength of the field is not taken into account. For example, for each round of the TOUR Championship the average value of strokes gained putting is zero, even though the thirty competitors are some of the best players on the PGA Tour. In order to better analyze trends over time, this report uses a consistent benchmark of SG adjusted for the strength of the field. This adjustment method can be applied not only to scores, but to standard statistics (e.g., driving distance and putts per green in regulation) to account for course difficulty and the strength of the field.

The method is explained in three steps using a simple example. First, standard averages are computed. Second, the standard averages are adjusted for course difficulty. This is the method used for the strokes gained results on `pgatour.com`. Third, the standard averages are adjusted for the course difficulty and strength of the field. This is the method used in this report and in this section it will be termed "strokes gained$^+$."

Table 1 gives scores for Tom, Dick and Harry on the two courses, Red and Blue. There are only four rounds to keep the example very small, but the ideas and procedures apply to many players with many rounds at many courses. Note that 'scores' could be replaced by any performance measure, e.g., putts per round, fraction of fairways hit, driving distance, etc., and the same procedures could be applied. The average score of Tom is 70, Harry is 70 and Dick is 69. Most traditional stats in sports are computed using simple averages.

Player	Course	Score
Tom	Red	70
Harry	Red	72
Dick	Blue	69
Harry	Blue	68

Player	Average score	Rounds played
Tom	70	1
Harry	70	2
Dick	69	1

Table 1: Simple average method: Tom and Harry have the same average score of 70. Dick's average score is 69. This method estimates Tom as one stroke better than Dick. However, this method does not account for the difficulty of the courses nor the different field strengths.

A big problem with the simple average method is that courses can differ substantially in their difficulty (and weather and conditions can vary dramatically on the same course from one round to the next). The "course difficulty adjustment method" accounts for the course difficulty by measuring scores relative to the field average. If one course is harder than another, the field average score will reflect the differences in course difficulty (because the average score of large group of tour players will mainly reflect course difficulty). This is illustrated in Table 2. The column "score to field" shows each player's score relative to the field average score at that course. Each player's "score to field" is then averaged, giving Tom with an average score to field of +1 (i.e., one stroke better than the field average), Harry −0.25 and Dick −0.5. This "average score to field" suggests that Tom is better than Harry by an average of 1.25 strokes, unlike the simple average method that had the two rated equal. The "average score to the field" is also called "strokes gained," i.e., this is the procedure used for strokes gained stats on `pgatour.com`.

Player	Course	Score	Field avg score	Score to field
Tom	Red	70	71	+1
Harry	Red	72	71	−1
Dick	Blue	69	68.5	−0.5
Harry	Blue	68	68.5	+0.5

Player	Avg score to field
Tom	+1
Harry	−0.25
Dick	−0.5

Table 2: Course difficulty adjustment: The method accounts for the course difficulty by measuring scores relative to the field average. If one course is harder than another, the field average score will reflect differences in course difficulty. Measuring scores relative to the field is a way of adjusting for course difficulty. Tom's average score to field is +1 (i.e., one stroke better than the field average), Harry is −0.25 and Dick is −0.5. The average score to the field is also called strokes gained. This method estimates Tom as 1.5 strokes better than Dick. However, the results do not account for the strength of the field.

A problem with the "course difficulty adjustment" method is that fields at different courses vary in quality. That is, the scores at one course could be lower not because the course is easier, but because the players in the field are better. Since Harry plays at both the Red and Blue courses, we can infer that the Red course is four strokes more difficult than the Blue course. Put another way, the Red course is two strokes more difficult than an average, or "neutral" course, and the Blue course is two strokes easier than a neutral course. The "connecting" player (Harry) allows

us to infer course difficulty and to compare players (Dick and Tom) who never played the same course together. Using these course difficulty factors, player scores at a course can be converted to scores that they would be estimated to shoot playing on the same neutral course. Averaging these neutral course scores gives Tom with an average of 68, Harry 70 and Dick 71. Accounting for the course difficulty and the strength of the field shows that Tom is an average of three strokes better than Dick, not 1.5 strokes better as given by the course difficulty adjustment method (and not one stroke better as given by the simple average method). Another way to express player ratings is by comparing average neutral course scores for each player to the overall average neutral course score of 69.75. That difference is called "strokes gained$^+$" and gives Tom at $+1.75$, Harry at -0.25, and Dick at -1.25. The strokes gained$^+$ method accounts for both course difficulty and the strength of the field and is distinguished from the simpler "strokes gained" stats that use the course difficulty adjustment method (and does not account for the strength of the field).

In this small example, the course difficulty factors could be inferred directly from Harry's scores on the two courses. In general, it is necessary to simultaneously estimate course difficulty and strength of field factors. This is typically done using a standard *fixed effects* regression method.[4] The strokes gained$^+$ method accounts for both course difficulty and strength of field and gives a more accurate measure of performance than the field adjustment method and is much more accurate than the simple average method. Most of the analysis in this report uses data transformed with the strokes gained$^+$ method. The method applies not only to scores, but to any other stat, e.g., putts per round, driving distance, fairways hit, etc. These adjusted stats are called "relative stats" in the text when referring to driving distance, driving accuracy and other traditional golf stats. When these strokes gained$^+$ adjustments are applied to scores or strokes gained values, this report will simply use the term "strokes gained," (since strokes gained$^+$ is non-standard terminology), with it being understood that the strokes gained results include a strength of field adjustment.

Player	Course	Score	Course difficulty	Neutral course score	Tour avg neutral score	Strokes gained$^+$
Tom	Red	70	$+2$	68	69.75	$+1.75$
Harry	Red	72	$+2$	70	69.75	-0.25
Dick	Blue	69	-2	71	69.75	-1.25
Harry	Blue	68	-2	70	69.75	-0.25

Table 3: Strokes gained$^+$ (SG$^+$) method: This method accounts for course difficulty and the strength of the field. In this small example, Harry is assumed to have a constant skill, so his scored can be used to estimate course difficulty factors.

[4]See `https://en.wikipedia.org/wiki/Fixed_effects_model` for more detail and references on fixed effects models.

Player	Avg strokes gained$^+$	Rounds played	Tour avg neutral score	Adjusted avg score
Tom	+1.75	1	69.75	68
Harry	−0.25	2	69.75	70
Dick	−1.25	1	69.75	71

Table 4: Strokes gained$^+$ (SG$^+$) method: Tom's SG$^+$ is +1.75 (i.e., 1.75 strokes better than an average player), Harry is −0.25 and Dick is −1.25. If Tom and Dick played on the same course, Tom would be expected to score three strokes better than Dick.

2.2. Tests for Statistical Significance

Throughout this report, p values are computed using the nonparametric bootstrap procedure described in Efron and Tibshirani, 1993, *An Introduction to the Bootstrap*, Chapman & Hall/CRC. See also `https://en.wikipedia.org/wiki/Bootstrapping_(statistics)`. Bootstrap p values were compared to the standard (parametric) p values of regression coefficients and the results were very similar. The standard parametric p value and the bootstrap method are compared next using the trend in relative greens in regulation (GIR) on the PGA Tour from 2004 to 2018 as an example (see Figure 4 in Section 4).

A simple linear regression of GIR (dependent variable) on year (independent variable) gives a slope of 0.02% with an associated p value of 0.55. The p value is computed under the assumption that the linear regression error terms are normally distributed. (For a brief introduction to linear regression see, e.g., `https://en.wikipedia.org/wiki/Simple_linear_regression`). The interpretation of the p value is related to the null hypothesis that the slope of the regression line is zero. The p value is the probability that the slope would have been at least as large as the observed value (0.02% in this case) if the null hypothesis (and other model assumptions, including normally distributed error terms) were true. A small p value indicates that it is unlikely that the observed slope is due to chance.

In the nonparametric bootstrap procedure, the y values are randomly permuted (i.e., shuffled) to give a new ordering of values. A regression is performed and a slope is computed. The process is repeated many times and the slope values are recorded. These simulated values give the distribution of slopes under the null hypothesis that there is no time trend in the data. A p value is computed as the fraction of times that the simulated slope is greater than the observed value. The procedure is nonparametric in that it does not rely on the assumption of normally distributed errors. Applying the bootstrap procedure to the relative GIR data, with 50,000 simulation trials, gives a p value of 0.53 (which is very close to the 0.55 value obtained from the parametric method).

2.3. Detection of a Break in a Trend

When plotting the time trend of a variable, it is often the case that the trend (i.e., the slope of the line) does not appear to be constant over time. For example, a positive slope over the entire range of data could mask a positive trend in early years followed by a negative trend in later years.

While visual inspection can be suggestive of a change in a trend, it is often not obvious where a break occurs or if the change is statistically significant.

In order to objectively identify the year corresponding to the most significant point of a trend change, a procedure was used based on Welch's t-test for the difference of two means with unequal variances. For more details on Welch's t-test, see, e.g.,`https://en.wikipedia.org/wiki/Student%27s_t-test#Independent_(unpaired)_samples`.

To illustrate the procedure, we'll use the example from Figure 5 in Section 5 which shows relative driving accuracy from 1983 to 2018. Suppose a candidate break year Y is given. Then a slope X_1 and associated standard error s_1 is computed for the years 1983 to Y. Similarly, a slope X_2 and associated standard error s_2 is computed for the years $Y+1$ to 2018. We want to assess the statistical significance of the difference $X_1 - X_2$. Welch's test statistic is $t = (X_1 - X_2)/s$, where

$$s = \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$$

and where n_1 is the number of years from 2003 to Y and n_2 is the number of years from $Y+1$ to 2018. This procedure takes into account the difference in slopes in the two time periods and the uncertainty in the estimates of the two slopes.

In this trend break detection procedure, t values are computed separately for each candidate break year from 1986 to 2015. For the relative driving accuracy data, the t values are 0.1, -7.6, -13.9, -17.1, -4.4, and -8.6 for the years 1990, 1995, ..., 2015, respectively. Examining all of the candidate break years shows that the largest absolute t value is 17.3 for the year 2003.

The year with the largest absolute t value is identified as the most significant break year. The same procedure applied to relative driving distance from 1983 to 2018, and shows the most significant break year as 2004 (by a small margin compared to 2003). For simplicity, the same 2003 break year is used for both variables in Figure 5.

3. Strokes Gained Results, 2004-2018

The main goals of this study are to examine: (i) the contributions of various parts of the game to superior scoring and (ii) the time trends in these contributions. The initial analysis uses shot-level PGA Tour ShotLink data that has been available since 2004.[5]

To illustrate, consider Dustin Johnson in the 2018 season, who led the PGA Tour in strokes gained total at 2.87. This means Johnson scored an average of 2.87 stokes better per round than average PGA Tour player.[6] As shown in Table 5, the 2.87 scoring advantage can be broken down by shot category, with driving contributing 1.12 strokes per round, approach shots 0.92, short game

[5]There is PGA Tour ShotLink data from 2003 but it contains more errors in the first year of production.

[6]On the PGA Tour website, Dustin Johnsons's 2018 strokes gained total is 2.37. The 2.37 value is smaller than our 2.87 mainly because the 2.37 is measured against the fields Johnson played against, and it does not take into account that Johnson played in events with tougher competition. When comparing result across players, better results are obtained by adjusting for the strength of the field.

0.45 and putting 0.39. Because strokes gained is measured in strokes, and since strokes gained summed across shot categories equals strokes gained total, this analysis directly shows which parts of Johnson's game contributed the most to his scoring advantage.

Strokes gained driving is decomposed into distance and accuracy components. Dustin Johnson's drives (i.e., tee shots on par-4 and par-5 holes) averaged 17.8 yards longer and he missed 0.2 more fairways per round relative to an average PGA Tour player.[7] Strokes gained analysis splits Johnson's strokes gained driving of 1.12 into distance and accuracy components, showing a gain of 1.17 from added distance (labelled SGD-Dis in Table 5) and -0.05 for his slightly reduced accuracy (labelled SGD-Acc in Table 5). Note that SGD-Dis and SGD-Acc sum to strokes gained driving.

Different players have different strengths and weaknesses, so to draw more general conclusions, the results of the top 40 players in strokes gained total are averaged. Table 5 shows that in the 2018 season, these players gained an average of 1.53 strokes per round against an average PGA Tour player, with driving contributing 32%, approach shots 36%, short game 17%, and putting 14%. Furthermore, of the 32.4% contribution of driving, 28.6% was from driving distance and 3.9% was from driving accuracy.

This "top 40" analysis directly estimates the contributions of different parts of the game to superior scoring performance. The analysis is possible because of the "additivity" property of strokes gained. In contrast, previous studies used "regression" or "analysis of variance" methods because driving distance, driving accuracy, putts per round, etc., were all in different units and do not sum to a player's score or a player's scoring advantage. Nevertheless, there is a connection between the two types of analysis that is detailed in Section 11.2 in the Appendix.

Next we analyze the time trends of these contributions to superior scoring performance. From one year to the next there is considerable variability, but the one statistically significant trend is the contribution of driving increasing at a rate of 0.5% per year, with a p value less than 0.01. From 2004 to 2010, the top 40 scorers gained an average of 23.6% of their strokes from better driving; from 2011 to 2018 it was 27.6%, a gain of 4%. The contribution of approach shots declined at a rate 0.3% per year, short game declined at a rate 0.3% per year, and putting was steady with a slope of 0.0% per year, but none of these trends are significant at the 0.05 level. These trends are illustrated in Figure 1.

Figure 2 splits the driving contribution into distance and accuracy components. Over the period 2004-2018, the top 40 scorers gained 26% of their scoring advantage from better driving, with 21% from longer drives and 5% from more accurate drives. From one year to the next there is considerable variability in the distance and accuracy contributions, but the trends over the period are driving distance increasing at a rate of 0.7% per year (with a p value of 0.01) and driving accuracy decreasing at a rate of 0.2% per year (with a p value of 0.30). The driving distance trend is statistically significant; the driving accuracy trend is not. From 2004 to 2010, the top 40 scorers gained an average of 18% of their strokes from longer driving distance; from 2011 to 2018 it was

[7] As with our strokes gained results, driving distance and driving accuracy are adjusted to take into account course conditions and the strength of the field. For example, players are not rewarded just because they play on courses with wide fairways. Course characteristics and strength of field effects are "controlled for" in the analysis.

Strokes gained leaders on the PGA Tour in 2018

	Total	Drive	Appr	Short	Putt	SGD-Dis	SGD-Acc
Top 40 average	1.53	0.50	0.55	0.26	0.22	0.44	0.06
Fraction of total	100%	32%	36%	17%	14%	29%	4%

		Strokes gained per round					SG Drive breakdown		Number
Rank	Player	Total	Drive	Appr	Short	Putt	SGD-Dis	SGD-Acc	of rounds
1	Dustin Johnson	2.87	1.12	0.92	0.45	0.39	1.17	-0.05	66
2	Justin Rose	2.48	0.79	0.75	0.44	0.50	0.48	0.31	57
3	Justin Thomas	2.33	0.62	0.86	0.55	0.31	0.92	-0.30	72
4	Tommy Fleetwood	2.15	0.74	0.69	0.32	0.40	0.36	0.38	58
5	Tiger Woods	2.01	0.25	0.82	0.63	0.30	0.51	-0.26	63
6	Rory McIlroy	2.00	0.98	0.38	0.46	0.17	1.30	-0.32	55
7	Rickie Fowler	1.92	0.42	0.72	0.31	0.46	0.21	0.20	65
8	Bryson DeChambeau	1.88	0.75	0.59	0.23	0.32	0.51	0.24	82
9	Tony Finau	1.81	0.58	0.66	0.24	0.33	0.86	-0.28	85
10	Jason Day	1.81	0.40	0.10	0.55	0.75	0.50	-0.10	53
...	...	...	...	...	...	...	...	...	...
36	Kevin Na	1.10	-0.30	0.41	0.41	0.58	-0.31	0.01	70
37	Keegan Bradley	1.07	0.31	1.00	0.08	-0.32	-0.12	0.43	80
38	Bubba Watson	1.06	1.00	0.15	-0.17	0.08	0.95	0.04	72
39	Luke List	1.06	0.86	0.32	0.32	-0.44	1.26	-0.40	78
40	Joaquin Niemann	1.06	0.67	0.62	-0.09	-0.14	0.59	0.08	44

Strokes gained results include "course difficulty" and "strength of field" adjustments

Table 5: Strokes gained of the top 40 players in the 2018 season. These players gained an average of 1.53 strokes per round against an average PGA Tour player. Driving contributed an average of 32%, approach shots 36%, short game 17%, and putting 14%. Furthermore, of the 32.4% contribution of driving, 28.6% was from driving distance and 3.9% was from driving accuracy (additional decimal places not shown in the table).

23%, a gain of 5%.

Driving distance has contributed an increasing (and statistically significant) share of the scoring advantage of the top players in the 2004 to 2018 period. All other factors (driving accuracy, approach shots, short game and putting) show no statistically significant trends over this period.

4. Standard Statistics Results, 2004-2018

Since reliable ShotLink data is only available from 2004 to the present, any pre-2004 analysis needs to be done without ShotLink, i.e., with traditional statistics of driving distance collected on two holes, fairways hit, greens in regulation, and putts per round. In order to assess the validity of any analysis with standard statistics, it is useful to see if results similar to those with strokes gained can be obtained for the years 2004 to 2018.

A key to the analysis is to use standard statistics that are adjusted for course difficulty and the strength of the field. For example, driving distance at a high altitude course is greater than a course at sea level, so players at the high altitude course will appear to be longer drivers than they really are. Score differences depend on drive distances differences, i.e., drive distances relative to the field. Absolute (or unadjusted raw) driving distance values do not properly reflect player

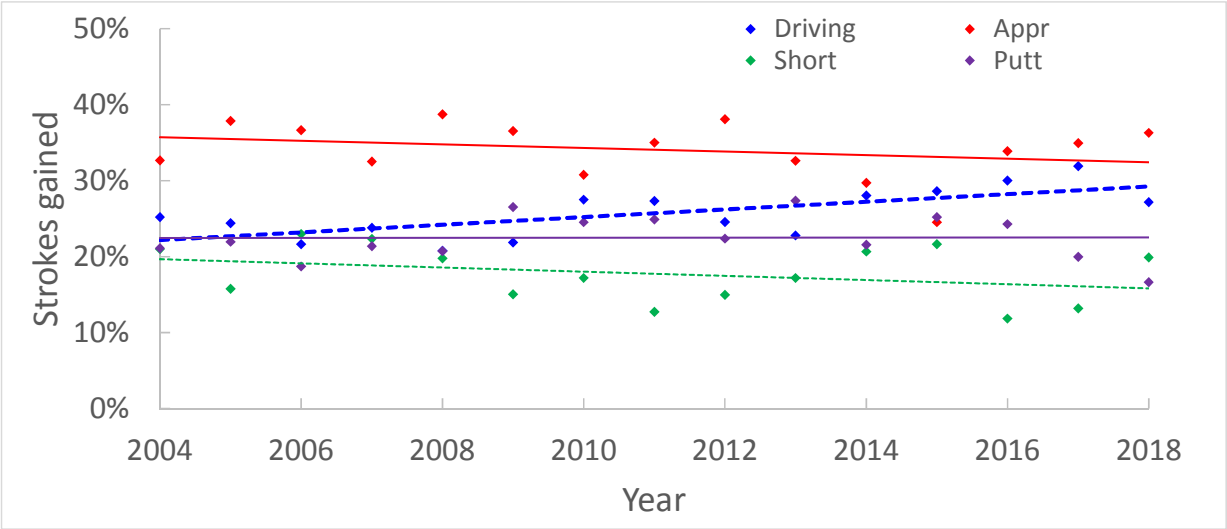

Figure 1: Strokes gained of the top 40 players in SG total. In 2004 the top 40 players had a 1.67 stroke scoring advantage relative to an average PGA Tour field. Driving contributed an average of 25% of their scoring advantage, approach shots 33%, short game 21%, and putting 21%. The regression lines indicate trends over time, with the contribution of driving increasing at a rate of 0.5% per year (p value 0.005), approach shots declining at a rate 0.3% per year (p value 0.32), short game declining at a rate 0.3% per year (p value 0.23), and putting steady with a slope of 0.0% per year (p value 0.98). The driving trend is statistically significant; the other trends are not.

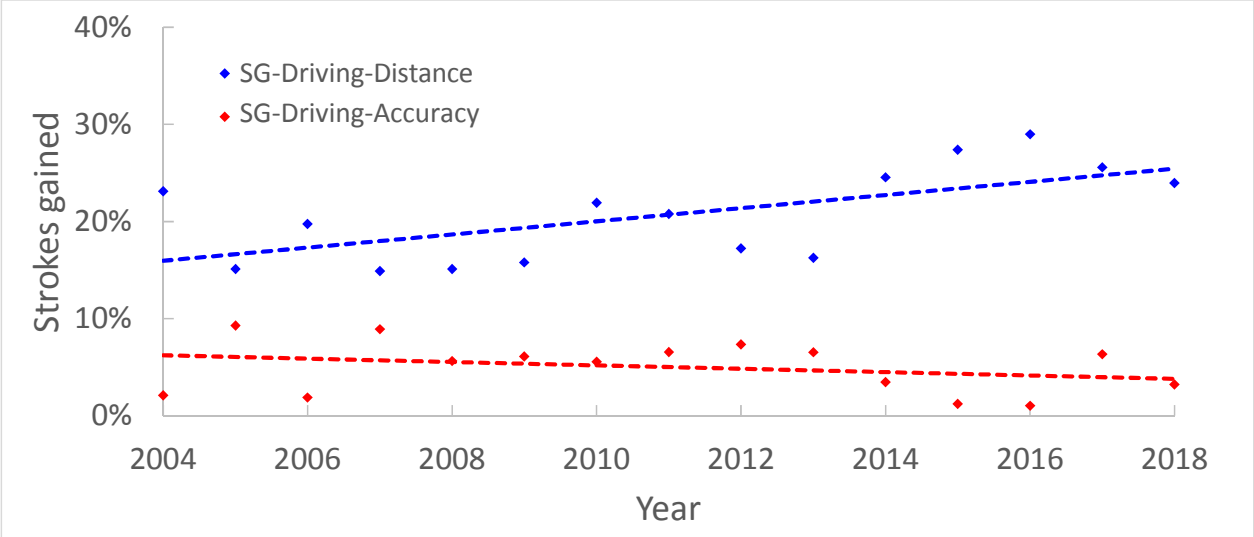

Figure 2: Strokes gained driving of the top 40 players in SG total, split into SG-Drive-Distance and SG-Drive-Accuracy. The 0.5% per year increase in the contribution of driving to scoring advantage comes from a 0.7% per year increase in the contribution of driving distance (p value 0.01) and a 0.2% per year decline in the contribution of driving accuracy (p value 0.30). The driving distance trend is statistically significant; the driving accuracy trend is not.

performance against the field. The analysis instead uses *relative* driving distance, which is driving distance relative to the field, adjusted for course difficulty and the strength of the field as described in Section 2.1.

The top 40 players in SG total are longer drivers than the PGA Tour average and also hit more

fairways. Figure 3 shows the trends of relative driving distance (in yards) and relative driving accuracy (in %) of the top 40 SG total players in each year. As before, year-to-year results show considerable variability. The relative driving distance of the top 40 SG total players increased at a rate of 0.2 yards per year (p value 0.00) and relative driving accuracy increased at a rate of 0.01% per year (p value 0.80). The relative driving distance trend is statistically significant; the relative driving accuracy trend is not. From 2004 to 2010 the top 40 SG total players averaged 4.0 yards longer than an average PGA Tour field; from 2011 to 2018 it was 5.9 yards, an increase of 1.9 yards (a 47% increase).

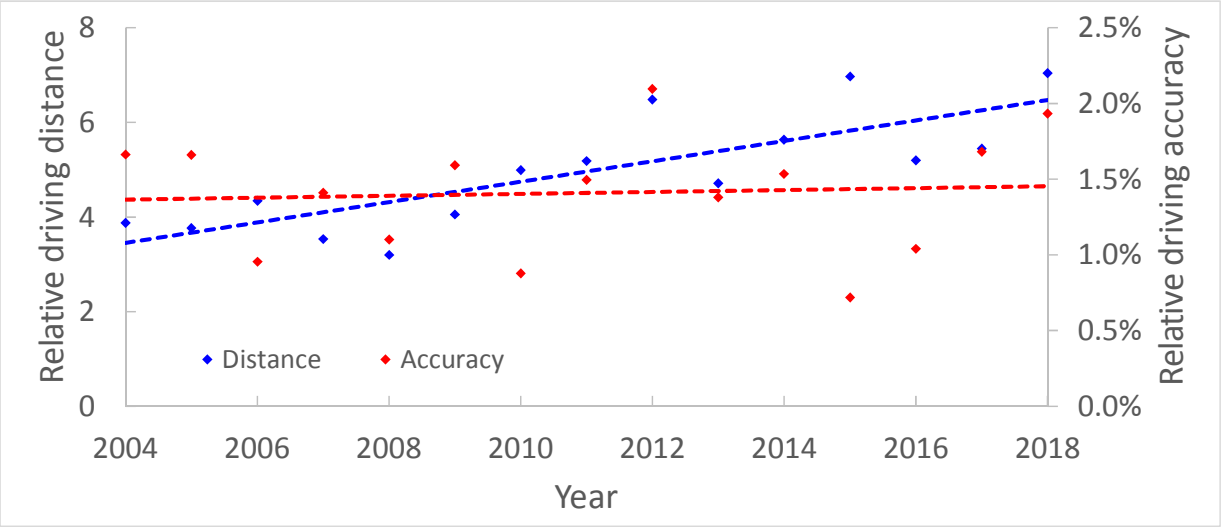

Figure 3: Relative driving distance and relative accuracy of the top 40 players in SG total. The regression lines indicate trends over time, with the relative driving distance of the top 40 SG total players increasing at a rate of 0.2 yards per year (p value 0.00) and relative driving accuracy increasing at a rate of 0.01% per year (p value 0.80). The relative driving distance trend is statistically significant; the relative driving accuracy trend is not.

Figure 4 shows the trends of relative greens in regulation (GIR) and relative putts per round (PPR) of the top 40 players in SG total in each year. As expected, the top 40 players in SG total hit more greens and take fewer putts than the PGA Tour average. Both trends are "flat" and neither trend is statistically significant.

The results using relative standard statistics are broadly consistent with the strokes gained trends. That is, driving distance has contributed an increasing share of the scoring contribution of the top players, while trends in driving accuracy, GIR and putts per round are not statistically significant. It is difficult to quantify the impact on scores using standard statistics, but at least the trends are consistent between the two methods.

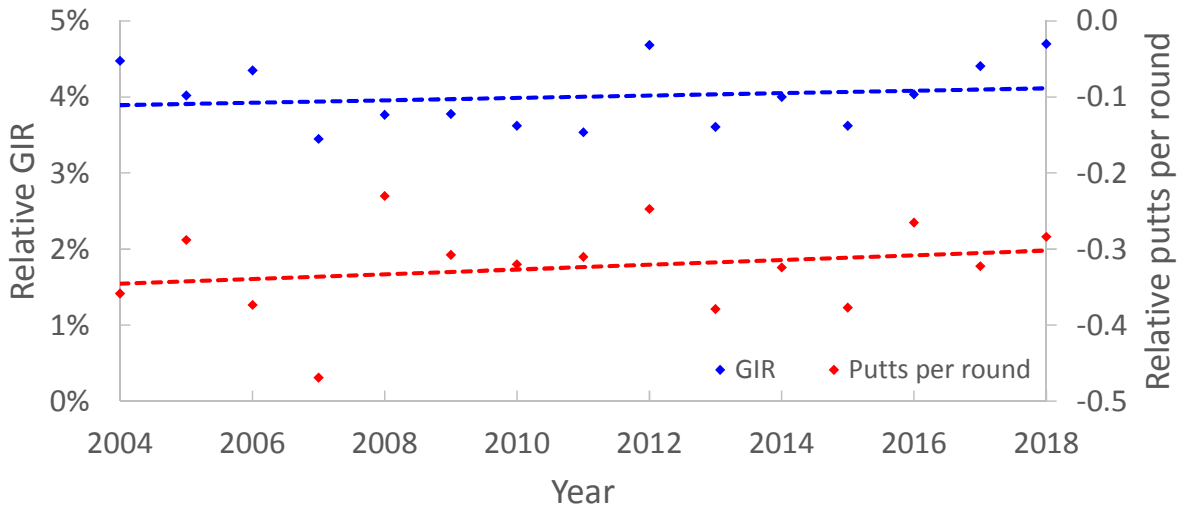

Figure 4: Relative greens in regulation (GIR) and relative putts per round (PPR) of the top 40 players in SG total. The regression lines indicate trends over time, with the relative GIR of the top 40 SG total players changing at a rate of 0.02% per year (p value 0.55) and relative putts per round changing at a rate of 0.003 putts per year (p value 0.41). Neither trend is statistically significant.

5. Standard Statistics Results, 1983-2018

Since relative standard statistics (i.e., standard statistics adjusted for course difficulty and the strength of the field) give broadly similar results to SG analysis, it makes sense to analyze the pre-ShotLink years 1983 to 2003 using the relative stats. (Putts per round data was only available in the data from 1993 onward.)

Figure 5 shows the trends of relative driving distance and relative driving accuracy of the top 40 SG total players in each year. Using the procedure described in Section 2.3, the most significant break point for driving distance was 2004 and driving accuracy was 2003. Since these were so similar, the break point of 2003 was used for both. In the years 1983-2003 relative driving distance increased at a rate of 0.08 yards per year (p value 0.03) and relative driving accuracy decreased at a rate -0.1% per year (p value 0.00).

In the 1980s, the top 40 scorers (as measured by SG total) were 3.1 yards longer than the Tour average; 3.8 yards in the 1990s, 3.9 yards in the 2000s, and 5.7 yards in the 2010s. In the 1980s, the top 40 scorers hit 4.1% more fairways than the Tour average; 2.8% more in the 1990s, 1.8% more in the 2000s, and 1.4% more in the 2010s.

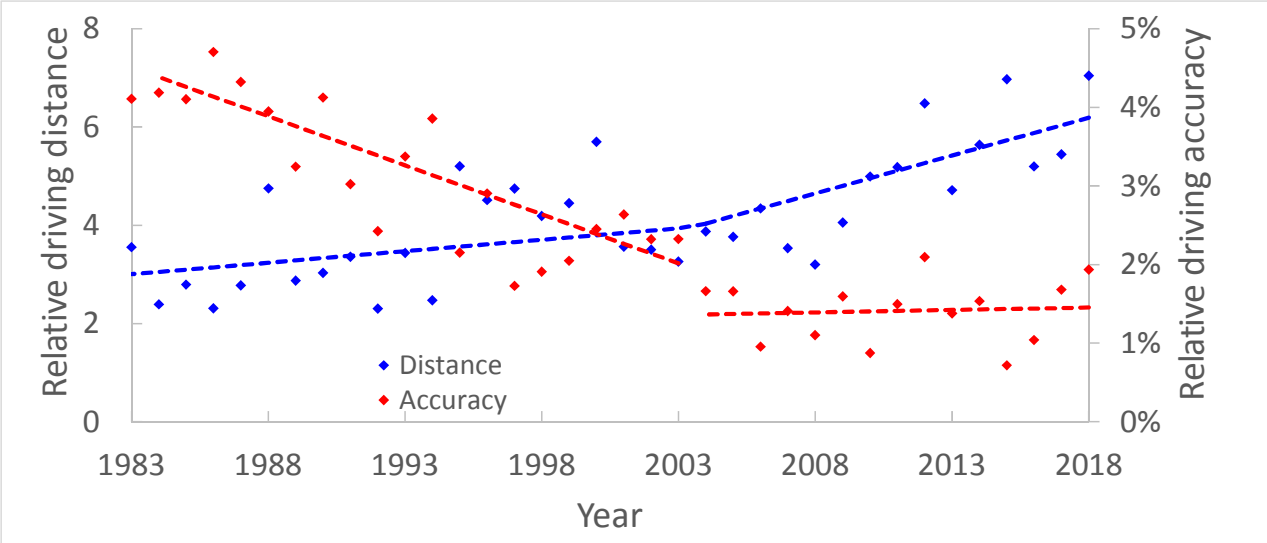

Figure 5: Relative driving distance and relative accuracy of the top 40 players in SG total. The regression lines indicate trends over time, with a split at the beginning of 2004, which was identified using a procedure based on Welch's t-test described in Section 2.3. Relative driving distance trends are statistically significant in 1983-2003 (p value 0.03) and 2004-2018 (p value 0.00). The relative driving accuracy trend is statistically significant in 1983-2003 (p value 0.00) but not in 2004-2018 (p value 0.80).

Figure 6 shows the trends of relative GIR and relative PPR of the top 40 players in SG total in each year. None of the trends are statistically significant. (For consistency, the same 2003 break year used in Figure 5 was also used in Figure 6.)

Throughout the period 1983 to 2018 the importance of driving distance increased and was statistically significant. The only other statistically significant trend observed was the decreased importance of driving accuracy from 1983 to 2003.

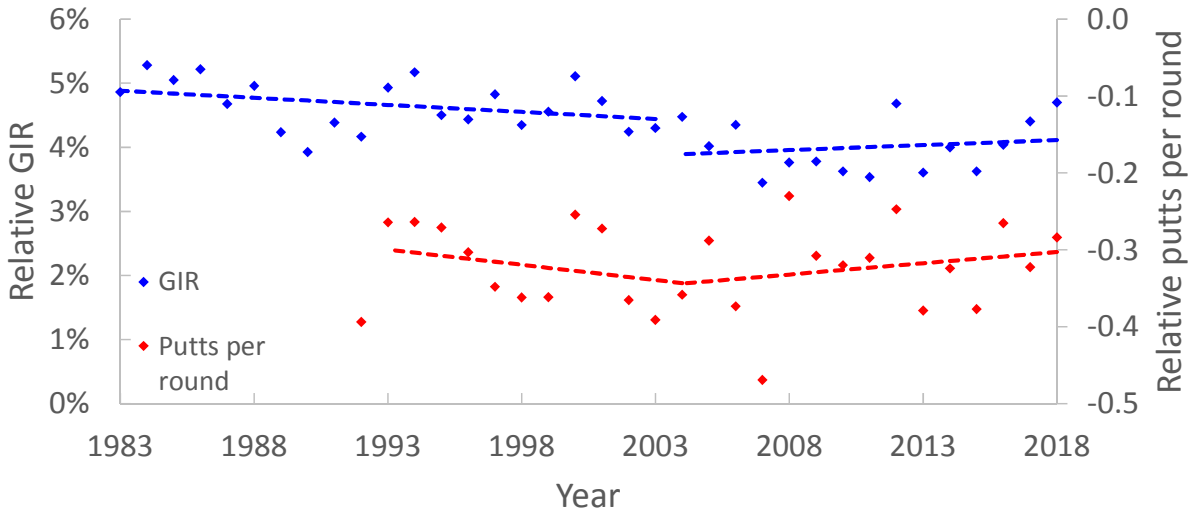

Figure 6: Relative greens in regulation (GIR) and relative putts per round (PPR) of the top 40 players in SG total. The regression lines indicate trends over time, with a split at 2003, the same break year used in Figure 5. GIR trends are not statistically significant in 1983-2003 (p value 0.12) and 2004-2018 (p value 0.55). Relative PPR trends are not statistically significant in 1993-2003 (p value 0.45) and 2004-2018 (p value 0.41).

6. Missed Fairway Cost, 1992-2018

One could naturally suspect that the decreasing trend in the relative driving accuracy of the top players from 1983 to 2003 happened because of a decreased cost for missing the fairway (i.e., a change in course conditions that could include less penal rough or wider fairways). That is, players could favor distance over accuracy more if the cost of missing a fairway was smaller. That turns out *not* to be the case. In this section, the cost of missing a fairway, measured in strokes, is measured through time.

Missing a fairway leads to a tougher approach shot from the rough, or worse if the tee shot ends in the woods, hazard or out of bounds. A simple way of defining the missed fairway cost for a given par-4 or par-5 hole is the average hole score of players who miss the fairway minus the average hole score of players who hit the fairway. This definition measures the missed fairway cost in natural units of strokes and requires hole-level information to compute. Note that the missed fairway cost includes the cost of hitting out of bounds, in the water, into the woods, sand, etc. It also includes the cost due to shots in the rough not rolling as far as shots that finish in the fairway.

Computation of the missed fairway cost does not require shot-level data, only hole scores and fairway hit information. Results from 1992 to 2018 are shown in Figure 7. The average missed fairway cost was 0.35 strokes. The trend through time is not statistically significant (p value 0.65).[8]

[8]Unfortunately, this kind of hole-level information is not available from 1983 to 1991. For these early years, the missed fairway cost can be approximated using round-level data. That is, the average round score of players can be regressed against the fraction of fairways hit. The coefficient of this regression indicates the change in score as the fraction of fairways hit changes. A little algebra can then be used to compute a missed fairway cost. The round-level data gives results that are similar to those with the hole-level data. Using round-level data from 1992 to 2018, the average missed fairway cost was 0.37 strokes compared to 0.35 strokes using hole-level data.

Taken together, *the cost of missing a fairway has not changed significantly over the period 1992 to 2018.* The missed fairway cost varies greatly by course. See Section 12 in the Appendix.

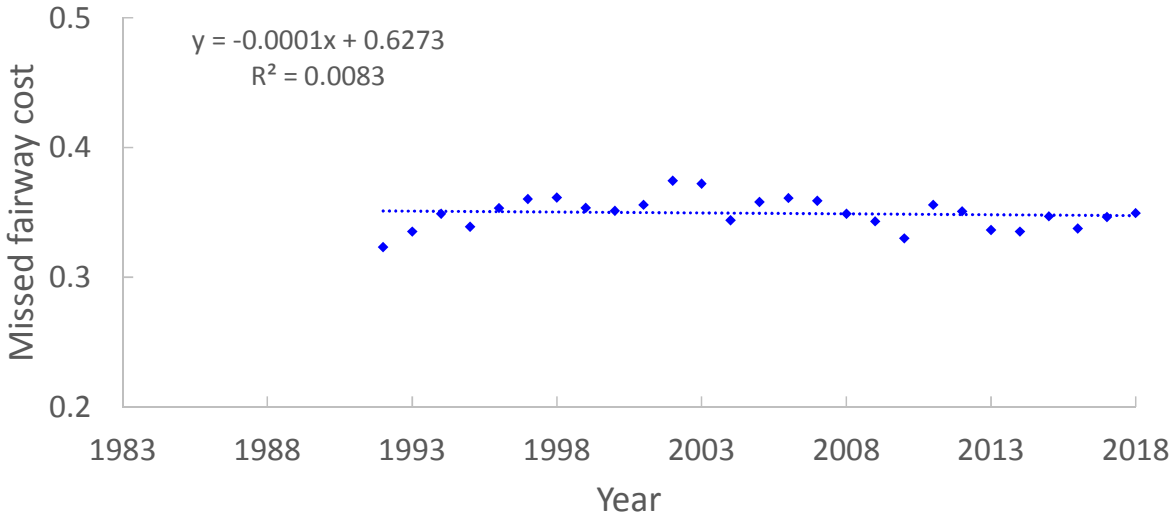

Figure 7: Missed fairway cost through time based on hole-level data. The trend is not statistically significant (p value 0.65). The average missed fairway cost over the period from 1992 to 2018 was 0.35 strokes, with a maximum value of 0.37 in 2002 and a minimum value of 0.32 in 1992.

7. Rough Penalty, 2004-2018

The cost of a missed fairway includes out of bounds shots, shot into water and other penalty and recovery situations. By contrast, the *rough penalty* only looks at the cost of hitting out of the rough versus the fairway. For this analysis, the rough category is defined by the ShotLink designations of rough, primary rough, native area, other, unknown, and second cut rough. It does not include intermediate rough (i.e., the fringe of the fairway) nor recovery shots. Shots from a given distance to the pin in the rough are compared to shots from the same distance in the fairway.

To begin, the top chart in Figure 8 shows the average strokes to hole out on the PGA Tour from 2013 to 2018 from the fairway, intermediate rough, rough, sand, and recovery positions. The bottom chart in Figure 8 shows average strokes to hole out relative to the same distance from the pin in the fairway.

With shot-level data, the rough penalty can be estimated for different distance ranges. Notice in Figure 8 that the rough penalty is not exactly constant as the distance to the pin changes. The overall rough penalty is the average difference between the fairway and rough strokes to hole out curves weighted by the number of shots from each distance.[9]

[9]Another way to estimate the rough penalty uses a strokes gained analysis. For every shot starting from the fairway, it's strokes gained is computed. These are averaged across all fairway shots to give SG_f. This value will be close to zero because of the definition of strokes gained. For every shot starting from the rough, it's strokes gained is computed *as if* it started from the fairway. These values are averaged across all rough shots to give SG_r. Then the rough penalty is $\text{SG}_f - \text{SG}_r$. This strokes gained analysis explicitly accounts for different fairway and rough starting distances, weights the starting distances by the number of shots, and is more accurate for small data sets (because,

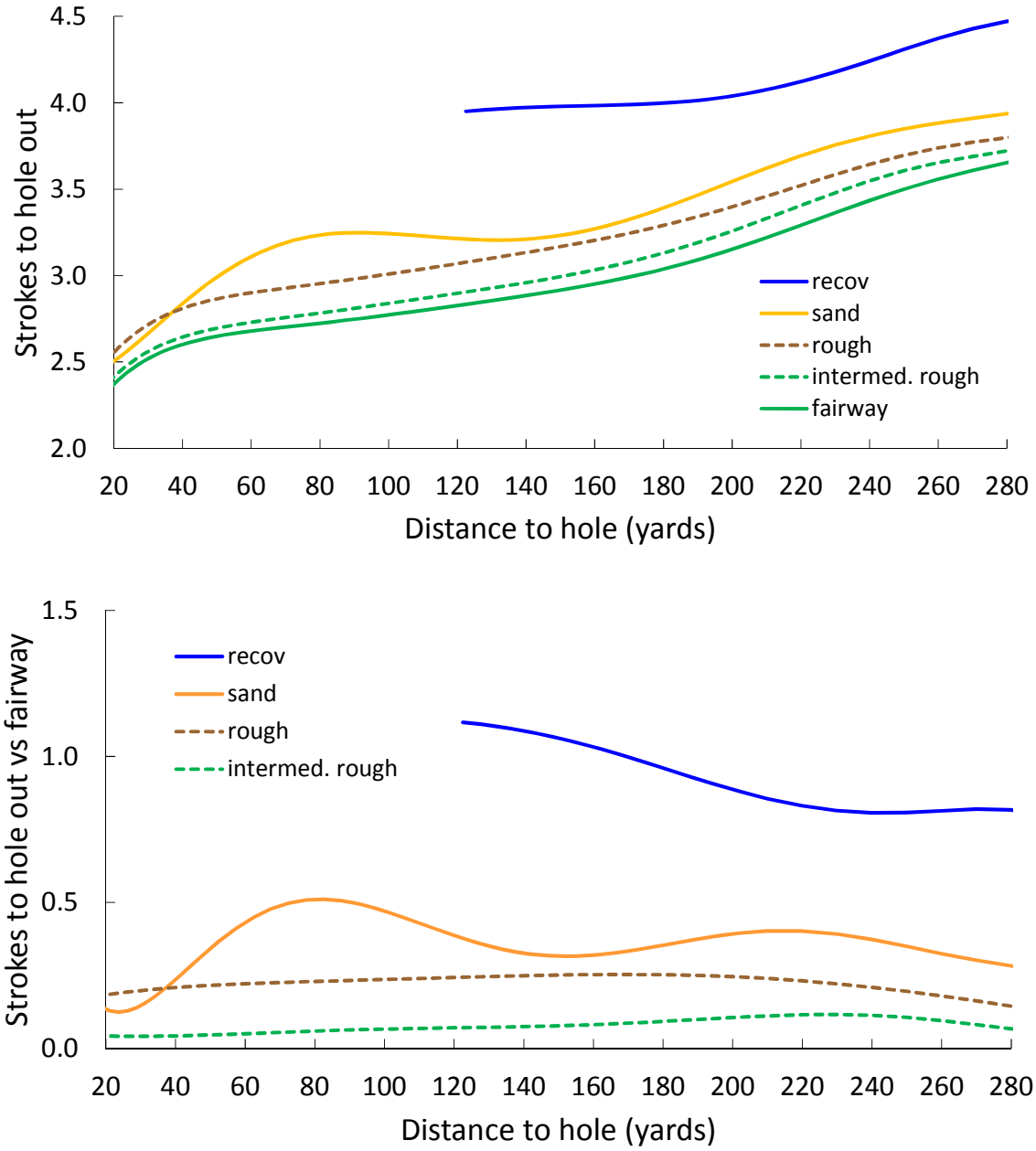

Figure 8: Top chart: Average strokes to hole out on the PGA Tour from 2013 to 2018. For example, from 100 yards in the fairway the average strokes to hole out is 2.77, 2.84 from the intermediate rough, 3.01 from the rough and 3.24 from the sand. Bottom chart: Average strokes to hole out with the on the PGA Tour from 2013 to 2018 relative to being in the fairway. For example, from 100 yards from the pin, the average strokes to hole out is 0.07 strokes more from the intermediate rough than from the fairway, 0.24 additional strokes from the rough, and 0.47 additional strokes from the sand. From 100 yards, the rough penalty is 0.24 strokes.

e.g., it credits an eight-foot putt with 1.5 strokes, where it will either be sunk or not when looking at a hole score). Strokes gained and strokes to hole out analysis give nearly identical results for a full season. Strokes gained gives better results with less data and smaller distance categories, e.g., when looking at shots from 75 to 100 yards, the average distance to the pin from the fairway will be smaller than from the rough.

Rough penalty results for the period 2004 to 2018 for shots starting between 30 and 300 yards from the hole are given in Figure 9. *The rough penalty has not changed significantly over the period 2004 to 2018* (p value 0.32). The average rough penalty over the period 2004 to 2018 was 0.24 strokes. As expected, the rough penalty is smaller than the missed fairway cost of 0.35 strokes over the same period because penalty and recovery shots and distance differences are excluded from the rough penalty calculation. Figure 10 splits the rough penalty from 30 to 300 yards into three distance categories, 30 to 100 yards, 100 to 200 yards, and 200 to 300 yards. The rough penalty trends in the first two distances categories are not statistically significant. The distance category 200 to 300 yards shows that the rough penalty trend is statistically significant with a p value of 0.03, though the magnitude of the decline is small.

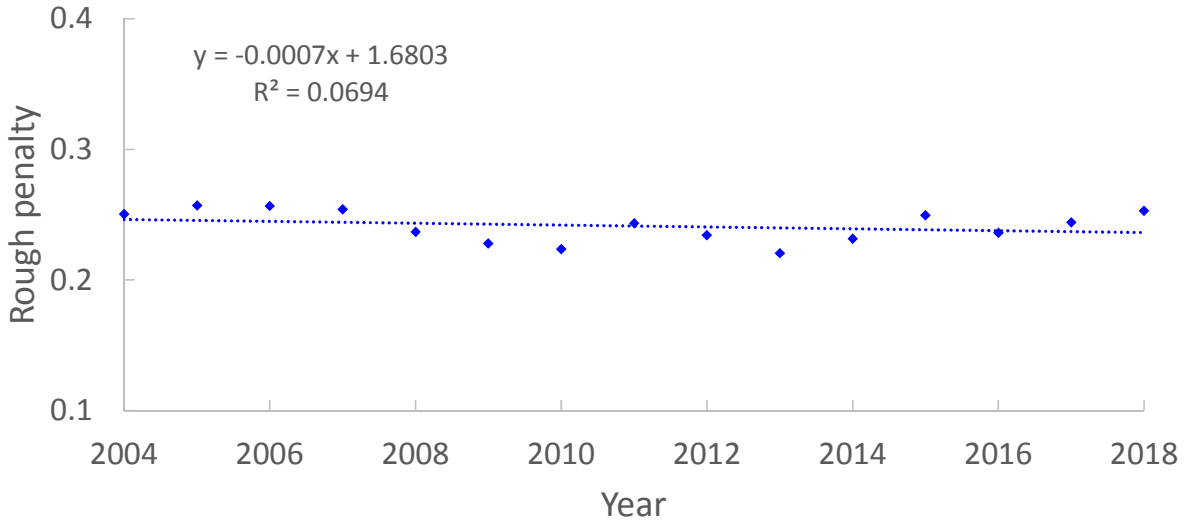

Figure 9: Rough penalty through time based on shot-level data, for shots starting between 30 and 300 yards from the hole. The trend is not statistically significant (p value 0.32). The average rough penalty over the period from 2004 to 2018 was 0.24 strokes. Fairway is taken to be the strict fairway and does not include the intermediate rough. Rough is defined to be the primary rough and does not include the intermediate rough or recovery shots. The rough penalty is smaller than the missed fairway cost because penalty and recovery shots are excluded.

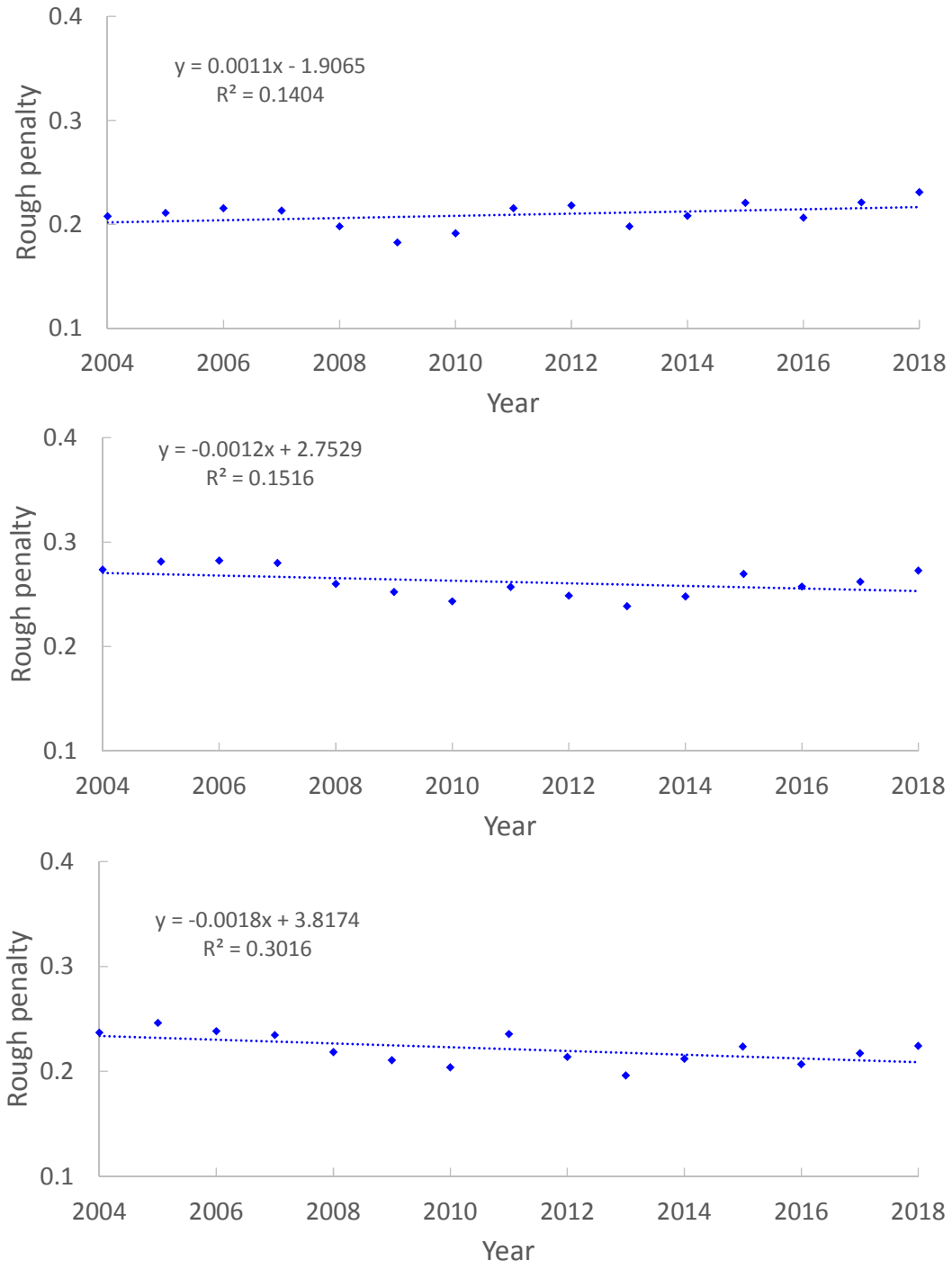

Figure 10: Top chart: Rough penalty through time based on shot-level data for shots starting between 30 and 100 yards from the hole. The slight upward trend is not statistically significant (p value 0.15). The average rough penalty over the period was 0.21 strokes for shots starting between 30 and 100 yards. Middle chart: Shots starting between 100 and 200 yards from the hole. The trend is not statistically significant (p value 0.14). The average rough penalty over the period was 0.26 strokes for shots starting between 100 and 200 yards. Bottom chart: Shots starting between 200 and 300 yards from the hole. The trend is statistically significant (p value 0.03). The average rough penalty over the period was 0.22 strokes for shots starting between 200 and 300 yards.

8. Hole Distances and Second Shot Distances

This section shows the evolution of hole distances and approach shot distances. There were significant data issues in determining hole distances. In the hole-level data, hole distances are recorded in two ways, scorecard distance and actual distance. In much of the data, actual distances are not available. Note that scorecard and actual distances are measured 'along the fairway' and not 'as the crow flies' (i.e., straight line distance). Obvious scorecard and actual hole distance errors in the data the were removed, e.g., holes over 700 yards, holes under 95 yards, par-5 holes under 300 yards, etc. To distinguish various measures of hole distance, we'll call these two "scorecard-from-hole" and "actual-from-hole."

In addition, shot-level data contains the distance from the tee to the hole. We'll called this "actual-from-shot." The main difficulty is that the actual-from-hole distances are generally much larger than the actual-from-shot distances. For example, in 2018 on par-3 holes, the average actual-from-hole distance was 198 yards while the average actual-from-shot distance was 189 yards. This is a huge difference and makes it very difficult to understand the evolution of hole distances from 1983 to 2003 when, in many years, only scorecard distances are available. Given the reliability of the shot-level data, this indicates that many of the actual-from-hole distances are incorrect, but without other information, there does not seem to be an easy way to correct the 1983 to 2003 hole-level data. For that reason, the results in this section will be restricted to the period 2004 to 2018 using shot-level data.

In addition to the actual-from-shot hole distance, the distance can be estimated directly from the shots themselves. This is done by computing the distance from the tee to the median position[10] of tee shots that land in the fairway, and adding the distance from the median fairway position to the hole. Call this distance "est-from-shot." The actual-from-shot and est-from-shot are very similar, except on sharp dogleg holes. For the analysis in this section, holes where actual-from-shot and est-from-shot differed by less than 5% were kept. This gives reliable hole lengths and restricts attention to relatively straight holes which gives more reliable year-to-year comparisons of hole lengths and approach shot distances.

Figure 11 shows how est-from-shot hole distances for par-3, 4, and 5 holes have evolved from 2004 to 2018. Rather than showing only average distances, which could obscure trends in long and short holes by par, the figure shows the 10, 25, 50, 75, and 90 percentiles of hole distances. The top chart in Figure 11 shows no trends in any of the percentiles of par-3 hole distances.[11] In short, par-3 hole distances have not changed appreciably over the period. The middle chart in Figure 11 shows that par-4 holes have increased in length over time, and all of the percentiles have increased

[10] For an odd number of elements in a sorted list, the median is the middle value. For an even number of elements in a sorted list, the median is the average of the middle two values. Compared to the average, the median value is less susceptible to influence by extreme values. For example, a drive that hits a tree close to the tee could have a big effect on the average driving distance but will have little influence on the median driving distance. The median position of shots in the fairway is taken to be the position corresponding to the median of latitude values and the median of longitude values.

[11] The p values for the five percentiles of par-3 hole distances are 0.84, 0.34, 0.92, 0.38, and 0.90 for the 10, 25, 50, 75, and 90 percentiles, respectively.

and are statistically significant.[12] The bottom chart in Figure 11 shows that the 10, 25, and 50 percentiles of par-5 hole distances have increased over time, while the 75 and 90 percentiles haven't changed significantly.[13] That is, short and medium par-5s are longer in 2018 than 2004, but long par-5s have not gotten longer.

Next we look at approach shot distances over time, in particular, the distance of the second shot to the pin on par-4 and par-5 holes. Figure 12 shows results for par-4 holes. In short, players had shorter approach shots in 2011 than 2004 and shorter in 2018 than 2011. However, the distance declines varied substantially with the length of the hole. For par-4 holes, the biggest declines were from 2004 to 2011 on short and long par-4 holes. Par-4 second shot distances declined an average of 7 yards from 2004 to 2018.

Figure 13 shows results for par-5 holes. Again, players had shorter second shot distances in 2011 than 2004 and shorter in 2018 than 2011. Par-5 second shot distances declined an average of 9 yards from 2004 to 2018.

For an illustration of a specific hole, Figure 14 shows starting points of second shots at the par-4 tenth hole at Riviera Country Club for the three years 2004, 2011 and 2018. Shots were labeled "go-for-it" if the start of the second shot was within 57 yards of the center of the green, otherwise they were labeled as "lay up." In each of the years the second shot distances for go-for-it shots averaged about 32 yards to the pin; lay up shots averaged about 84 yards to the pin. Second shot distances declined over the time because there was a dramatic shift in the fraction of players choosing the go-for-it strategy. In 2004, 36% of shots were labeled go-for-it. In 2011 the go-for-it frequency was 52% and in 2018 it was 85%.

[12] The p values for the five percentiles of par-4 hole distances are 0.04, 0.02, 0.00, 0.00, and 0.00 for the 10, 25, 50, 75, and 90 percentiles, respectively.

[13] The p values for the five percentiles of par-5 hole distances are 0.00, 0.00, 0.05, 0.99, and 0.81 for the 10, 25, 50, 75, and 90 percentiles, respectively.

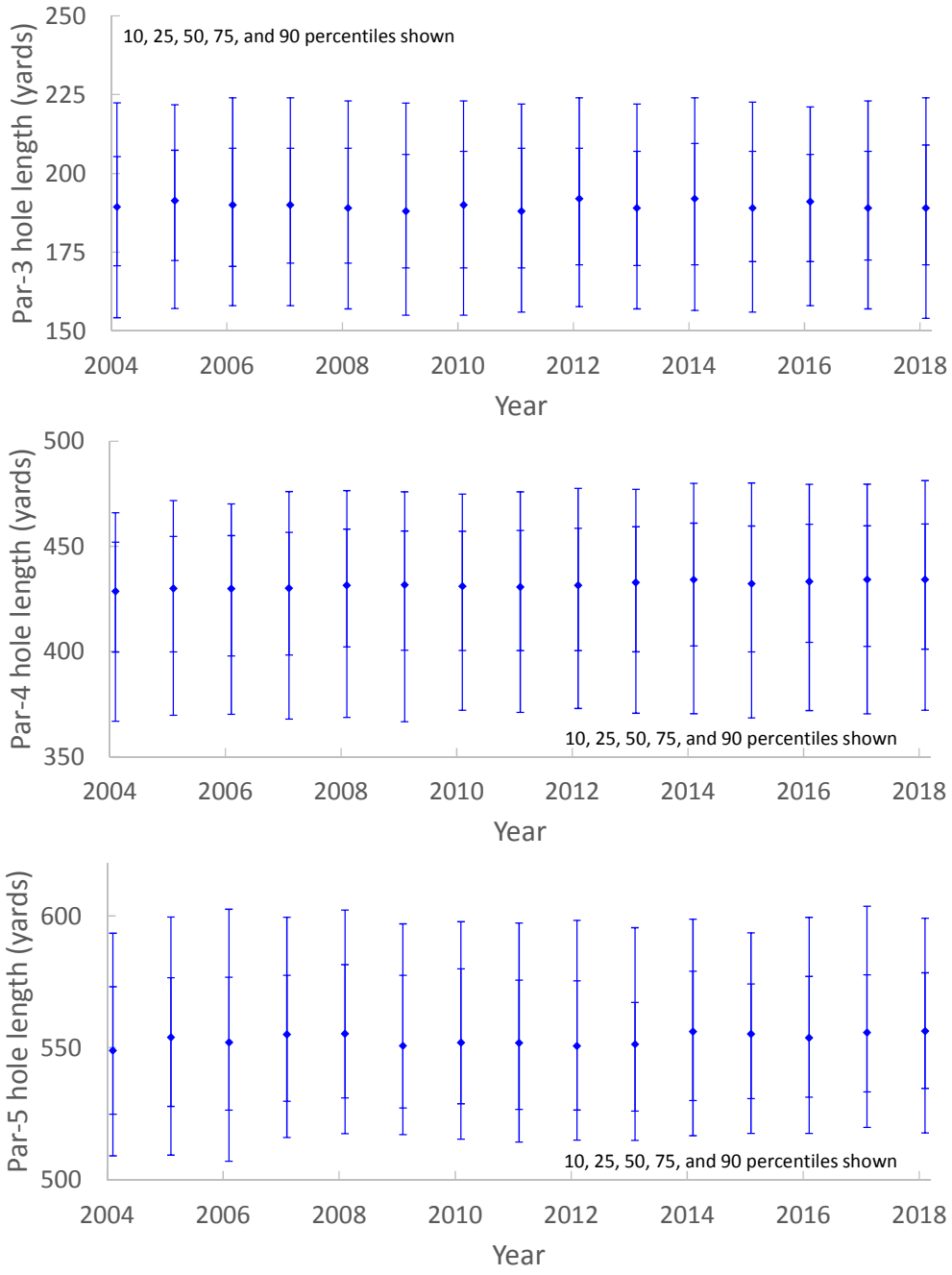

Figure 11: Percentiles of PGA Tour hole lengths from 2004 to 2018, with 10, 25, 50 (i.e., median), 75 and 90 percentiles shown. Top chart: Par-3 hole lengths. The median par-3 hole distance was 189 yards in 2004 and 189 in 2018. In fact, there was no trend in any of the par-3 hole distance percentiles. Middle chart: Par-4 hole lengths. The median par-4 hole distance increased by five yards over the period, from 429 yards in 2004 to 434 yards in 2018. The upward trends in all of the par-4 percentiles are statistically significant. From 2004 to 2018 the increase in percentile 10 was 3 yards, percentile 25 was 3 yards, percentile 50 was 5 yards, percentile 75 was 7 yards, and percentile 90 was 12 yards. The 90th percentile par-4 hole distance increased from 470 yards in 2004 to 482 yards in 2018. Bottom chart: Par-5 hole lengths. The median par-5 hole distance increased by about five yards over the period, from 551 yards in 2004-6 to 556 yards in 2018. From 2004 to 2018 the increase in percentile 10 was 9 yards, percentile 10 was 6 yards, percentile 50 was 5 yards, percentile 75 was 0 yards, and percentile 90 was 1 yard. The short and median length par-5 holes are longer in 2018 than 2004 while the distance of the long par-5 holes is unchanged.

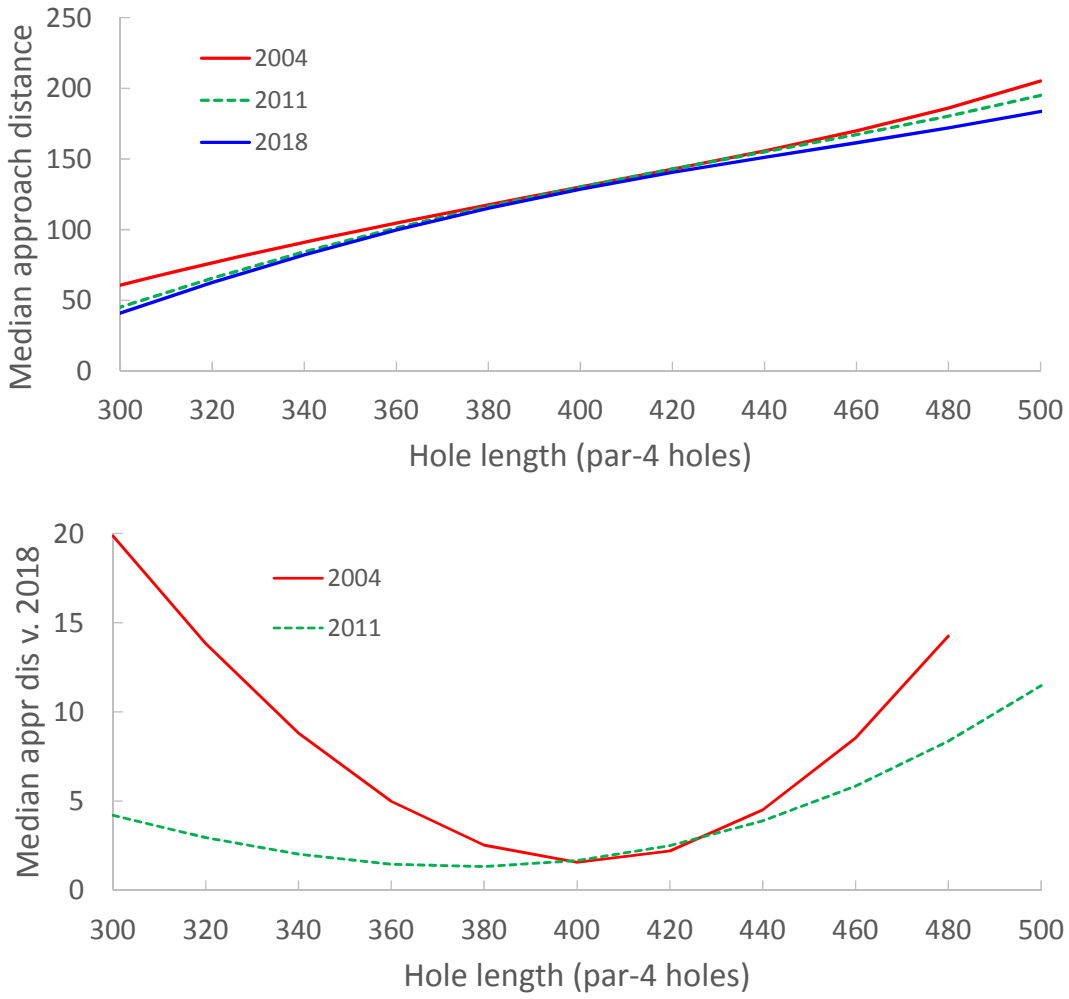

Figure 12: Top chart: Median distance of the second shot from the pin on par-4 holes for the years 2004, 2011, and 2018. Players had shorter second shots in 2011 than 2004 and shorter shots in 2018 than 2011. For example, for a 340-yard hole, the median second shot distances were 91 yards in 2004, 84 yards in 2011 and 82 yards in 2018. Interestingly, for hole lengths between 390 and 420 yards, there is little difference in median second shot distances in 2004 and 2011 and only a slight decline in 2018. Bottom chart: Differences of the median distance of the second shot from the pin on par-4 holes relative to 2018. For example, for a 340-yard hole, the median second shot distances were 2 yards shorter in 2018 compared to 2011 and 9 yards shorter in 2018 than in 2004. Par-4 second shot distances declined an average of 7 yards from 2004 to 2018.

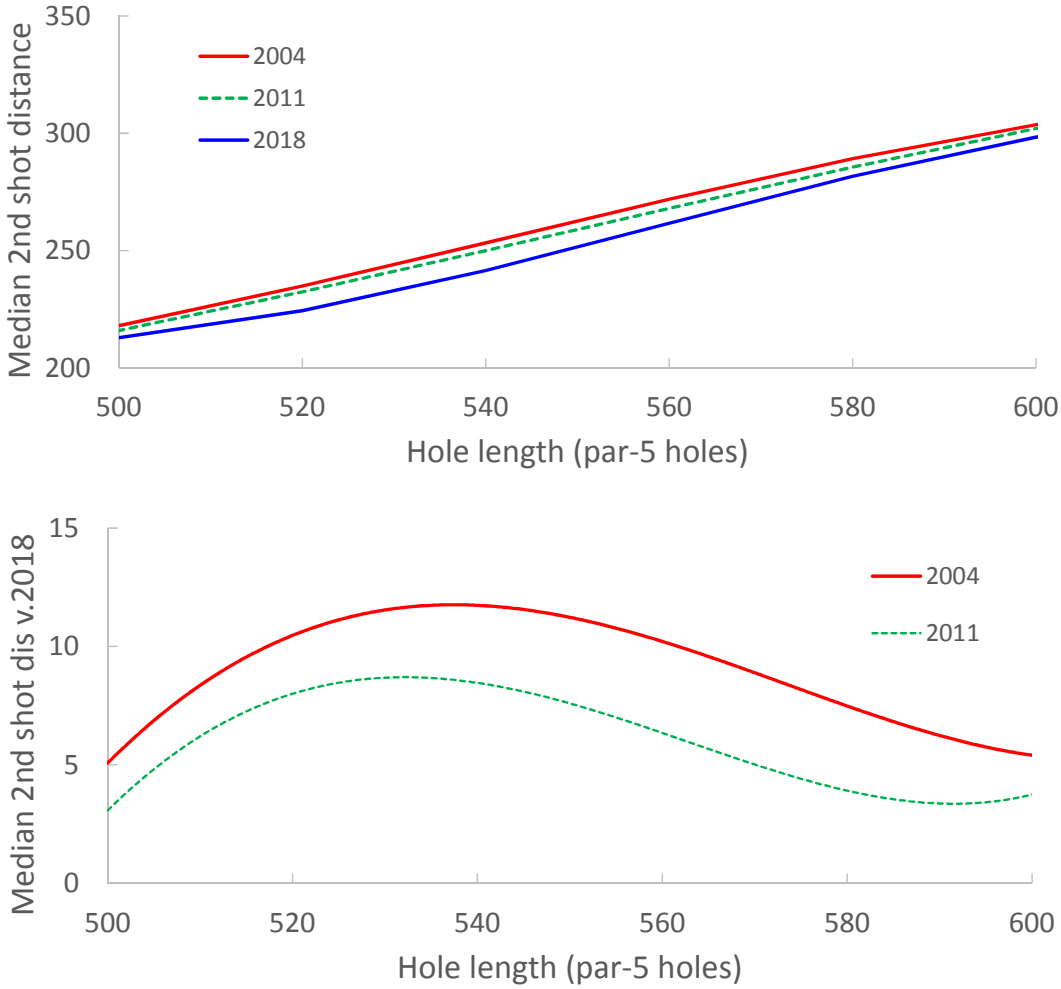

Figure 13: Top chart: Median distance of the second shot from the pin on par-5 holes for the years 2004, 2011, and 2018. Players had shorter second shots in 2011 than 2004 and shorter shots in 2018 than in 2011. For example, for a 540-yard hole, the median second shot distances were 254 yards in 2004, 250 yards in 2011 and 242 yards in 2018. Bottom chart: Differences of the median distance of the second shot from the pin on par-5 holes relative to 2018. For example, for a 540-yard hole, the median second shot distances were 8 yards shorter in 2018 compared to 2011 and 12 yards shorter in 2018 than 2004. Par-5 second shot distances declined an average of 9 yards from 2004 to 2018.

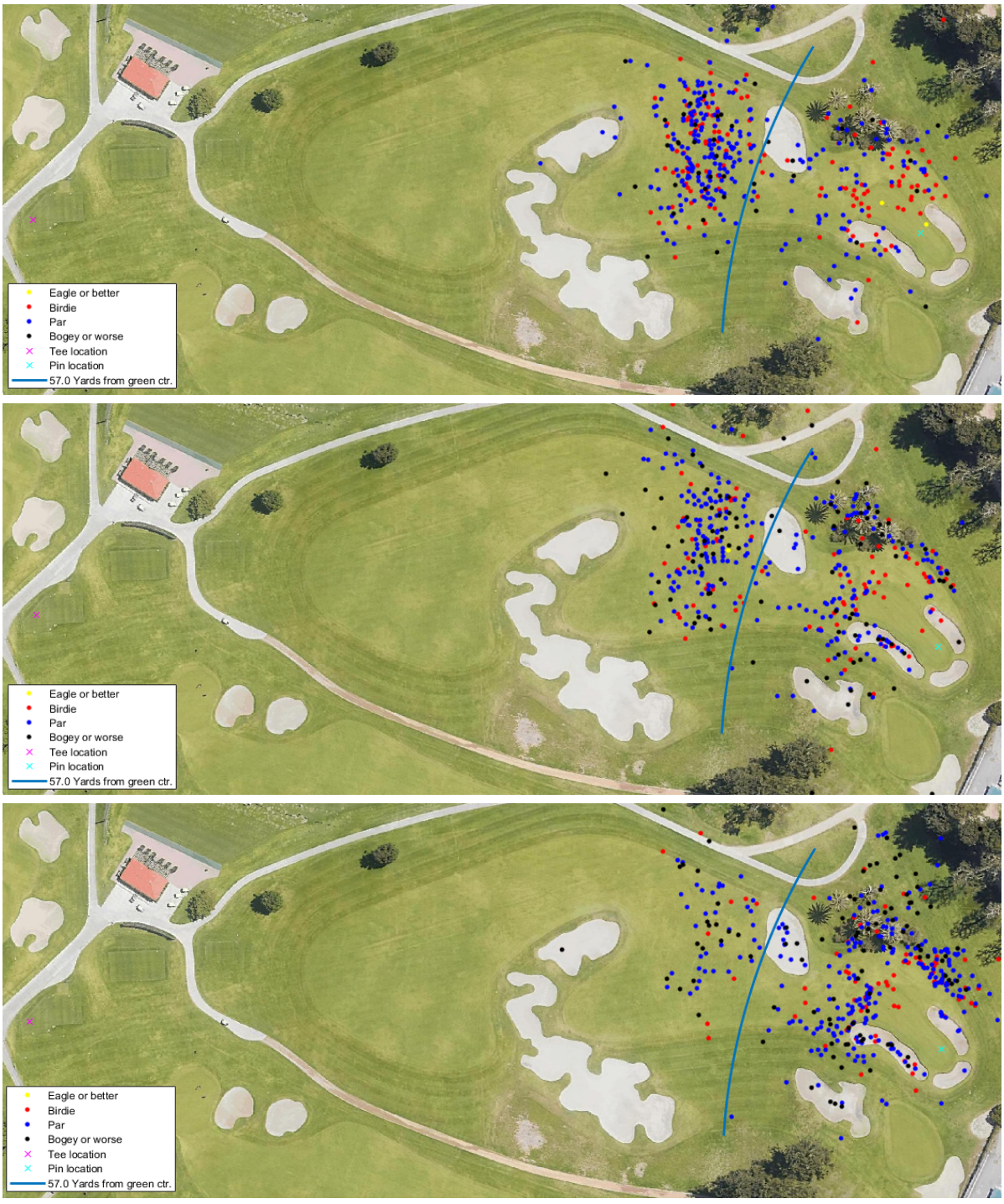

Figure 14: Starting points of second shots at Riviera Country Club for the three years 2004, 2011 and 2018. Shots were labeled "go-for-it" if the start of the second shot was within 57 yards of the center of the green, as indicated by the blue curve; otherwise shots were labeled as "lay up." Top chart: Year 2004, lay up 64% (average score 3.86), go-for-it 36% (average score 3.65). Middle chart: Year 2011, lay up 48% (average score 4.05), go-for-it 52% (average score 4.00). Bottom chart: Year 2018, lay up 15% (average score 4.19), go-for-it 85% (average score 4.03).

9. LPGA Tour Results

This section repeats similar analyses using data from the LPGA Tour. The data provided included hole-level data from 1993 to 2018 and round-level data from 1993 to 2007.[14] The hole-level data included player, par, and score information. The round-level data included drive distance for two drives, fairways hit, greens in regulation and putts per round. With this data, the main meaningful analysis that could be done was from 1993 to 2007. Much work was needed to clean the data as best as possible to deal with instances of incomplete, missing, and inaccurate data.

Figure 15 shows LPGA average scores by hole distance for the years 1993 and 2007. The hole distances are estimated by scorecard yardages, which are approximations of the actual hole distances. Although the difference between actual hole distances and scorecard distances are not known, one would expect that the two measures would be very highly correlated. For fixed hole distances less than 190 yards, average scores remained virtually constant over the period. For fixed hole distances greater than 350 yards, average scores dropped about 0.08 strokes from 1993 to 2007.

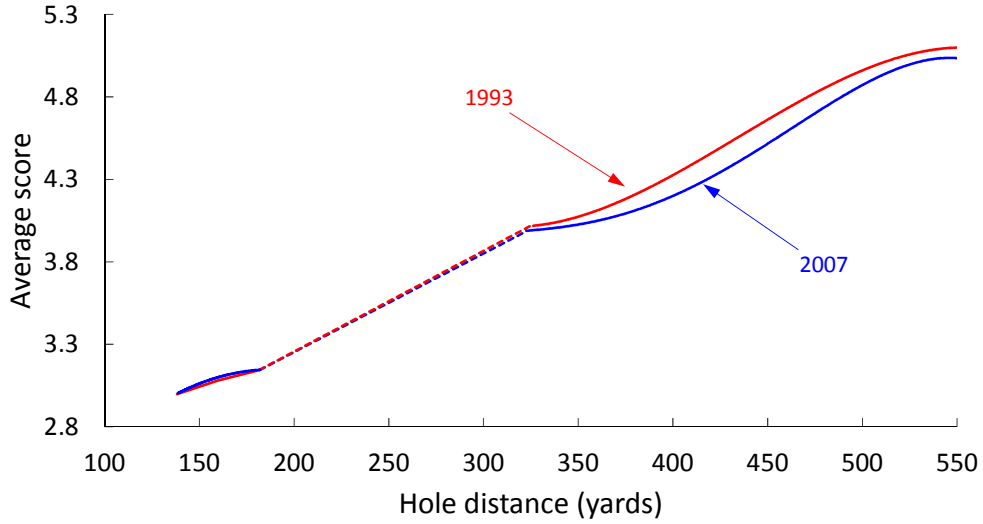

Figure 15: LPGA Tour scoring averages by hole distance for 1993 and 2007. For holes under 190 yards long, the average scores did not change significantly. There was not enough data for holes between 190 and 350 yards to make any statistically significant conclusions. For holes greater than 350 yards, the scoring average declined in a statistically significant way from 1993 to 2007. Analysis of all years of data over the period 1993 to 2007 (not just the two years 1993 and 2007) indicates that the average score dropped by about 0.08 strokes for holes over 350 yards long.

Figure 16 shows the evolution of par-3, 4, and 5 scorecard hole distances from 1993 to 2018. The average par-3 hole distance increased about 10 yards over the period while par-4 hole distances increased 20 yards and par-5 hole distances increased 28 yards.

Figure 17 shows the trend in average LPGA round scores by year. Round scores have declined an average of 0.04 strokes per year, or about 1.1 strokes over the period 1993 to 2018. Round scores

[14] Round-level files for 2008 to 2018 contained only a small fraction of data compared to previous years, which was not sufficient for reliable analysis.

have declined in spite of the increase in hole distances and course length.

Figures 18–21 show trends in LPGA Tour driving distance, fairways hit, greens in regulation, and putts per round. Over the period 1993 to 2006, LPGA Tour median driving distance increased 1.8 yards per year (24 yards increase total, p value 0.00); LPGA Tour average fairways hit increased 0.02 (per round) per year (0.3 fairways hit increase total, p value 0.02); LPGA Tour average greens in regulation increased 0.1% (per round) per year (1.6% GIR increase total, p value 0.03); LPGA Tour average putts per round decreased (improved) 0.04 per year (0.52 decrease total, p value 0.00). All trends are statistically significant.

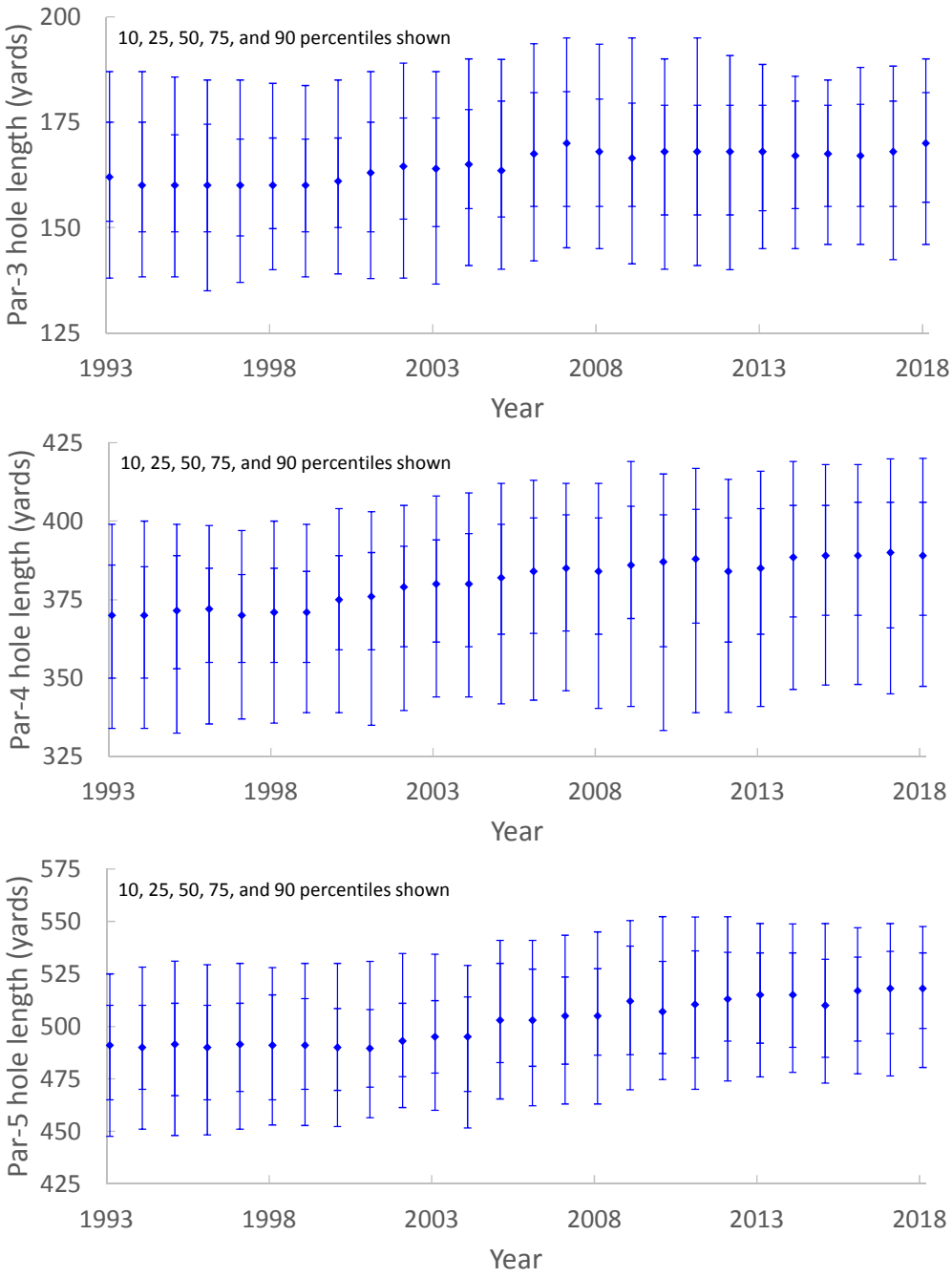

Figure 16: LPGA Tour par-3 hole lengths from 1993 to 2018 , with 10, 25, 50 (i.e., median), 75 and 90 percentiles shown. Hole lengths are from scorecard data, not the actual hole distances. Top chart: LPGA Tour par-3 hole lengths. The median par-3 hole distance was about 160 yards in 1993 and 170 yards in 2018. The average increase of 0.4 yards per year is statistically significant with a p value of 0.00. The upward trends in all of the par-3 percentiles are statistically significant. Middle chart: LPGA Tour par-4 hole lengths. The median par-4 hole distance was about 370 yards in 1993 and 390 yards in 2018. The average increase of 0.9 yards per year is statistically significant with a p value of 0.00. The upward trends in all of the par-4 percentiles are statistically significant. Bottom chart: LPGA Tour par-5 hole lengths. The median par-5 hole distance was about 490 yards in 1993 and 518 yards in 2018. The average increase of 1.3 yards per year is statistically significant with a p value of 0.00. The upward trends in all of the par-5 percentiles are statistically significant.

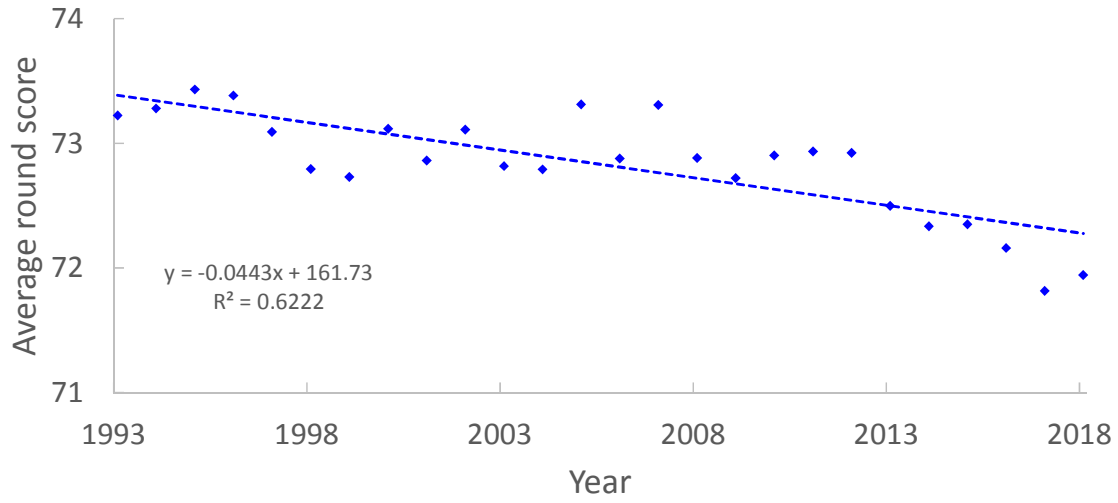

Figure 17: Average LPGA Tour round scores by year. Round scores have declined an average of 0.04 strokes per year, or about 1.1 strokes over the period 1993 to 2018. The decline is statistically significant with a p value of 0.00.

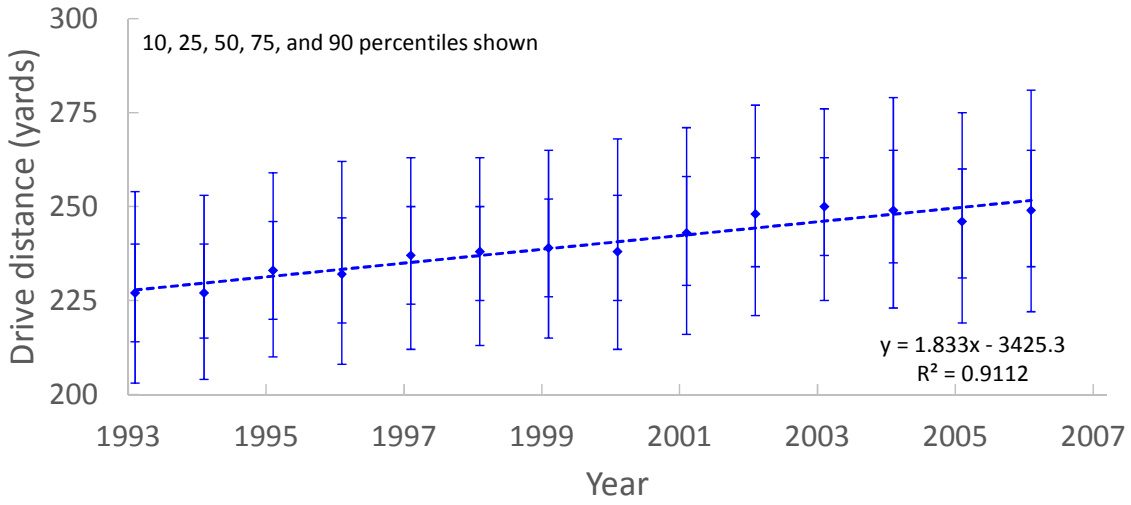

Figure 18: LPGA Tour drive distance results from 1993 to 2006. Percentiles 10, 25, 50, 75, and 90 of driving distance are shown. A trend line of the median driving distance is shown. The positive slope indicates that the LPGA Tour median driving distance increased an average of 1.8 yards per year over the period. The increase is statistically significant with a p value of 0.00. The total increase in the LPGA Tour median driving distance was about 22 yards over the period.

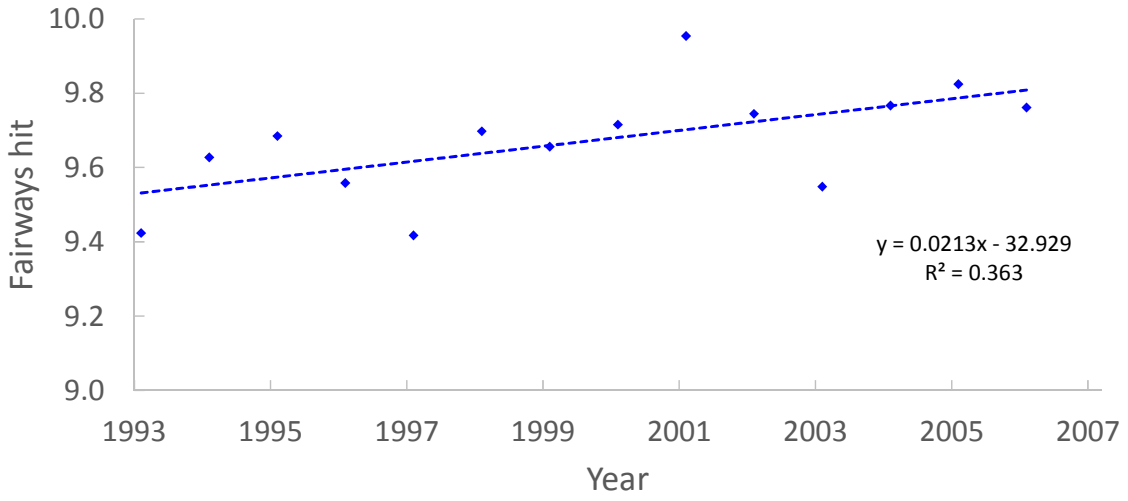

Figure 19: LPGA Tour average fairways hit per round (drive accuracy) results from 1993 to 2006. A trend line of the average fairways hit is shown. The positive slope indicates that the LPGA Tour average fairways hit increased an average of 0.02 per year over the period. The increase is statistically significant with a p value of 0.02. The total increase in LPGA Tour average fairways hit per round was 0.3 over the period.

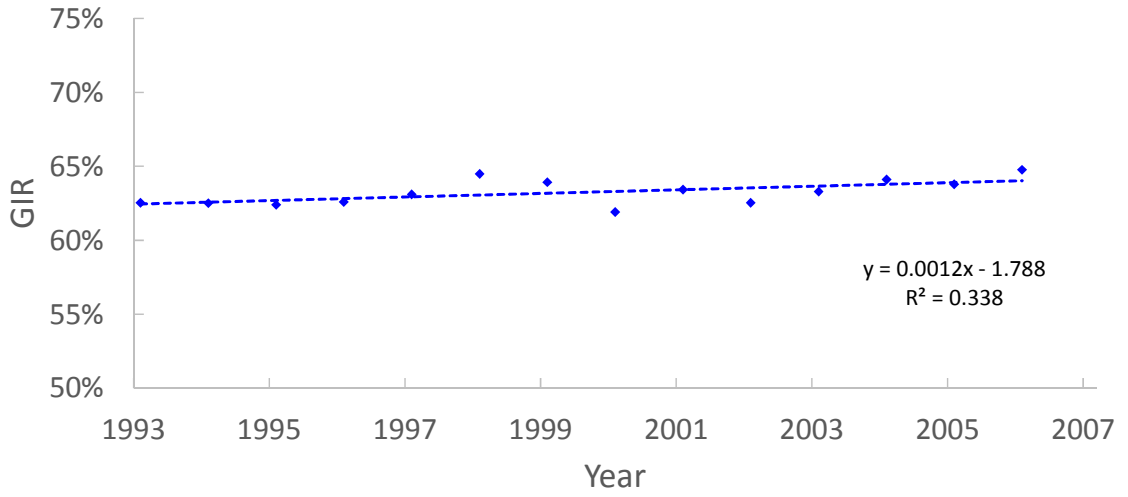

Figure 20: LPGA Tour average greens in regulation (GIR) results from 1993 to 2006. A trend line of the average GIR is shown. The positive slope indicates that the LPGA Tour average GIR increased an average of 0.1% per year over the period. The increase is statistically significant with a p value of 0.03. The total increase in LPGA Tour average GIR was 1.6% over the period.

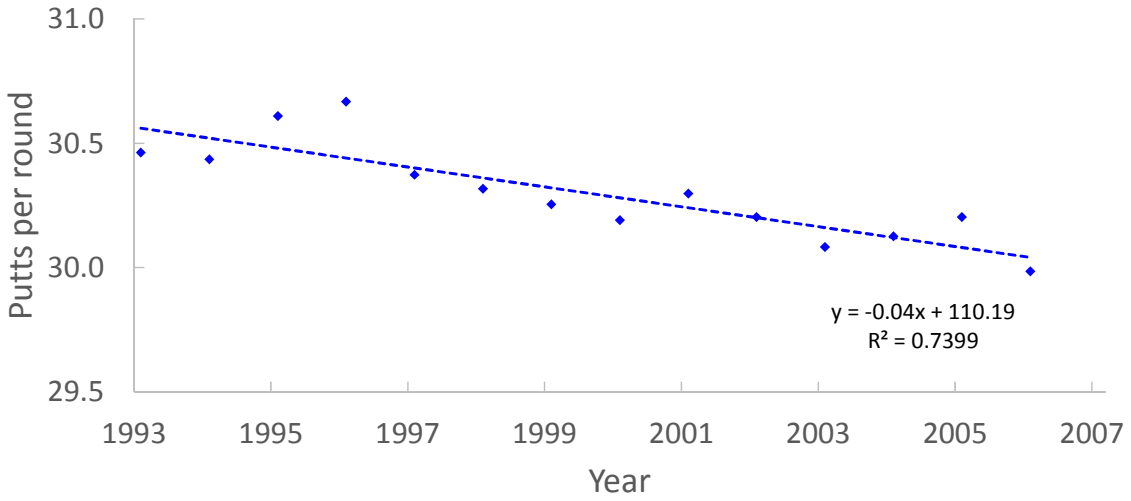

Figure 21: LPGA Tour average putts per round (PPR) results from 1993 to 2006. A trend line of the average putts per round is shown. The negative slope indicates that the LPGA Tour average PPR decreased an average of 0.04 per year over the period. The increase is statistically significant with a p value of 0.00. The total decrease in LPGA Tour average PPR was 0.4 over the period.

Tables 6–8 show the top 40 LPGA Tour players in strokes gained total (i.e., the top scorers) in the years 1993, 2000 and 2007. The advantage of these top SG total players in *relative* driving distance, fairways hit, greens in regulation and putts per round are given. For example, Table 6 shows that Nancy Lopez led the LPGA Tour in SG total in 1993, gaining 2.41 strokes per round. Compared to the LPGA Tour, and after adjusting for course difficulty and strength of field, Lopez averaged 16 yards longer with her drives, hit 0.1 more fairways per round, hit 1.4 more greens in regulation, and took 0.35 fewer putts per round. In 1993 the top 40 players scored an average of 1.51 strokes better than the LPGA Tour average, hit their drives 3.8 yards longer, hit 0.36 more fairways per round, hit 0.88 more greens in regulation and took 0.34 fewer putts per round. Table 8 shows that in 2007 the top 40 players scored an average of 1.65 strokes better than the LPGA Tour average, hit their drives 6.9 yards longer, hit 0.14 more fairways per round, hit 0.97 more greens in regulation and took 0.25 fewer putts per round.

In 1993 the LPGA Tour average driving distance was 228 yards and in 2007 it was 249 yards. In 1993 the top 40 LPGA Tour SG total leaders had an average driving distance of 231 (4 yards longer than the LPGA Tour average). In 2007 the top 40 LPGA Tour SG total leaders had an average driving distance of 256 (7 yards longer than the LPGA Tour average). Tables 6 and 8 suggest that while the LPGA Tour average driving distance was increasing, the driving distance of the top 40 SG total players increased even more. The results from these two years are only suggestive because there is considerable year-to-year variability in the results. To investigate trends over time, it is better to look at all years over the period, and not just the first and last years, and that is done next.

Strokes gained total leaders on the LPGA Tour in 1993

	SG:Total	Dis	Acc	GIR	Putt
Top 40 change	1.51	3.8	0.36	0.88	-0.34
Top 40 average	71.72	231.4	9.78	12.14	30.12
Tour average	73.23	227.6	9.42	11.26	30.46

Rank	Player	SG:Total	Dis	Acc	GIR	Putt	Rounds
1	Nancy Lopez	2.41	15.9	0.09	1.4	-0.35	65
2	Betsy King	2.39	10.1	0.51	1.7	-0.35	90
3	Patty Sheehan	2.37	3.7	0.29	1.4	-0.74	74
4	Brandie Burton	2.36	17.8	-0.51	1.4	-0.51	88
5	Dottie Pepper	2.18	3.0	1.08	2.1	-0.13	87
6	Helen Alfredsson	2.05	15.7	-0.36	1.4	-0.05	73
7	Trish Johnson	2.01	2.2	0.69	0.7	-0.75	55
8	Donna Andrews	1.84	-2.5	1.94	1.1	-0.22	83
9	Tammie Green	1.81	3.4	0.75	0.9	-0.58	76
10	Michelle McGann	1.76	24.0	-0.24	1.5	0.76	86
…	…	…	…	…	…	…	…
36	Juli Inkster	1.03	10.8	0.23	0.4	-0.03	66
37	Amy Benz	1.01	-0.1	0.16	0.8	0.23	71
38	Alice Ritzman	1.00	8.5	0.45	0.9	0.10	62
39	Joanne Carner	0.97	4.6	-1.12	0.1	-0.57	61
40	Alison Nicholas	0.97	-0.3	1.12	0.4	-0.31	47

All results include "course difficulty" and "strength of field" adjustments

Table 6: The table shows the top 40 LPGA Tour players in strokes gained total in 1993. For each player, their relative driving distance, relative fairways hit, relative greens in regulation, and relative putts per round are given (where "relative" refers to values that are relative to the LPGA Tour average, adjusted for course difficulty and the strength of the field). Nancy Lopez led the LPGA tour in SG total gaining 2.41 strokes per round. The top 40 players scored an average of 1.51 strokes better than the LPGA Tour average. Their drives averaged 3.8 yards longer, they hit 0.36 more fairways per round, they hit 0.88 more greens in regulation and they took 0.34 fewer putts per round.

Strokes gained total leaders on the LPGA Tour in 2000

	SG:Total	Dis	Acc	GIR	Putt
Top 40 change	1.53	4.4	0.21	0.97	-0.31
Top 40 average	71.62	243.4	9.92	12.12	29.88
Tour average	73.15	239.0	9.71	11.15	30.19

Rank	Player	SG:Total	Dis	Acc	GIR	Putt	Rounds
1	Karrie Webb	3.57	13.2	0.56	2.3	-0.36	74
2	Annika Sorenstam	3.05	6.1	1.30	2.4	0.07	72
3	Juli Inkster	2.95	8.5	0.67	2.0	-0.60	62
4	Dottie Pepper	2.65	-2.3	-0.28	1.2	-1.33	60
5	Meg Mallon	2.51	2.3	0.85	1.6	-0.56	84
6	Mi Hyun Kim	2.21	4.4	0.48	0.9	-0.96	91
7	Pat Hurst	2.10	15.8	-0.55	1.5	-0.02	94
8	Lorie Kane	2.05	6.2	1.20	1.1	-0.80	94
9	Rosie Jones	2.02	-8.5	1.19	0.9	-0.87	81
10	Se Ri Pak	1.99	11.2	-0.21	1.4	0.21	76
...	...	...	...	...	...	...	...
36	Tina Barrett	0.89	-9.0	1.61	0.7	-0.30	75
37	Michelle McGann	0.88	14.2	-1.31	0.7	0.16	82
38	Nancy Scranton-Brown	0.86	1.0	-0.25	0.5	-0.30	80
39	Susie Redman	0.83	-3.4	1.05	0.6	0.34	75
40	A.J. Eathorne	0.83	7.9	0.48	0.5	-0.35	83

All results include "course difficulty" and "strength of field" adjustments

Table 7: The table shows the top 40 LPGA Tour players in strokes gained total in 2000. For each player, their relative driving distance, relative fairways hit, relative greens in regulation, and relative putts per round are given (where "relative" refers to values that are relative to the LPGA Tour average, adjusted for course difficulty and the strength of the field). Karrie Webb led the LPGA tour in SG total gaining 3.57 strokes per round. The top 40 players scored an average of 1.53 strokes better than the LPGA Tour average. Their drives averaged 4.4 yards longer, they hit 0.21 more fairways per round, they hit 0.97 more greens in regulation and they took 0.31 fewer putts per round.

Strokes gained total leaders on the LPGA Tour in 2007

	SG:Total	Dis	Acc	GIR	Putt
Top 40 change	1.65	6.9	0.14	0.97	-0.25
Top 40 average	71.66	256.3	9.86	12.19	29.82
Tour average	73.30	249.4	9.72	11.22	30.07

Rank	Player	SG:Total	Dis	Acc	GIR	Putt	Rounds
1	Lorena Ochoa	4.03	25.3	0.11	2.6	-0.49	41
2	Paula Creamer	3.03	-0.1	1.22	1.9	-0.24	41
3	Suzann Pettersen	2.80	26.5	-0.19	2.3	-0.19	37
4	Annika Sorenstam	2.62	6.1	0.30	0.9	-1.13	20
5	Jiyai Shin	2.46	8.8	1.94	1.4	-0.11	11
6	Stacy Prammanasudh	2.13	3.5	-0.53	0.4	-1.39	35
7	Jee Young Lee	2.05	27.2	-0.66	2.4	0.38	37
8	Mi Hyun Kim	2.04	-7.5	1.56	0.2	-1.83	44
9	Morgan Pressel	2.00	-0.2	0.86	1.4	-0.83	39
10	Cristie Kerr	1.92	3.4	0.20	1.0	-0.79	31
…	…	…	…	…	…	…	…
36	Jimin Kang	0.67	-0.1	0.84	0.7	0.54	37
37	Alena Sharp	0.67	13.6	-1.21	0.6	0.68	27
38	Wendy Ward	0.64	2.1	0.68	1.4	1.71	29
39	Michele Redman	0.57	-0.2	-0.05	0.5	0.88	34
40	Ilmi Chung	0.53	-4.0	0.07	0.1	-0.75	42

All results include "course difficulty" and "strength of field" adjustments

Table 8: The table shows the top 40 LPGA Tour players in strokes gained total in 2007. For each player, their relative driving distance, relative fairways hit, relative greens in regulation, and relative putts per round are given (where "relative" refers to values that are relative to the LPGA Tour average, adjusted for course difficulty and the strength of the field). Lorena Ochoa led the LPGA tour in SG total gaining 4.03 strokes per round. The top 40 players scored an average of 1.65 strokes better than the LPGA Tour average. Their drives averaged 6.9 yards longer, they hit 0.14 more fairways per round, they hit 0.97 more greens in regulation and they took 0.25 fewer putts per round.

Figures 22–25 show trends in *relative* driving distance, fairways hit, greens in regulation, and putts per round of the top 40 SG total players. Unlike Tables 6–8 which contain results for three years only, the trends in Figures 22–25 are based on all years of data from 1993 to 2007.

The trend line in Figure 22 shows that the relative driving distance advantage of the top 40 SG total players increased from 4.5 yards to 6.9 yards, a 40% increase over the period 1993 to 2007. This trend is statistically significant with a p value of 0.03. The trend line in Figure 23 shows that the fairways hit advantage of the top 40 SG total players decreased from 0.33 to 0.21, with a p value of 0.08 (which is not considered statistically significant).

The trend line in Figure 24 shows virtually no change in the greens in regulation advantage of the top 40 SG total players over the period 1993 to 2007 (with a p value of 0.87). The trend line in Figure 25 shows that the putts per round advantage of the top 40 SG total players decreased from 0.34 to 0.23, with a p value of 0.08 (not considered statistically significant).

To recap, the only statistically significant trend was the increased driving distance advantage of the top 40 SG total LPGA Tour players. *While the LPGA Tour driving distance increased, the distance of the top 40 SG total players increased even more.*

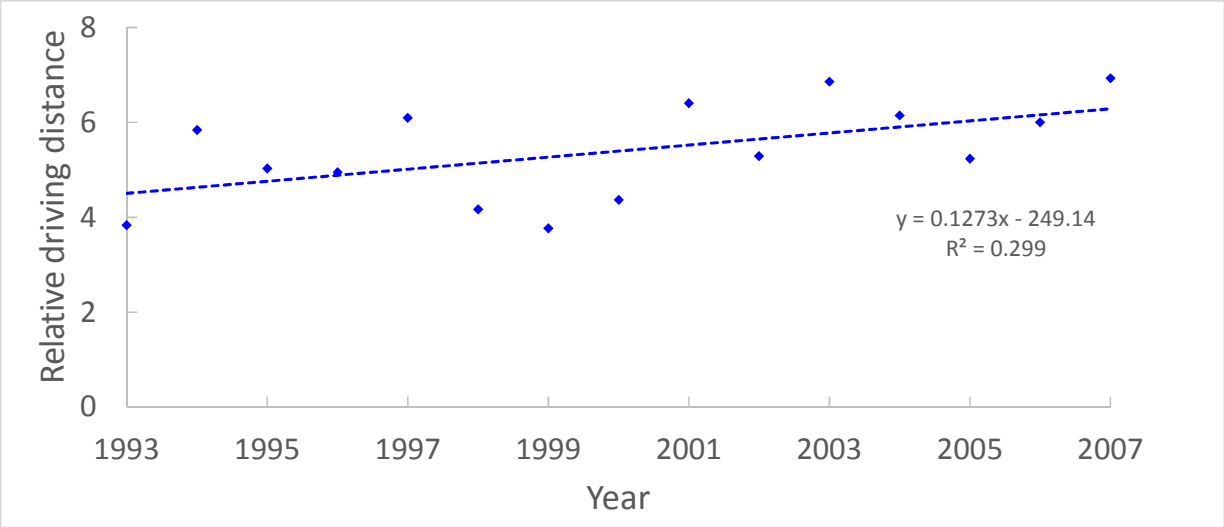

Figure 22: The chart shows the relative driving distance from 1993 to 2007 of the top 40 LPGA Tour players in strokes gained total in each year. The relative driving distance indicates the driving distance advantage of the top 40 SG total players relative to the LPGA Tour average, after adjusting for course difficulty and strength of field. The positive 0.13 slope of the trend line indicates that the top 40 players increased their distance advantage by an average of 0.13 yards per year, or 1.8 yards over the period. The trend is statistically significant with a p value of 0.03.

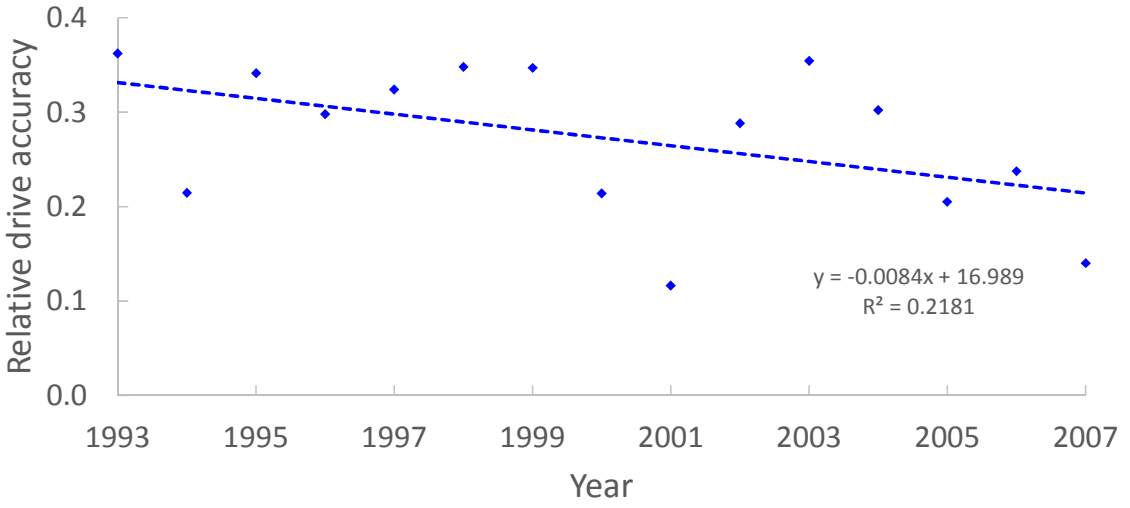

Figure 23: The chart shows the relative fairways hit per round (driving accuracy) from 1993 to 2007 of the top 40 LPGA Tour players in strokes gained total in each year. The relative fairways hit indicates the driving accuracy advantage of the top 40 SG total players relative to the LPGA Tour average, after adjusting for course difficulty and strength of field. The negative 0.01 slope of the trend line indicates that the top 40 players decreased their accuracy advantage by an average of 0.01 fairways hit (per round) per year, or 0.1 fairways hit (per round) over the period. The trend is not statistically significant with a p value of 0.08.

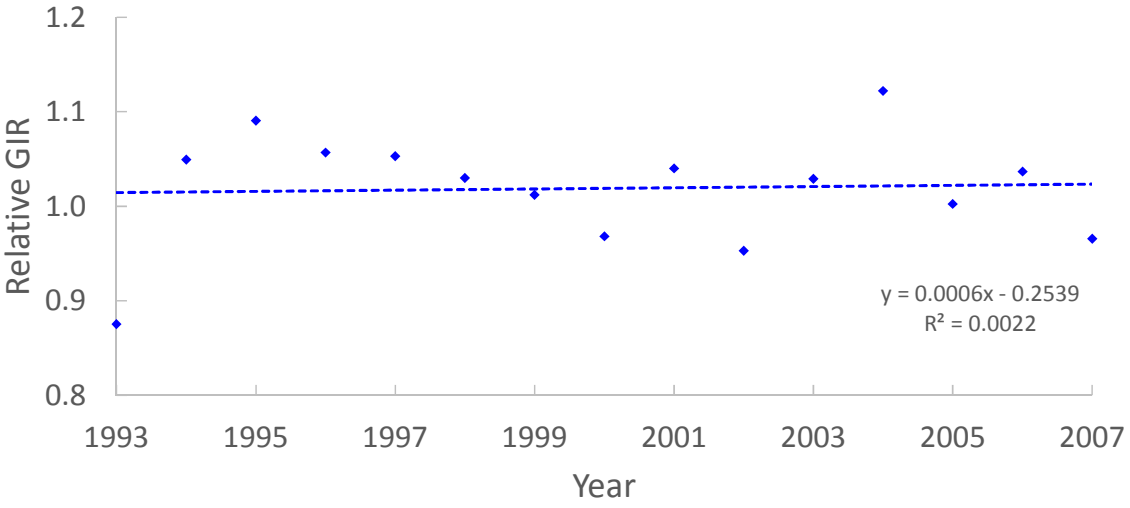

Figure 24: The chart shows the relative greens in regulation (GIR) from 1993 to 2007 of the top 40 LPGA Tour players in strokes gained total in each year. The relative GIR indicates the GIR advantage of the top 40 SG total players relative to the LPGA Tour average, after adjusting for course difficulty and strength of field. The zero slope of the trend line indicates that the top 40 players did not change their GIR advantage over the period. The trend is not statistically significant with a p value of 0.87.

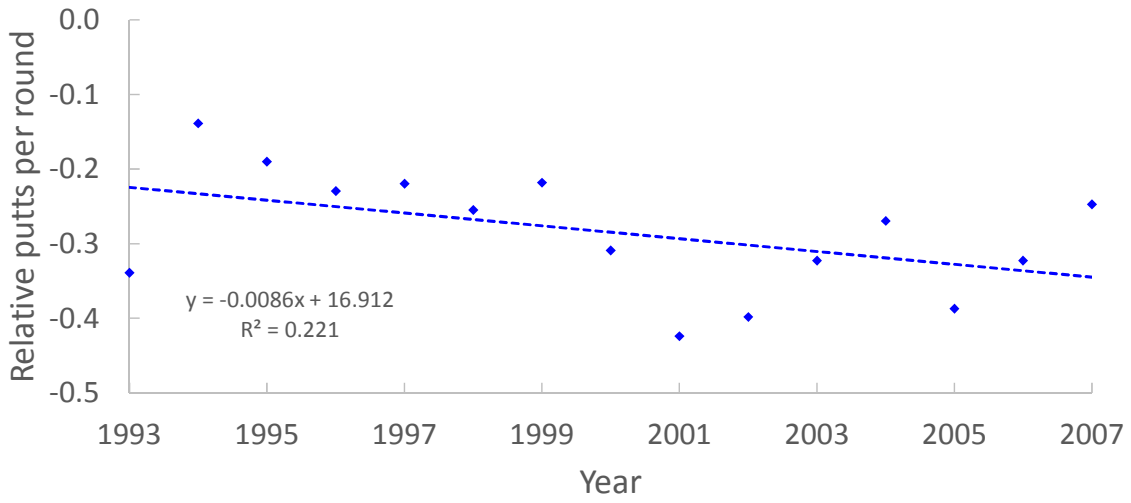

Figure 25: The chart shows the relative putts per round (PPR) from 1993 to 2007 of the top 40 LPGA Tour players in strokes gained total in each year. The relative PPR indicates the putting advantage of the top 40 SG total players relative to the LPGA Tour average, after adjusting for course difficulty and strength of field. The negative 0.01 slope of the trend line indicates that the top 40 players increased their PPR advantage (fewer putts are better) by a total of 0.12 putts per round over the period. The trend is not statistically significant with a p value of 0.08.

10. Concluding Remarks

This report investigated the components of superior performance in professional golf. In particular, the contributions of various skills (driving distance, driving accuracy, approach shots, short game and putting) to superior scoring was examined through time. The trends in the cost of missing a fairway, and the related rough penalty measure, were examined. Hole lengths and second shot distances on par-4 and par-5 holes were analyzed.

The main findings of the PGA Tour analysis:

1. *The contribution of driving distance to superior scoring increased over the period 1983 to 2018.*
    - The top scorers were 3.1 yards longer than the PGA Tour average in the 1980s and 5.7 yards longer in the 2010s.
    - In the ShotLink era from 2004 to 2018, the contribution of skills can be measured in terms of strokes, which allows for direct scoring comparisons. From 2004 to 2010, the top scorers gained an average of 18% of their strokes from longer driving distance; from 2011 to 2018 it was 23%, a gain of 5%.
2. *The contribution of driving accuracy to superior scoring decreased over the period 1983 to 2003 and has been steady from 2004 to 2018.*
    - The top scorers hit 4.1% more fairways than the PGA Tour average in the 1980s and 1.8% more in the 2000s.
3. *The contribution of greens in regulation and putting to superior scoring did not change significantly over the period 1983 to 2018.*
4. *The cost of missing a fairway is about 0.35 strokes and has not changed significantly over the period 1992 to 2018.*
    - Though the average cost of missing a fairway has been fairly constant through time, it varies greatly from one course to the next. See Section 12 in the Appendix.
    - The rough penalty, which measures the difference in strokes to hole out from the same distance in the rough versus the fairway, is about 0.24 strokes, and has not changed significantly over the period 2004 to 2018.
5. *Par-4 second shot distances declined an average of 7 yards from 2004 to 2018. Par-5 second shot distances declined an average of 9 yards from 2004 to 2018.*
    - Shorter second shot distances in 2018 compared to 2004 means that the increased length of par-4 and par-5 holes has been more than offset by the increase in driving distance (see Figure 27 in the Appendix in Section 11.1).

The main findings of the LPGA Tour analysis:

6. Over the period 1993 to 2018, LPGA Tour average round scores declined about 1.1 strokes, in spite of the increase in par-3 hole lengths of 10 yards, par-4 hole lengths of 20 yards, and par-5 hole lengths of 28 yards.

7. Over the period 1993 to 2006, LPGA Tour median driving distance increased 24 yards, fairways hit increased 0.3 per round, GIR increased 1.6%, and putts per round improved (i.e., declined) by 0.5.

8. *On the LPGA Tour, the contribution of driving distance to superior scoring increased over the period 1997 to 2007.*

    - The top scorers were 4.1 yards longer than the LPGA Tour average in 1993 and 6.9 yards longer in 2007, a statistically significant 40% increase over the 15-year period.
    - There were no statistically significant changes in the driving accuracy, greens in regulation or putts per round advantage of the top scorers.

The Appendix contains additional results with standard statistics, shows the connection between the "top 40" analysis and regression analysis, and shows how the missed fairway cost varies by course.

11. Appendix

11.1. Absolute Standard Stats, 1983-2018

This section shows trends in PGA Tour absolute (i.e., raw or unadjusted) standard statistics through time. These trends indicate little about the importance of these skills to scoring or winning, but do indicate how skills might have developed over time. For example, if green conditions improve so that every player takes one less putt per round, then scores will decline by one stroke per round but the relative contribution of putting to superior scoring will not change.[15]

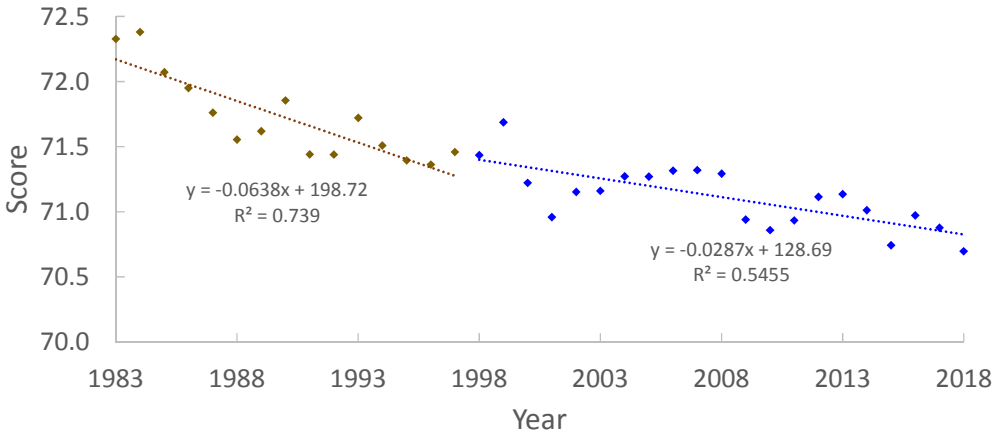

Figure 26: Average PGA Tour round scores from 1983 to 2018. The procedure in Section 2.3 found the most significant break (i.e., change in slope) in the year 1997. The downward trend from 1983 to 1997 is statistically significant with a p value of 0.00. The downward trend from 1998 to 2018 is statistically significant with a p value of 0.00.

[15]Here's another example. If every player hit every drive 300 yards into the fairway, then driving skill would have no importance in winning since it is not a differentiating factor in scoring. At some later time, if every player hit every drive 310 yards into the fairway, then scores would drop, but driving skill would still have no importance in winning. Put another way, it is performance relative to the field (not absolute performance) that determines the importance of a skill to winning.

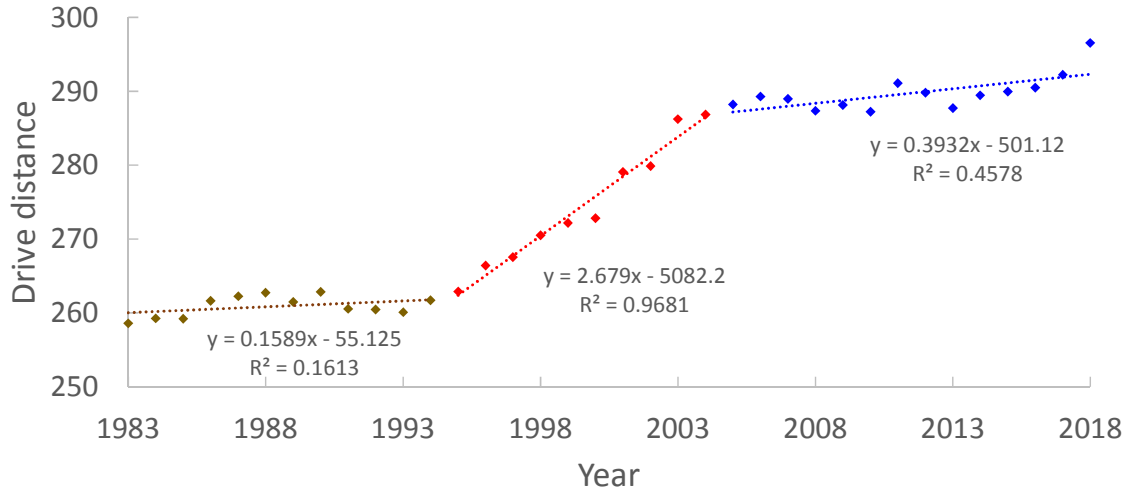

Figure 27: PGA Tour drive distance (using two measured holes) from 1983 to 2018. The procedure in Section 2.3 was applied twice to find the two most significant breaks (i.e., changes in slope) in the years 1994 and 2004. The upward trend from 1983 to 1994 (0.2 yards per year) is not statistically significant (p value 0.18). The upward trend from 1995 to 2004 (2.7 yards per year) is statistically significant (p value 0.00). The upward trend from 2005 to 2018 (0.4 yards per year) is statistically significant (p value 0.00). Overall from 1983 to 2018, drive distance increased about 34 yards, with a 5-yard increase from 1983 to 1994, a 24-yard increase from 1995 to 2004, and a 5-yard increase from 2005 to 2018.

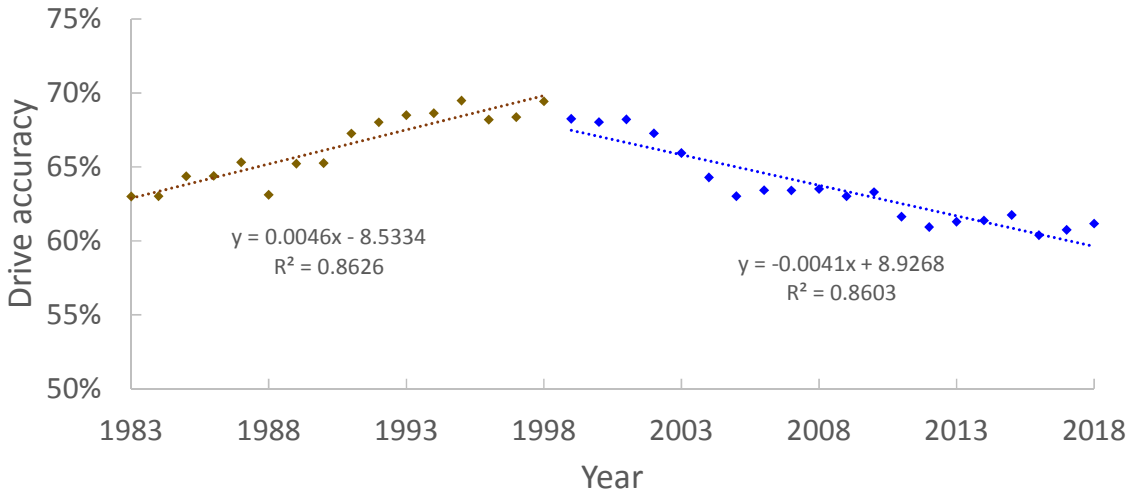

Figure 28: PGA Tour driving accuracy from 1983 to 2018. The procedure in Section 2.3 found the most significant break (i.e., change in slope) in the year 1998. The upward trend from 1983 to 1998 is statistically significant with a p value of 0.00. The downward trend from 1999 to 2018 is statistically significant with a p value of 0.00.

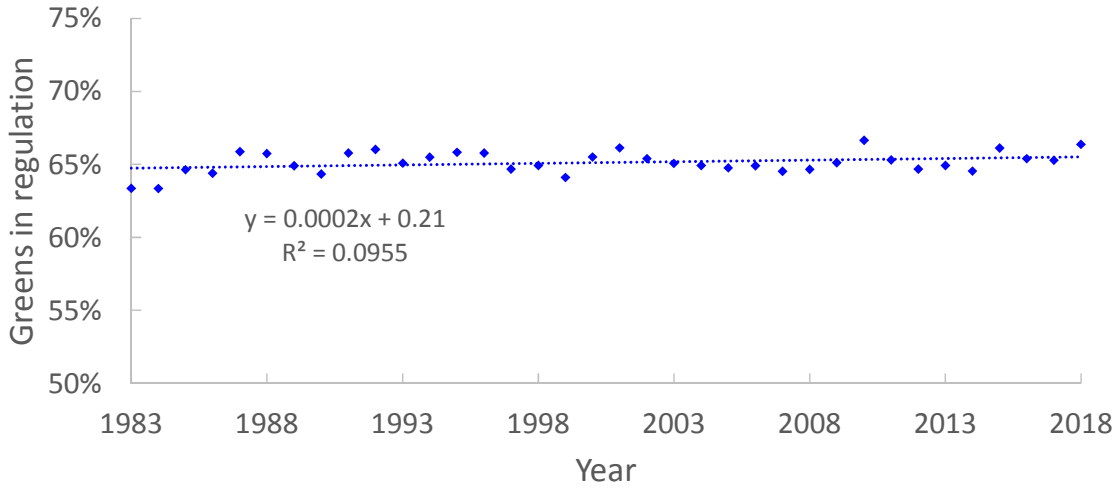

Figure 29: PGA Tour GIR from 1983 to 2018. The slight upward trend is not statistically significant (p value 0.08).

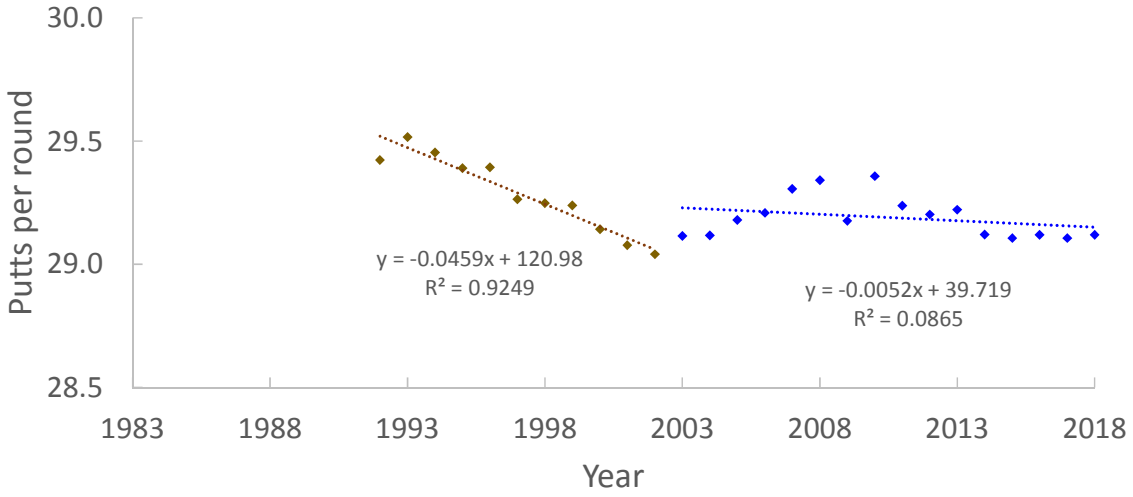

Figure 30: PGA Tour putts per round 1992 to 2018. The procedure in Section 2.3 found the most significant break (i.e., change in slope) in the year 2002. The downward trend from 1992 to 2002 is statistically significant with a p value of 0.00. The slight downward trend from 2003 to 2018 is not statistically significant with a p value of 0.76.

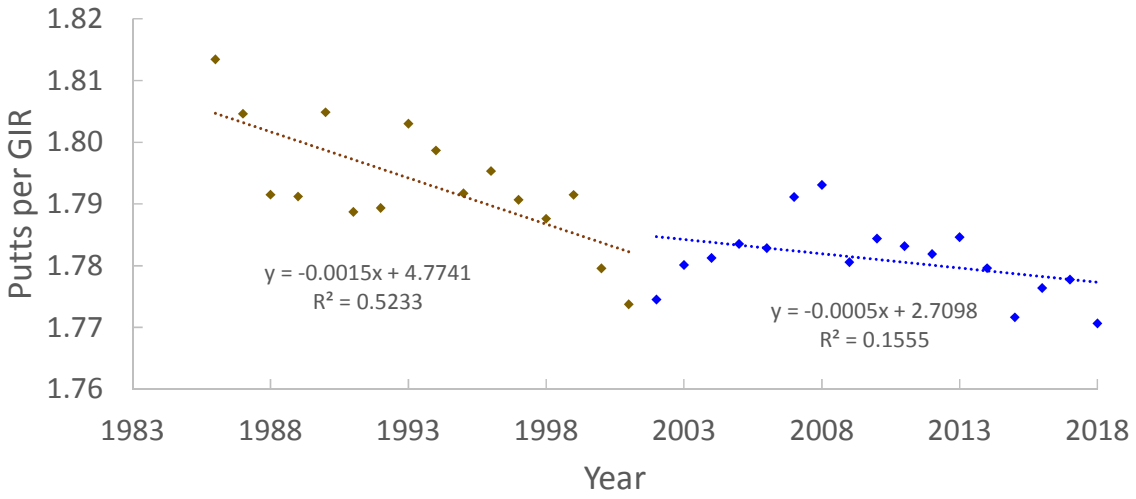

Figure 31: PGA Tour putts per green in regulation 1986 to 2018. The procedure in Section 2.3 found the most significant break (i.e., change in slope) in the year 2001. The downward trend from 1986 to 2001 is statistically significant with a p value of 0.00. The slight downward trend from 2002 to 2018 is not statistically significant with a p value of 0.11.

11.2. Top 40 Analysis Versus Analysis of Variance

This section explains the connection between the "top 40" analysis used in this report and more standard regression and analysis of variance techniques. Note that the "top 40" analysis is preferable because it directly estimates the contributions of different parts of the game to superior scoring performance.

Before shot tracking data, golf analysis was restricted to traditional fairways, greens and putts golf stats. The limitations of these stats are well known. To give one example, Tiger Woods had a very good 2018 season, with one win and seven top tens in 18 starts, and winning $5.4 million. He ranked fifth in strokes gained total. Yet, if you want to explain his superior results with traditional stats, Woods ranked 127 in fairway hit (driving accuracy percentage), ranked T32 in driving distance, ranked 82 in greens in regulation, and ranked 22 in putts per round. Analysis of traditional stats might lead you to believe that putting was the key to Tiger's success. Using shot tracking data, the quality of every shot can be measured using the strokes gained (SG) method. Woods ranked 100 in SG: off the tee, ranked 3 in SG: approach, ranked 11 in SG: around the green, and ranked 48 in SG: putting. Modern analysis using more accurate and detailed shot tracking data reveals that Woods's success was primarily due to the excellence of his approach shots.

The analysis using strokes gained is considerably easier and simpler to do for two reasons: (1) strokes gained results for each shot category are all in the same unit of strokes, while traditional stats have incommensurate units, and (2) strokes gained across shot categories sums exactly to strokes gained total. If a regression was done on strokes gained total (y variable) against SG:off-the-tee, ..., SG:putting, there is no "error" term because the equation is exact. This means that the contributions of various shot categories to strokes gained total does not require regression or ANOVA analysis. Instead, simply look at the top players in SG: total and average the SG contributions of each shot category. This simple and direct calculation shows the contributions of each shot category to strokes gained total.

Nevertheless there is a connection between these methods of analysis. Let $S(j)$ represent SG: total for player j and let $X_i(j)$ represent SG in each of the shot categories (e.g., $X_1()$ is SG: off-the-tee, $X_2()$ is SG: approach, $X_3()$ is SG: around the green, and $X_4()$ is SG: putting). Then by the definition of strokes gained, $S(j) = X_1(j) + X_2(j) + X_3(j) + X_4(j)$ for each player j. Further, the average SG across players (weighted by the number of rounds) is zero.

To model strokes gained, assume the random variable $X_i(\cdot) \sim N(0, \sigma_i^2)$, i.e., across a large group of players X_i is normally distributed with mean zero and variance σ_i^2. Also assume X_i and X_k are independent for $i \neq k$ (empirical analysis confirms this is a reasonable approximation). Denote the variance of S by $\sigma^2 = \sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \sigma_4^2$.

Given a player with a strokes gained total value of s, the average contribution of shot category i

is $\mathsf{E}[X_i|S=s]/\mathsf{E}[S|S=s] = \mathsf{E}[X_i|S=s]/s$. Some algebra[16] shows

$$\frac{\mathsf{E}[X_i|S=s]}{s} = \frac{\sigma_i^2}{\sigma^2} = \frac{\mathrm{Var}(X_i)}{\mathrm{Var}(S)}. \tag{1}$$

Since equation (1) holds for any given s, it follows that

$$\frac{\mathsf{E}[X_i|S>s_0]}{\mathsf{E}[S|S>s_0]} = \frac{\mathrm{Var}(X_i)}{\mathrm{Var}(S)}. \tag{2}$$

The lefthand side of equation (2) is equivalent to the "top 40" analysis. Conditioning on $S > s_0$ is the same as conditioning on the top players in strokes gained total. The empirical version of the expected values in the numerator and denominator correspond to taking the average values of SG in a shot category divided by the average value of SG total, exactly as was done in Table 5. The righthand side of equation (2) is the standard "analysis of variance." In other words, if the strokes gained across shot categories are independent and normally distributed, then the "top 40" analysis that uses the average strokes gained of the top players is equivalent to the standard variance decomposition analysis. A major advantage of the "top 40" analysis is that it does not rely on normality or independence assumptions.

11.3. Performance versus Skill Using Correlation Analysis

A report titled *Statistical Analysis of PGA Tour Skill Rankings 1980-2006* (hereafter USGA Skill Rank Study) was published by the USGA in June 2007. The report looked at the correlation of performance, as measured by money earned rank, with skills as measured by ranks in driving distance, driving accuracy, greens in regulation, and putting average (i.e., putts per green in regulation) on the PGA Tour. A major finding of the study was "Of these key skills, Driving Accuracy has changed the most over the time period studied." (USGA Skill Rank Study, p.4). Figure 32 shows the main charts from the USGA Skill Rank Study. A primary finding of the report was the declining correlation of end-of-season money earned ranks and driving accuracy ranks from 1980 to 2006.

The rank correlation analysis has several potential flaws that could impact the conclusions: (1) ranks are nonlinearly related to the underlying values (e.g., the difference in driving distance between the rank 1 and rank 10 player in 2018 was 7.1 yards and just 0.6 yards between ranks 61 and 70), (2) money earned is a highly variable measure of performance (e.g., a one-stroke difference between first and second place represents a big change in money and not necessarily a big change in skill), (3) the statistics are not adjusted for course difficulty and the strength of the field.

The performance-skill correlation analysis was repeated with four differences: (1) correlation of values were computed instead of ranks, (2) SG total was used instead of money earned, (3) "relative"

[16] Let $\sigma = \sqrt{\sigma_1^2+\sigma_2^2+\sigma_3^2+\sigma_4^2}$. Note that the covariance of X_i and S is σ_i^2. So the correlation of X_i and S is $\rho(X_i,S) = \mathrm{Cov}(X_i,S)/(\sigma(S)\sigma(X_i)) = \sigma_i^2/(\sigma\,\sigma_i) = \sigma_i/\sigma$. If Y and Z are correlated normals, then the distribution of Y given $Z=z$ is normal with mean $\mu_Y + \rho\sigma_Y(z-\mu_Z)/\sigma_Z$ and variance $\sigma_Y^2(1-\rho^2)$. Using these formulas $\mathsf{E}[X_i|S=s] = 0 + \rho(X_i,S)\sigma_i(s-0)/\sigma = (\sigma_i/\sigma)\sigma_i(s/\sigma) = s\sigma_i^2/\sigma^2$.

statistics were used (i.e., standard statistics adjusted for course difficulty and the strength of the field), and (4) the analysis was extended to 2018. Figure 33 shows the results. There were eight trends analyzed using four skill measures and two time periods (1983 to 2006 and 2007 to 2018). The time period 1983 to 2006 was chosen to match the period used in the USGA Skill Rank Study. Five of the correlation trends were not statistically significant. Three correlation trends were significant with p values of 0.00: (1) the decline in the correlation of SG total and driving accuracy from 1983 to 2006, (2) the decline in the correlation of SG total and greens in regulation (GIR) from 1983 to 2006 (though the small change in the GIR correlation does not seem practically significant), and (3) the increase in the correlation of SG total and driving distance from 2007 to 2018. In short, relative driving accuracy declined in importance in the period 1983 to 2006 and relative driving distance increased in importance in the period 2007 to 2018.

The trend of declining rank correlation between money and driving accuracy from 1980 to 2006 in the upper right chart in Figure 32 from the USGA Skill Rank Study is broadly consistent with the decline in the correlation of SG total and relative driving accuracy from 1983 to 2006 in the upper right chart in Figure 33.[17]

From 2007 to 2018 the correlation of relative driving accuracy and SG total (see the upper right chart in Figure 33) remained constant. In the same period, the correlation of relative driving distance and SG total increased (see the upper left chart in Figure 33). These results are broadly consistent with the earlier findings in Figure 2.

Note that GIR must be highly related to score by its definition.[18] If one player hits 17 greens in regulation versus another who hits only four, that gives considerable information about each player's score. The average correlation of relative GIR and SG total from 1983 to 2018 was 82%. This is larger than the rank correlation average of 54%. The main reason for the difference is the adjustment of GIR and score to account for course difficulty and the strength of the field. Similarly, the correlation of relative PPGIR and SG total is 70% while the rank correlation is 56%.

[17] The similarity of the correlation results in Figure 33 and earlier "top 40" strokes gained results is explained in part by the analysis in Section 11.2.

[18] A player is said to hit a green in regulation if the player's first shot on a par-3 hole finishes on the green, or first or second shot on a par-4 hole, or first, second or third on a par-5 hole.

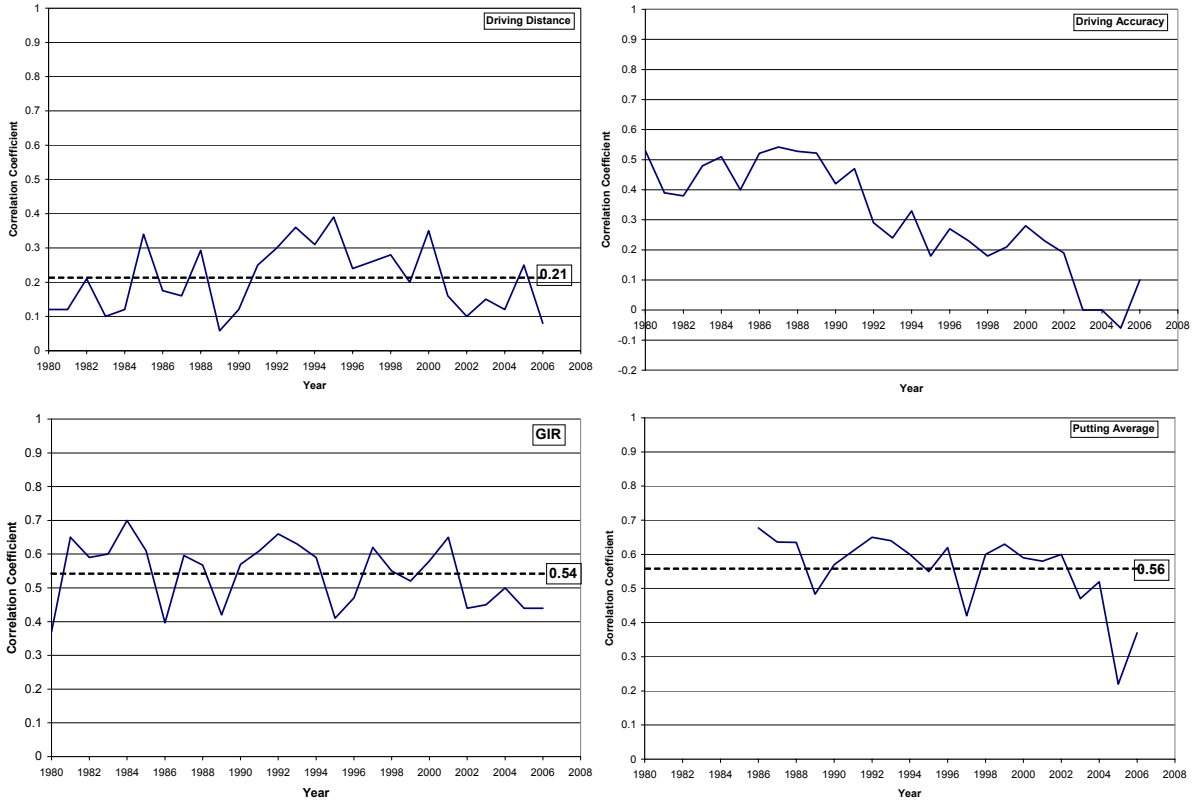

Figure 32: PGA Tour: Correlation coefficient between money earned rank and driving distance rank (upper left), driving accuracy rank (upper right), GIR rank (lower left) and putts per GIR (i.e., putting average, lower right), from 1980 to 2006. These figures are from pages 2 to 4 of the June 1, 2007 USGA Report titled *Statistical Analysis of PGA Tour Skill Rankings 1980-2006*.

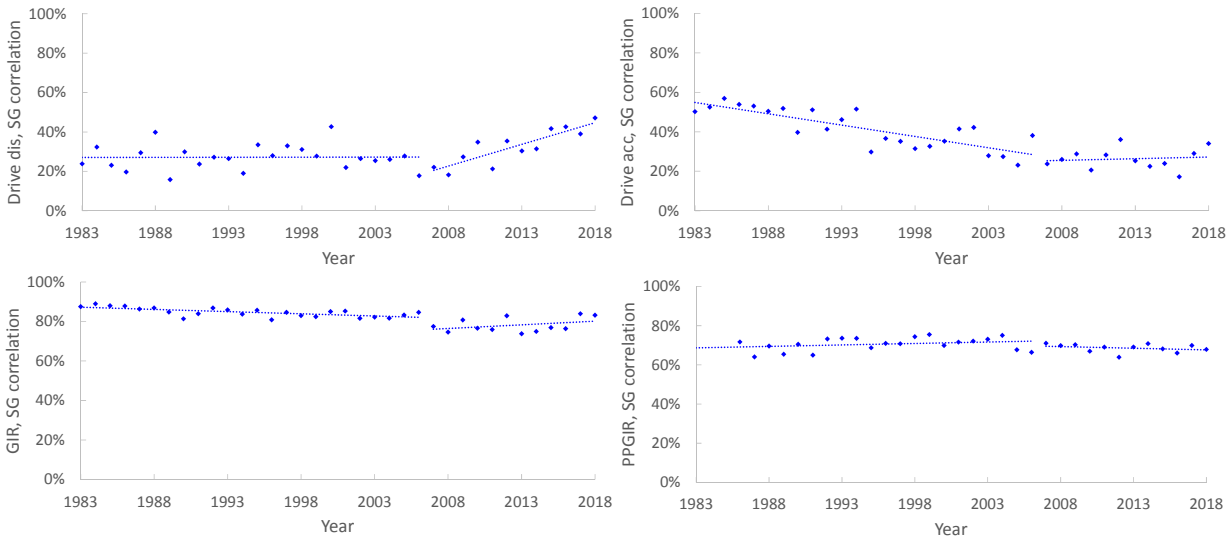

Figure 33: PGA Tour: Correlation coefficient between SG total and relative driving distance (upper left), relative driving accuracy (upper right), relative GIR (lower left) and relative putts per GIR (PPGIR, lower right), from 1983 to 2018. The breaks were all at year 2006 so that the first period results from 1983 to 2006 can be directly compared to those in Figure 32. Of the eight regression lines shown, three are statistically significant at the 0.05 level: (1) driving accuracy 1983-2006 (p value 0.00), (2) GIR 1983-2006 (p value 0.00), and (3) driving distance 2007-2018 (p value 0.00). For the 1983 to 2018 period, the average correlation values are: relative driving distance 29%, relative driving accuracy 37%, relative GIR 82% and relative PPGIR 70%.

12. Missed Fairway Cost by Course, 2013-2018

Recall that the missed fairway cost is the average hole score of players who miss the fairway minus the average hole score of players who hit the fairway. The missed fairway cost includes the cost of shots hit out of bounds and into penalty and recovery situations. The missed fairway cost of a course is the average missed fairway cost across the par-4 and par-5 holes of that course. The cost of a missed fairway varies greatly by course. Table 9 shows the missed fairway cost for PGA Tour courses played from the 2013 season through the 2018 season. The largest missed fairway costs are dominated by U.S. Open courses.

Average cost of a missed fairway by course

Rank	Course	Number of seasons	Missed fairway cost
1	Chambers Bay GC	1	0.55
2	Merion GC	1	0.54
3	Erin Hills	1	0.54
4	Liberty National GC	1	0.47
5	TPC Potomac at Avenel Farm	2	0.46
6	TPC Sawgrass	6	0.43
7	Oakmont CC	1	0.43
8	Muirfield Village GC	6	0.42
9	Whistling Straits	1	0.42
10	Bellerive CC	1	0.41
11	TPC River Highlands	6	0.41
12	Plainfield CC	1	0.41
13	Bay Hill Club & Lodge	6	0.41
14	Trinity Forest Golf Club	1	0.41
15	TPC Four Seasons Resort	1	0.40
16	Quail Hollow-PGA Championship	1	0.39
17	TPC Southwind	6	0.38
18	TPC Deere Run	6	0.38
19	TPC Summerlin	5	0.38
20	El Camaleon GC	5	0.38
21	Sea Island Resort (Plantation)	3	0.38
22	TPC Kuala Lumpur	5	0.38
23	Bethpage State Park (Black)	1	0.37
24	Glen Oaks Club	1	0.37
25	PGA West (Nicklaus)	3	0.37
26	Firestone CC (South)	6	0.36
27	Sheshan International GC	5	0.36
28	Baltusrol GC	1	0.36
29	RTJ Trail (Grand National)	3	0.36
30	TPC Four Seasons Resort	5	0.36
31	Valhalla GC	1	0.36
32	The Old White TPC	5	0.36
33	Sea Island Resort (Seaside)	5	0.35
34	TPC Scottsdale	6	0.35
35	Club de Golf Chapultepec	2	0.34
36	Waialae CC	6	0.34
37	PGA National (Champion)	6	0.34
38	Quail Hollow Club	1	0.34
39	Glen Abbey GC	5	0.34
40	Oak Hill CC	1	0.34
41	GC of Houston	6	0.34
42	TPC Boston	6	0.34
43	Ridgewood CC	1	0.34
44	Trump National Doral	4	0.33
45	Colonial CC	6	0.33
46	CordeValle GC	1	0.33
47	Ridgewood CC	1	0.33
48	Crooked Stick GC	1	0.33
49	Sedgefield CC	6	0.33
50	Annandale GC	1	0.33
51	Congressional CC (Blue)	3	0.33
52	Pinehurst Resort (No. 2)	1	0.32
53	Monterey Peninsula CC	6	0.32
54	Silverado Resort and Spa North	4	0.32
55	Robert Trent Jones GC	1	0.32
56	Quail Hollow Club	4	0.31
57	Aronimink GC	1	0.31
58	La Quinta CC	6	0.31
59	PGA West (Palmer)	3	0.30
60	Cherry Hills CC	1	0.30
61	Nicklaus Tournament Course	3	0.30
62	Torrey Pines GC (South)	6	0.30
63	Royal Montreal GC (Blue)	1	0.30
64	Innisbrook Resort (Copperhead)	6	0.30
65	TPC Louisiana	4	0.29
66	Coco Beach Golf & CC	5	0.29
67	Stadium Course	3	0.29
68	Keene Trace Golf Club	1	0.29
69	CC of Jackson	4	0.28
70	Conway Farms GC	3	0.28
71	Riviera CC	6	0.28
72	Club at Nine Bridges	1	0.28
73	Harbour Town GL	6	0.27
74	TPC San Antonio - AT&T Oaks	6	0.27
75	Pebble Beach GL	6	0.27
76	Spyglass Hill GC	6	0.25
77	Plantation Course at Kapalua	6	0.24
78	Eagle Point Golf Club	1	0.24
79	Corales Golf Club	1	0.23
80	East Lake GC	6	0.11
81	Torrey Pines (North)	6	0.09

Missed fairway cost: Average score from missed fairways minus the average score from the fairway.
Results for the 2013-2018 PGA Tour seasons
Overall average missed fairway cost: 0.33 strokes

Table 9: PGA Tour missed fairway cost by course, 2013 to 2018. The average missed fairway cost over the period was 0.33 strokes, with the largest at Chambers Bay at 0.55 and the smallest at Torrey Pines North course at 0.09.