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Some Professionals Play Minimax: A Reexamination of the Minimax Theory in Major League Baseball

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SOME PROFESSIONALS PLAY MINIMAX: A REEXAMINATION OF THE MINIMAX THEORY IN MAJOR LEAGUE BASEBALL

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Chapter 1
Introduction

In competitive games, one's predictably often leads to one's downfall. The more unpredictable a player is, the more success he will find in the field. "The theory of mixed-strategy play, including von Neumann's Minimax Theorem… remains the cornerstone of our theoretical understanding of strategic situations that require unpredictability" (Walker and Wooders, 2001). Professional sports have offered economists a means to test the minimax theory[1] in a natural setting. However, studies have varied so far on whether professional athletes follow equilibrium play.

Kovash and Levitt (2009) add to the literature of minimax play in professional sports. Using OPS[2] to test minimax play in Major League pitchers, they find that pitchers deviate from minimax play. We reexamine Kovash and Levitt's (2009) conclusion using

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[1] Minimax theory states that players seek to equalize payoffs and choose strategies without serial correlation.

[2] OPS - On base percentage plus Slugging percentage. For a more information, refer to appendix A.

data from every pitcher in the Major Leagues over the period 2007-2010 – a total of almost 2,400 pitchers. We test to see whether pitchers continue to overuse fastballs, and whether the OPS statistic contributes to a pitcher's value.

We find that starting pitchers tend to throw too many fastballs, as an increase in fastball use leads to an increase in OPS. These results agree with Kovash and Levitt's (2009) conclusions. However, this study finds deviations from their conclusions in the case of relief pitchers. We find no significant effect of pitch types on OPS, suggesting that the pitch choice of relief pitchers may adhere to minimax play. This study also concludes that the OPS, along with the K/BB and HR/9 statistics,[3] are good indicators of a pitcher's value. IP[4] also helps explain a pitcher's WAR[5], but its inherent endogeneity makes it difficult to gauge how useful this statistic is.

These findings are not trivial. During the 2010 season, starting pitchers threw fewer fastballs than they did in any of the previous three seasons. Accordingly, 2010 saw season bests in many pitching categories compared to any of the previous three seasons. In addition, our findings on OPS and WAR suggest that a team that properly exploits these statistics can find undervalued pitchers that can help win more games.

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[3] K/BB – strikeout to walk ratio. HR/9 – home runs given up per nine innings. For more information, refer to Appendix A.
[4] IP – innings pitched. For more information, refer to Appendix A.
[5] Wins Above Replacement - a statistic that tries to quantify a player's value relative to the rest of the league. For more information, refer to Appendix A.

Chapter 2
Literature Review

Before Walker and Wooders' (2001) study, tests on minimax theory were performed in controlled laboratories (O'Neill, 1987). Minimax studies in natural settings had not been performed until Walker and Wooders (2001). They analyzed field data from ten professional tennis matches in order to test the minimax theory in a natural setting. They observed that win rates in the serve and return play of top professional tennis players were consistent with the minimax theory. However, the players' choices were not consistent with the serial independence implied by the minimax theory, as even the best tennis player switched too often from one action to another (Walker and Wooders, 2001).

Two years later, Ignacio Palacios-Huerta (2003) published an examination on the minimax theory in a different sport. He analyzed penalty shots in professional soccer, testing whether soccer players remained consistent with equilibrium play. His results reflected a consistency with equilibrium play in every respect: (i) winning probabilities were statistically identical across strategies for players; (ii) players' choices were serially independent (Palacios-Huerta, 2003). This paper is important because it was the first time the minimax theorem was fully supported in the field.

Kovash and Levitt (2009) refute Palacios-Huerta's (2003) conclusion on the minimax theory. Observing all pitches thrown during the regular season from 2002 to 2006 and play calling patterns of NFL teams from 2001 to 2005, they conclude that professionals' choices do not follow the minimax theory. Using OPS as an indicator of a pitch's success, Kovash and Levitt (2009) conclude that pitchers throw too many fastballs, as batters systematically have better outcomes when thrown fastballs versus any other type of pitch. Additionally, the pattern of pitches is particularly predictable. Pitchers are more likely to throw a non-fastball if the previous pitch was a fastball, and vice versa. In contrast to Palacios-Huerta (2003), they find substantial deviations from minimax behavior, both with respect to equalizing payoffs and serially correlated actions. Kovash and Levitt's estimate that the failure to follow minimax play results in the average team giving up an extra 20 runs a season, resulting in a loss of $4 million a year for the typical baseball team.[6]

While Kovash and Levitt (2009) calculate all pitches thrown from 2002-2006, they fail to factor the differences in pitching strategies between starting and relief pitchers. Starting pitchers throw more innings and have to throw more fastballs. They are exposed to batters for a longer period of time, providing batters with information on a

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[6] The rule of thumb in converting runs to win is: 10 runs = 1 win (Dave Cameron). Thus, by giving up an extra 20 runs, a team loses two extra games a season, and these two games can make a difference. In 2010, the San Diego Padres lost two more games than the division winners San Francisco Giants, and they were denied a spot to the 2010 playoffs. Seeing as how the San Francisco Giants won the 2010 World Series, we can see how two games play such a significant role to teams. Moreover, according to MLB Average Postseason Ticket Revenue over the last decade, making the playoffs can net a gain of up to $15.7 million dollars for the average team owner.

starter's pitch types, velocities, and tendencies. Thus, starters concentrate on varying their pitching strategies in order to effectively retire their opposition

Relief pitchers throw considerably fewer innings.[7] Because they are exposed to batters for a shorter period of time, batters do not have as much information on a reliever's pitch types, velocities, and tendencies. Even though scouting reports exist, batters still must get used to the tendencies of the new pitcher. They must retime the pitches, learn new tendencies, and expect different pitch types and movements. Relief pitchers also tend to face a lineup only once before making way for another pitcher, resetting a batter's learning curve. This is not to say that relief pitchers do not mix their pitches as well. However, they can afford to throw more fastballs due to their shorter exposure, possibly skewing the data set that Kovash and Levitt (2009) use. In addition, relief pitchers typically have only two pitch types in their repertoire, whereas starting pitchers typically use four. Thus, relievers have fewer options to begin with; they inevitably have to throw their fastball more often in order to keep the batters off-balance. With such differences, it might be difficult to make general conclusions that pitchers throw too many fastballs.

This paper seeks to remedy this oversight, by separately analyzing starters and relievers. This study also tests whether OPS is a good indicator of a pitcher's value. Further possible studies on this topic can explore the differences in strategies between relief pitchers and starting pitchers, test minimax play within relief pitchers using a more specific data set or test the minimax theory in other sports.

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[7] From the years 2007-2010, starting pitchers threw 1,837,343 pitches in which 1,102,405 were fastballs. Meanwhile, relief pitchers threw 951,377 pitches in which 951,377 were fastballs.

Chapter 3
Data Analysis

Our data on pitching statistics in Major League Baseball was collected from Fangraphs.com.[8] The data set includes information for each pitcher in the major leagues over the 2007 to 2010 regular season, particularly concentrating on pitch type percentage, OPS, WAR, and IP. The data for OPS was retrieved from ESPN's player statistics page. Our raw data covers every starting and relieving pitcher from 2007-2010. After separating starting and relieving pitchers as well as excluding pitchers who have thrown fewer than ten innings, we end up with 1,040 starting pitchers and 1,358 relief pitchers.

A risk of selection bias exists. Kovash and Levitt look at all pitchers from 2002-2006, while we concentrate on 2007 to 2010. Due to many time-dependent issues such as steroid/HGH usage[9] and other regulations, this difference may seem like an "apple to

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[8] Fangraphs serves as an advanced baseball statistics encyclopedia as well as a comprehensive database for baseball statistics that go as far back as 1974.

[9] Refers to the use of performance enhancing drugs such as steroids or Human Growth Hormone that was often credited for increased home run production and inflated offensive statistics in the late 1990's and early 2000's.

orange" comparison. Still our results are valid because of our focus on relative performance. Steroid/HGH usage would not eliminate established baseball strategies or the relative successes of some pitchers versus others. Variables that existed from 2002-2006 would still be in-play in 2007-2010. While outcomes in absolute terms might differ due to a chemically-enhanced offense, we observe relative performance.[10]

Tables 1 and 2 present the summary statistics for both types of pitchers, reporting the average, maximum, and minimum recordings of each explanatory variable for both starting and relief pitchers from 2007-2010. The bottom section of each table reports the summary statistics of pitch types and velocities thrown during the 2007-2010 seasons. Over the sample years, OPS has decreased for both starters and relievers while WAR has increased. Fastballs remain the most common pitch. While relievers' reliance on the fastball has stayed the same over the period 2007-2010, starting pitchers' reliance has dropped 3%. This drop accounts for approximately 6,000 less fastballs in 2010 compared to 2007. Starting pitchers throw around 105 innings on average from 2007 to 2009, only to see a jump of 15 innings to 120.63 innings in 2010. Foreshadowing our results, 2010 reported the lowest fastball reliance for starting pitchers, the same year in which pitchers recorded season bests in many different statistics.[11] The data does not show any spike of this caliber for relief pitchers.

Tables 3 and 4 report the correlation matrix of all explanatory variables for starting and relieving pitchers respectively. For starting pitchers, the IP statistic is

[10] The only caveat of this assumption would probably be a fly-ball pitcher who might have given up more homeruns during the steroids era than he does now, but in general, these time-dependent issues would affect hitters much more than pitchers.

[11] ERA, WAR, OPS, K/9, K/BB, HR/9, BABIP, AVG and WHIP are all at the best levels in 2010 compared to any other year in the sample period.

correlated with every statistic except for those related to pitch types. We can also see from Table 3 that ERA, AVG, WHIP, WPA, REW, and HR/9 are all highly correlated with the OPS statistic. Table 4 shows ERA, BABIP, AVG, WPA, REW, and xFIP's[12] high correlation with OPS.

Table 5 presents the regression results testing whether an increase in fastball use leads to an increase in OPS for the years 2007-2010. Regressing pitch types on OPS, the more fastballs a starting pitcher throws, the higher his OPS is. This finding is in agreement with Kovash and Levitt's (2009). Increasing a starting pitcher's fastball use by one percent increases his OPS by 0.064. The economic significance of this effect is not negligible. The top-five batting leaders in OPS during the 2010 season were all within 0.049 of each other. An extra 0.064 in OPS can redefine a good hitter into a superstar hitter. As for relief pitchers, none of the coefficients were statistically significant. This suggests either that the sample size is not large enough or that their choices are in accordance with the minimax theory. We will delve further into this phenomenon when we discuss Table 8.

Tables 6 and 7 test whether there is a difference in WAR between pitchers who threw more fastballs and those who threw fewer. From 2007-2010, 318 starting pitchers threw fewer fastballs in one season compared to the one before, while 216 starting pitchers threw more. In the same period, 340 relief pitchers threw fewer fastballs in one season compared to the one before, while 307 relievers threw more. These t-tests show a difference in WAR between those who threw more fastballs in one season compared to

[12] ERA – Earned Run Average. AVG – Batting Average Against. WHIP – Walks + Hits per Innings Pitched. WPA – Wins Probability Added. REW – Run Expectancy Wins. BABIP – Batting Average of Balls In Play. xFIP – Expected Fielding Independent Pitching. For more information, refer to Appendix A.

the one before and those who did not. On average, starting pitchers increased their own value when they threw fewer fastballs; relief pitchers decreased their value when they threw fewer fastballs, but not as much as they would have if they increased their fastball use. These tables imply that starting pitchers are better off throwing fewer fastballs. That a relief pitcher's value decreases whether or not he throws more fastballs might indicate that they are throwing fastballs close to the optimal frequency.

Table 8 tests the difference in fastball use between starting pitchers and relief pitchers. By analyzing this difference, we can further explain why starting and relieving pitchers employ such different strategies. A fastball is usually a pitcher's best pitch;[13] thus, we should expect relievers to throw more fastballs than starters. On average, starting pitchers threw a fastball 60% of the time while relievers threw one 61.5% of the time. While 1.5% may not seem like a lot, the context behind these numbers is noteworthy. Starting pitchers typically have four different pitches that they can throw, yet they choose to throw a fastball 60% of the time. Relief pitchers typically only have two choices, so throwing a fastball 61.5% of the time seems more reasonable. The results from Table 8 along with the results from Table 5 hint that the choices relief pitchers make may follow minimax theory. However, we cannot decidedly conclude that they do, since our data set does not analyze each individual pitch a relief pitcher has thrown,

Graphs 1 and 2 show an inverse relationship between WAR and OPS for both starters and relievers. Column (1) of Table 9 reports the regression results of OPS on

[13] It is generally accepted that pitchers should throw their fastball a lot, even if it means giving up a few more hits during the course of the game or season. This way, pitchers will have "saved" their best pitches for later, more crucial, situations. For example, a pitcher will not throw his best pitch with two outs and nobody on base in the second inning; he saves it for situations such as when the bases are loaded with one out in the seventh inning.

WAR for starting pitchers. OPS alone explains 38% of the variation in WAR. An increase in OPS by 0.100 decreases a starting pitcher's WAR by almost 1win. Column (2) shows the impact IP has on WAR, but it is omitted from Column (3) due to its inherent correlation with the other explanatory variables. Moreover, we omit the BABIP, AVG, WHIP, WPA, REW, xFIP and HR/9 variables for the same reason. Column (3) adds a group of explanatory variables to the regression. With these additions, OPS' impact on WAR decreases to 0.6 wins. Column (3) also tells us that an increase in the K/BB ratio by 1 increases a pitcher's value by more than half a game. In other words, if two pitchers both walked two batters in nine innings, the pitcher who struck out four more batters could win one more game for his team than the batter who struck out fewer. Intuitively these results make sense, because a pitcher that allows fewer base runners certainly has more value than a pitcher who does not. We also see a statistically significant coefficient for fastball percentage on a pitcher's WAR, informing us that a 10% increase in fastball use lowers a pitcher's value by 0.14 wins.

Column (1) of Table 10 reports the regression results of OPS on WAR for relief pitchers. OPS alone explains 35% of the variation in WAR. An increase in OPS by 0.100 decreases WAR by 0.3 wins. Column (2) shows the impact IP has on WAR for relief pitchers, but it too is omitted from Column (3) for the same reasons as above. Adding other explanatory variables to the regression decreases OPS's impact on WAR to about 0.07 wins. These results indicate that OPS does not have as much of an impact on a relief pitchers' value as it does for a starting pitcher.[14] Instead, the explanatory variable that has the most impact on WAR is the HR/9 ratio. An increase in the HR/9 ratio by 1 decreases a relief pitcher's value by 0.4 wins. These results make sense as well. In general, starting pitchers do not want to allow base runners because the more batters they face, the more tired they get. Due to their short outings, this does not matter as much for relievers. As long as a relief pitcher does not allow a run, he will have pitched an effective inning. Therefore, it is reasonable that the HR/9 ratio affects a pitcher's value more than OPS. Granted, if a base runner does score, a relief pitcher's value is affected which explains why OPS still has some effect. The coefficient for fastball percentage is not statistically significant for relief pitchers.

Based on the regression analysis of WAR on the explanatory variables, our results are in accordance with Kovash and Levitt's (2009) conclusions for starting pitchers only. In general, starting pitchers are throwing too many fastballs and the overreliance on this pitch is adversely affecting their performance potential. Decreases in fastball use can lead to decreases in OPS. As for relief pitchers, our data does not find any significant relationship between fastball percentage and OPS. This might suggest that relief pitchers do follow the minimax theory with respect to equalizing payoffs. Our data does not have enough information to conclude anything on serial correlation however.

OPS plays a large role in explaining the variation in WAR. Nevertheless, other statistics also contribute to a pitcher's value. The K/BB statistic has the largest effect on a

[14] Additionally, because of their different roles, starting pitchers inherently have more value to a team than relief pitchers. Starting pitchers throw more innings and are in the game much longer than any relief pitcher, so they are more responsible for the outcome of a game. This reason also contributes to why OPS has a smaller effect for relief pitchers' WAR than it does for starting pitchers.

starting pitcher's OPS while the HR/9 has the largest effect for relief pitcher's OPS. Teams must be wary of these other statistics in order to properly evaluate these pitchers.

Chapter 4
Conclusion

This paper analyzes pitching data from 2007-2010 in order to (1) study minimax behavior in a natural setting by professionals in a high stakes environment, and (2) observe what OPS tells us about a pitcher's value. This study also makes some corrections on oversights that Kovash and Levitt (2009) make. Today's starting pitchers are throwing too many fastballs, and substantial deviations in minimax theory still exist in baseball. They are not implementing the most efficient strategies against batters; starters might find more success if they make small tweaks in the number of fastballs they throw over a given season. As for relievers, our results imply that relief pitchers mix their pitches well enough that their choices may follow minimax. However, due to data limitations, we cannot make conclusive statements proving this. Further analysis on each individual pitch thrown by relief pitchers is needed.

In addition, "high stakes alone are not sufficient to ensure that optimal decision-making will ensue, even among professionals operating in their natural environments"

(Kovash and Levitt, 2009). If coaches emphasize mixing pitches more often, starting pitchers can expect more success. This assertion is backed up by the data.[15] 2010 has been deemed the “year of the pitcher” due to an unusual spike in no-hitters, perfect games and general pitching dominance. (Evan Drellich, 2010) Thanks to the lowest fastball percentage in four years, starters during the 2010 season have recorded the lowest OPS, HR/9, BABIP, WHIP, AVG, and ERA, while recording highs in WAR, K/BB. These milestones were met with fewer pitchers who threw more innings on average than in the previous 3 seasons, further illustrating their dominance in 2010.

We find that while OPS is a good indicator of a pitcher’s value, it is not the only important predictor of his value. Other indicators, such as K/BB for starters and HR/9 for relievers, also play important roles in predicting a pitcher’s value to his team. In addition, IP plays an integral part in predicting pitching success, at the very most due to its correlation with other pitching statistics. The general manager that successfully evaluates pitchers by analyzing these statistics may be able to find undervalued pitchers that can help generate more wins.

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[15] In 2008, Brian Bannister, a starting pitcher for the Kansas City Royals, threw fastballs 59.6% of the time and batters owned a 0.826 OPS against him. That season, his WAR was 1.5, indicating that he provided one and a half more wins to his team than any random replacement player. In 2009, he drastically dropped his use of his fastball and only threw it 16.8% of the time, a -71.8% change. This time around, batters had an OPS of 0.713 against him, and his WAR increased to 2.9. Finally, this past season in 2010, his reliance on fastballs increased to 33.9%, a 101.8% change. Batters had an OPS of 0.871, while he obtained a WAR of 0.0. He provided no more value to his team than any other replacement player.
Another pitcher that benefitted greatly from cutting his reliance on fastballs is Minnesota Twins starting pitcher, Francisco Liriano. Coming off Tommy John Surgery that caused him to miss the entire 2007 season, Francisco Liriano only pitched in 14 games in 2008. In these 14 games, 53.6% of his pitchers were fastballs, resulting in an OPS of 0.719. That season, he had a WAR of 1.5. The next season, he increased his workload to 29 games. He threw his fastball 56.5% of the time, a 5.4% increase. Liriano’s 2009 statistics included an OPS of 0.831 and a WAR of 1.1. Finally, last season, in 31 games, Francisco Liriano threw his fastball at a rate of 48.6%, a 14% decrease from the previous year. In this season, batters recorded an OPS of 0.670 and Liriano posted a WAR of 6.0. By relying less on his fastball, Francisco Liriano was able to increase his value to the Minnesota Twins by almost 5 wins, and due to his fantastic performance, Francisco Liriano was awarded the 2010 Comeback Player of the Year in 2010.

Appendix A
Glossary of Baseball Statistics

(Definitions retrieved from Fangraphs.com and Wikipedia unless otherwise noted)

AVG - Batting Average Against – a statistic that measures a pitcher's ability to prevent hits during official at bats.

BABIP – Batting average for balls in play – a statistic measuring the percentage of plate appearances ending with a batted ball in play (excluding home runs) for which the batter is credited with a hit. BABIP is commonly used as a red flag in baseball statistical analysis, as a consistently high or low BABIP is hard to maintain – much more so for pitchers than hitters. Therefore, BABIP can be used to spot fluky seasons by pitchers, as those whose BABIPs are extremely high can often be expected to improve in the following season, and those pitchers whose BABIPs are extremely low can often be expected to regress in the following season. A normal BABIP is around .300, though the baseline regression varies depending on the quality of the team's defense. The equation for BABIP is:

$$BABIP = \frac{H - HR}{AB - K - HR + SF}$$

ERA – Earned Run Average – the mean of earned runs given up by a pitcher per nine innings pitched. An earned run is any run for which the pitcher is held accountable (i.e. the run scored as a result of normal pitching and not due to a fielding error or a passed ball). ERAs can be roughly interpreted as follows

ERA	Notes
< 2.00	Exceptional. Achieved very rarely
2.00 - 3.00	Excellent. Only achieved by best pitchers in the league
3.00 - 4.00	Better than average
4.00 - 5.00	Average
5.00 - 6.00	Worse than average
> 6.00	Very poor. Performance this consistently weak usually leads to reduction of pitching duties and possible demotion to a lower league

HR/9 – Home runs allowed per 9 innings – the average number of home runs given up by a pitcher per nine innings pitched

IP – Innings pitched – the number of innings a pitcher has completed, measured by the number of batters and base runners that are put out while the pitcher on the pitching mound in a game.

K/ 9 – Strikeouts per 9 innings – The average of how many batters a pitcher strikes out per 9 innings pitched.

K/BB – Strikeouts to Walks Ratio – A pitcher's ratio of strikes to walks. Measures a pitcher's ability to control pitches.

OPS – on-base percentage plus slugging percentage – The sum of on base percentage and slugging percentage. The on base percentage formula is defined below:

$$OBP = \frac{Hits+Walks+Hit\ By\ Pitch}{At\ Bats+Walks+Hit\ By\ Pitch+Sacrifice\ Flies}$$

The slugging percentage formula is defined as follows:

$$SLG = \frac{(Singles) + (2 * Doubles) + (3 * Triples) + (4 * Home\ Runs)}{At\ Bats}$$

Captures a hitter's ability to get on base and hit for power in a simple way so he can be compared to every other player. "In prior empirical research, OPS has been shown to be a strong predictor of the number of runs a team scores. (Fox, 2006) To conceptualize this statistic better, the following table provides a scale that OPS can be graded upon (James, 2010)

OPS Interval	Grade
.9000 and Above	Excellent (A)
.8333 to .8999	Very Good (B)
.7667 to .8333	Good (C)
.7000 to .7666	Average (D)
.6334 to .6999	Fair (E)
.5667 to .6333	Poor (F)
.5666 and Lower	Very Poor (G)

REW – Run Expectancy Wins - REW is the same as RE24, except it has been converted to a wins scale. RE24 is the difference in run expectancy (RE) between the start of the play and the end of the play. That difference is then credited/debited to the batter and the pitcher. Over the course of the season, each players' RE24 for individual plays is added up to get his season total RE24.

SwStr% - Percentage of pitches that induced a swinging strike.

WHIP – Walks + Hits per inning pitched – Advanced baseball statistical measurement of the number of base runners a pitcher has allowed per inning pitched. It is a measure of a pitcher's ability to prevent batters from reaching base.

WPA – Win Probability Added - WPA is the difference in win expectancy (WE) between the start of the play and the end of the play. That difference is then credited/debited to the batter and the pitcher. Over the course of the season, each players' WPA for individual plays is added up to get his season total WPA.

xFIP – Expected Fielding Independent Pitching – (HR x 13 + (BB + HBP - IBB) x 3 - K x 2) / IP, plus a league-specific factor (usually around 3.2). Eliminate everything a pitcher can't control (defense, park effects, bloop singles, etc.) and concentrate on the stuff he can control (strikeouts, walks, home runs, etc.). Also corrects HR/fly ball rate to the expected level, covering any pitcher who had bad luck with a couple of wind-blown homers or wall-scrapers. Interpreted on same scale as ERA.

Appendix B
Tables

Table 1: Summary Statistics for Starting Pitchers

	2007			2008			2009			2010		
	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min
WAR	1.3 (1.7)	7.1	-1.1	1.4 (1.7)	7.6	-1.3	1.4 (1.8)	9.4	-1.5	1.6 (1.8)	7.0	-1.6
OPS	0.810 (0.120)	1.357	0.525	0.792 (0.116)	1.238	0.552	0.794 (0.103)	1.174	0.519	0.758 (0.099)	1.115	0.459
ERA	5.24 (2.01)	15.55	1.54	5.07 (1.92)	16.4	1.83	5.00 (1.65)	13.06	2.16	4.51 (1.4)	11.08	0.9
K/9	6.02 (1.75)	11.44	1.74	6.2 (1.8)	12.86	2.13	6.32 (1.7)	10.91	2.23	6.53 (1.62)	12.18	3.09
BB/9	3.44 (1.3)	8.18	0.71	3.57 (1.57)	12.91	0.67	3.52 (1.33)	10.45	1.14	3.34 (1.23)	8.61	0.76
K/BB	2.03 (1.1)	10	0.4	2.03 (1.05)	10	0.23	2.04 (0.96)	5.94	0.33	2.22 (1.08)	10.28	0.5
HR/9	1.24 (0.67)	4.63	0	1.18 (0.54)	3.57	0	1.22 (0.52)	3.48	0	1.08 (0.48)	3.08	0
IP	104.13 (72.24)	241	10.3	104.73 (73.55)	253	10	105.22 (69.67)	240	10.3	120.63 (71.86)	250.7	10
Balls	628.9 (414.95)	1495	50	633.2 (418.2)	1408	64	642.6 (400.2)	1395	59	723.2 (410.7)	1424	55
Strikes	1065.2 (727.9)	2409	91	1074.3 (743.2)	2530	97	1083.8 (700.1)	2635	116	1235.8 (724.7)	2450	96
Pitches Thrown	1694.1 (1138.31)	3692	152	1707.5 (1157.2)	3814	161	1726.4 (1095.8)	3937	177	1959 (1130.7)	3748	151
% Strikes	0.6200 (0.03)	0.7283	0.5256	0.6209 (0.0294)	0.6929	0.5071	0.6235 (0.0272)	0.6929	0.5272	0.6255 (0.0253)	0.7114	0.5515
BABIP	0.313 (0.04)	0.453	0.188	0.310 (0.042)	0.494	0.189	0.308 (0.038)	0.464	0.173	0.304 (0.035)	0.462	0.179
AVG	0.284 (0.038)	0.434	0.190	0.277 (0.039)	0.43	0.190	0.276 (0.037)	0.423	0.140	0.268 (0.032)	0.415	0.151
WHIP	1.51 (0.29)	2.83	1.03	1.49 (0.30)	2.77	1.0	1.48 (0.27)	2.71	1.0	1.41 (0.24)	2.42	0.76
WPA	-0.10 (1.38)	4.33	-3.50	-0.07 (1.42)	5.96	-3.73	-0.07 (1.41)	6.07	-2.98	0.31 (1.52)	5.70	-3.41
REW	-0.12 (1.41)	3.83	-3.85	-0.09 (1.45)	5.04	-3.49	-0.07 (1.46)	6.01	-3.63	0.27 (1.58)	5.71	-4.23
SwStr%	0.077 (0.021)	0.161	0.024	0.076 (0.021)	0.15	0.03	0.078 (0.019)	0.153	0.028	0.077 (0.019)	0.130	0.034
xFIP	4.89 (0.81)	7.61	2.58	4.67 (0.80)	8.04	2.57	4.66 (0.82)	9.16	2.82	4.47 (0.72)	7.59	2.15
FB%	0.6063 (0.09)	0.808	0.136	0.6046 (0.1022)	0.826	0.133	0.5932 (0.1103)	0.900	0.071	0.5762 (0.0974)	0.819	0.125
CB%	0.0975 (0.0802)	0.342	0.000	0.0974 (0.0823)	0.354	0.000	0.1008 (0.0830)	0.368	0.000	0.1002 (0.0788)	0.365	0.000
SL%	0.12 (0.09)	0.505	0.000	0.1289 (0.0973)	0.486	0.000	0.1307 (0.1004)	0.388	0.000	0.1274 (0.0938)	0.369	0.000
CH%	0.13 (0.07)	0.450	0.000	0.1183 (0.0772)	0.457	0.000	0.1144 (0.0725)	0.392	0.000	0.1304 (0.0765)	0.334	0.000
Max	89.4 (2.8)	95.8	74.2	89.8 (2.7)	94.9	72.9	90.2 (2.6)	96.1	72.4	90.3 (2.7)	97.3	72.9
Diff	13.6 (3.1)	21.6	5.2	14.0 (3.2)	26.5	6.3	13.7 (3.3)	23.3	6.1	13.7 (3.1)	28	5.8
Count	268			267			266			239		

Table 2: Summary Statistics for Relief Pitchers

	2007			2008			2009			2010		
	Average	max	min	Average	max	min	average	max	min	average	max	min
WAR	0.4 (0.7)	3.2	-1.1	0.3 (0.7)	3.3	-1.3	0.3 (0.7)	2.9	-1.0	0.3 (0.7)	3.1	-1.5
OPS	0.744 (0.132)	1.231	0.440	0.731 (0.138)	1.209	0.000	0.744 (0.138)	1.194	0.315	0.725 (0.135)	1.246	0.403
ERA	4.46 (1.90)	12.15	0.38	4.22 (1.77)	12.46	0.00	4.39 (1.93)	13.50	0.60	4.13 (1.77)	11.32	0.00
K/9	7.2 (2.2)	14.9	0.8	7.3 (2.1)	13.1	2.0	7.4 (2.1)	14.9	1.6	7.8 (2.4)	17.4	1.5
K/BB	2.2 (1.3)	13.0	0.1	2.2 (1.3)	12.8	0.5	2.2 (1.4)	13.0	0.3	2.4 (1.5)	12.0	0.5
HR/9	0.9 (0.6)	3.7	0.0	1.0 (0.6)	3.1	0.0	1.0 (0.7)	4.5	0.0	0.9 (0.6)	4.2	0.0
IP	42.2 (22.2)	93.2	10.0	43.2 (21.7)	89.1	10.0	41.0 (22.1)	89.1	10.1	40.7 (20.9)	92.0	10.0
Balls	265.3 (131.5)	571.0	54.0	275.3 (135.9)	637.0	42.0	263.7 (136.6)	602.0	36.0	256.5 (124.9)	582.0	52.0
Strikes	438.8 (227.6)	1016.0	93.0	450.2 (225.0)	929.0	73.0	428.8 (227.6)	886.0	88.0	424.1 (213.8)	991.0	99.0
Pitches Thrown	704.1 (355.7)	1533.0	150.0	725.4 (357.9)	1509.0	115.0	692.5 (361.5)	1477.0	131.0	680.6 (335.9)	1573.0	155.0
% Strikes	0.6200 (0.0328)	0.7304	0.5373	0.6182 (0.0307)	0.7033	0.5236	0.6156 (0.0323)	0.7322	0.5027	0.6196 (0.0311)	0.7313	0.5380
BABIP	0.306 (0.050)	0.521	0.125	0.299 (0.050)	0.507	0.111	0.302 (0.051)	0.476	0.104	0.304 (0.050)	0.487	0.140
batting avg against	0.261 (0.047)	0.408	0.135	0.254 (0.046)	0.450	0.093	0.257 (0.049)	0.430	0.111	0.253 (0.047)	0.462	0.134
WHIP	1.44 (0.33)	2.85	0.63	1.41 (0.30)	2.77	0.29	1.45 (0.33)	2.63	0.59	1.40 (0.33)	3.00	0.68
WPA	0.24 (1.10)	5.98	-2.70	0.15 (1.08)	5.37	-3.02	0.16 (1.09)	5.13	-4.54	0.30 (1.11)	5.19	-2.70
REW	0.15 (0.87)	3.24	-1.57	0.14 (0.79)	2.59	-2.14	0.13 (0.78)	2.59	-2.43	0.21 (0.83)	2.54	-2.33
SwStr%	0.0946 (0.0259)	0.1960	0.0380	0.0926 (0.0247)	0.1790	0.0300	0.0908 (0.0242)	0.1790	0.0300	0.0932 (0.0242)	0.1640	0.0270
xFIP	4.70 (0.89)	7.61	2.42	4.44 (0.81)	6.88	2.16	4.54 (0.89)	8.04	2.05	4.30 (0.91)	7.98	1.87
FB%	0.6128 (0.1180)	0.9480	0.1830	0.6207 (0.1210)	0.9130	0.1200	0.6137 (0.1338)	0.8990	0.0710	0.6144 (0.1294)	0.9040	0.1150
CB%	0.1032 (0.0910)	0.4620	0.0010	0.1041 (0.0940)	0.3670	0.0010	0.1195 (0.1007)	0.4360	0.0010	0.1357 (0.0935)	0.5310	0.0020
SL%	0.2060 (0.1232)	0.5710	0.0030	0.2103 (0.1302)	0.6080	0.0010	0.2085 (0.1295)	0.6540	0.0010	0.2185 (0.1218)	0.6500	0.0010
CH%	0.0965 (0.0881)	0.5400	0.0010	0.0809 (0.0839)	0.3890	0.0010	0.0948 (0.0888)	0.3880	0.0010	0.0985 (0.0881)	0.4900	0.0010
Max	90.7 (2.8)	97.5	78.6	91.0 (2.8)	97.5	79.6	91.4 (2.8)	99.3	78.2	91.7 (2.9)	99.9	72.8
Diff	12.3 (3.2)	22.9	4.6	12.2 (3.3)	22.4	0.3	12.2 (3.4)	21.6	0.4	12.16 (3.3)	22.5	1.1
Count		344			332			350			332	

Table 3: Correlation Matrix for Starting Pitchers

	ERA	WAR	OPS	K/9	BB/9	K/BB	HR/9	IP	% Strikes	BABIP	FB%	CB%	SL%	CH%
ERA	1.0000													
WAR	-0.5441	1.0000												
OPS	0.8798	-0.6195	1.0000											
K/9	-0.2826	0.449	-0.3661	1.0000										
BB/9	0.4801	-0.4191	0.3929	0.0158	1.0000									
K/BB	-0.4337	0.5849	-0.452	0.5157	-0.6554	1.0000								
HR/9	0.6071	-0.5038	0.6992	-0.1628	0.1671	-0.204	1.0000							
IP	-0.4862	0.7938	-0.4956	0.2505	-0.3947	0.3721	-0.3378	1.0000						
% Strikes	-0.4074	0.4505	-0.3675	0.1888	-0.7705	0.6806	-0.1498	0.3795	1.0000					
BABIP	0.5576	-0.1108	0.5931	0.1022	0.1299	-0.0071	0.0537	-0.1997	-0.0589	1.0000				
FB%	0.1011	-0.0958	0.0695	-0.0078	0.1458	-0.1281	-0.0237	-0.1155	-0.1547	0.0853	1.0000			
CB%	-0.0198	0.0772	-0.0053	0.0698	-0.0347	0.0697	0.0079	0.0231	0.0102	0.0157	-0.199	1.0000		
SL%	-0.0728	0.0416	-0.0735	0.0916	-0.0434	0.0567	-0.0452	0.0633	0.0796	-0.0063	-0.044	-0.4904	1.0000	
CH%	0.0527	-0.1085	0.0807	-0.0878	0.0043	-0.0455	0.0858	-0.093	-0.0318	-0.0032	-0.0779	-0.1745	-0.2426	1.0000
Max	-0.1727	0.3166	-0.222	0.4057	0.0196	0.1927	-0.1901	0.1594	0.0311	0.0416	0.3692	0.0079	0.1511	-0.181
Diff	-0.1497	0.1506	-0.1402	0.1157	-0.0681	0.1106	-0.106	0.1391	0.0956	-0.0715	-0.0194	0.3118	-0.1439	-0.1331
AVG	0.7831	-0.4499	0.8779	-0.397	0.1584	-0.2934	0.4171	-0.3871	-0.1785	0.8157	0.0696	-0.0134	-0.0586	0.0613
WHIP	0.8601	-0.5614	0.8724	-0.2829	0.6735	-0.578	0.4079	-0.5143	-0.5565	0.6829	0.1317	-0.0266	-0.071	0.0511
WPA	-0.6058	0.7306	-0.6388	0.3471	-0.3087	0.4711	-0.3921	0.4579	0.3422	-0.3534	-0.0695	0.0585	-0.0131	-0.025
REW	-0.6376	0.7422	-0.6645	0.3418	-0.3305	0.4827	-0.408	0.4691	0.3618	-0.3796	-0.0768	0.0568	-0.0073	-0.0301
%SwStr	-0.3723	0.4634	-0.4278	0.7425	-0.1495	0.4835	-0.2236	0.3032	0.3207	-0.0399	-0.1255	-0.0565	0.1287	0.0883
xFIP	0.529	-0.4458	0.4861	-0.3766	0.4965	-0.4937	0.3021	-0.3424	-0.4088	0.1122	0.0717	-0.0288	-0.0766	0.0889

	Max	Diff	AVG	WHIP	WPA	REW	%SwStr	xFIP
Max	1.0000							
Diff	0.1496	1.0000						
AVG	-0.2044	-0.1455	1.0000					
WHIP	-0.1378	-0.1427	0.8309	1.0000				
WPA	0.2522	0.141	-0.5763	-0.584	1.0000			
REW	0.2539	0.1486	-0.6001	-0.6151	0.966	1.0000		
%SwStr	0.3332	0.0372	-0.4252	-0.3948	0.3839	0.3856	1.0000	
xFIP	-0.2013	-0.0799	0.3507	0.5421	-0.3802	-0.3865	-0.3689	1.0000

Table 4: Correlation Matrix for Relief Pitchers

	ERA	WAR	OPS	K/9	K/BB	HR/9	IP	%Strikes	BABIP	FB%	CB%	SL%	CH%	Max
ERA	1													
WAR	-0.4979	1												
OPS	0.8402	-0.5891	1											
K/9	-0.2576	0.4448	-0.348	1										
K/BB	-0.3524	0.4989	-0.4026	0.4251	1									
HR/9	0.5543	-0.4997	0.648	-0.1216	-0.0622	1								
IP	-0.3842	0.4276	-0.3808	0.2077	0.1768	-0.2382	1							
%Strikes	-0.2789	0.4121	-0.2812	0.1427	0.62	-0.0331	0.2714	1						
BABIP	0.5731	-0.0782	0.6293	0.099	-0.0934	0.0619	-0.1862	-0.0425	1					
FB%	-0.0192	0.0376	-0.0513	0.0467	0.0022	-0.0742	0.0218	-0.0312	-0.0036	1				
CB%	-0.0159	-0.0244	0.017	-0.0523	-0.0655	-0.0167	-0.0688	-0.0743	-0.016	-0.144	1			
SL%	0.0397	-0.0035	0.0269	0.1029	0.0064	0.0192	0.0134	0.0169	0.0644	-0.2803	-0.5213	1		
CH%	0.0653	-0.1204	0.0909	-0.1364	-0.0712	0.122	-0.0865	-0.0513	-0.0286	-0.2312	-0.0767	-0.2061	1	
Max	-0.0801	0.194	-0.1577	0.3625	0.0754	-0.1233	0.1748	-0.0389	0.0392	0.3142	-0.0327	-0.0647	-0.2537	1
Diff	-0.0208	0.0341	-0.0017	0.0539	-0.0328	0.0024	0.0118	-0.0149	-0.0132	0.046	0.4251	-0.322	-0.0098	0.1252
AVG	0.7642	-0.4093	0.8788	-0.4003	-0.2832	0.3874	-0.3126	-0.1039	0.8265	-0.0461	0.004	0.0154	0.0695	-0.1667
WHIP	0.8031	-0.5233	0.8641	-0.2705	-0.5656	0.3436	-0.39	-0.4846	0.7239	-0.006	0.0097	0.0184	0.0502	-0.0713
WPA	-0.5163	0.6102	-0.5564	0.2778	0.3444	-0.2913	0.3842	0.2618	-0.3726	0.0168	-0.0072	-0.0113	-0.0986	0.1082
REW	-0.7559	0.6521	-0.7432	0.2957	0.3786	-0.4343	0.4551	0.2895	-0.5202	0.0196	-0.0029	-0.0333	-0.0802	0.1032
%SwStr	-0.2729	0.4088	-0.3385	0.7266	0.42	-0.1029	0.253	0.2648	-0.0077	-0.127	-0.1736	0.2037	0.0483	0.2606
xFIP	0.5483	-0.6517	0.5872	-0.6202	-0.6772	0.3248	-0.3818	-0.5318	0.0633	-0.0394	0.0141	-0.0287	0.1527	-0.2246

	Diff	AVG	WHIP	WPA	REW	%SwStr	xFIP
Diff	1						
AVG	-0.0344	1					
WHIP	-0.013	0.8386	1				
WPA	0.0308	-0.524	-0.5355	1			
REW	0.026	-0.7004	-0.7176	0.7822	1		
%SwStr	-0.0643	-0.3595	-0.329	0.2587	0.3001	1	
xFIP	0.013	0.424	0.6483	-0.4135	-0.5059	-0.5361	1

Table 5: Regression Analysis of OPS vs. Pitch Type for Starters and Relievers

	Starting Pitchers	Relief Pitchers
Fastballs	.0642905*	-.0419765
	(.0353666)	(.032503)
Curveballs	-.0516897	.0393051
	(.0503779)	(.0495116)
Sliders	-.1038196*	.0297437
	(.0417578)	(.0347514)
R^2	0.0108	0.0033

Notes: The dependent variable is a pitcher's OPS. Standard errors are shown in parenthesis. The number of observations is equal to 1,040 for starters and 1,357 for relievers.
* p= <.1, **p = <.01, *** p<.001

Table 6: T-Test: Difference in WAR Sample Mean for Starting Pitchers Who Increased Fastball Use vs. Those Who Decreased Fastball Use

Decreased FB use			Increased FB use	
FB% Diff	WAR Diff		FB% Diff	WAR Diff
-0.052	0.077	Average	0.036	-0.163
0.051	1.644	Variance	0.035	1.65
318	318	Count	216	216

Results	t	df	Two-tailed p-value	Standard Dev
OPS	1.65	532	0.1	1.65

Table 7: T-Test: Difference in WAR Sample Mean for Relief Pitchers Who Increased Fastball Use vs. Those Who Decreased Fastball Use

Decreased FB use			Increased FB use	
FB% Diff	WAR Diff		FB% Diff	WAR Diff
-0.069	-0.069	Average	0.056	-0.214
0.003	0.606	Variance	0.002	0.703
340	340	Count	307	307

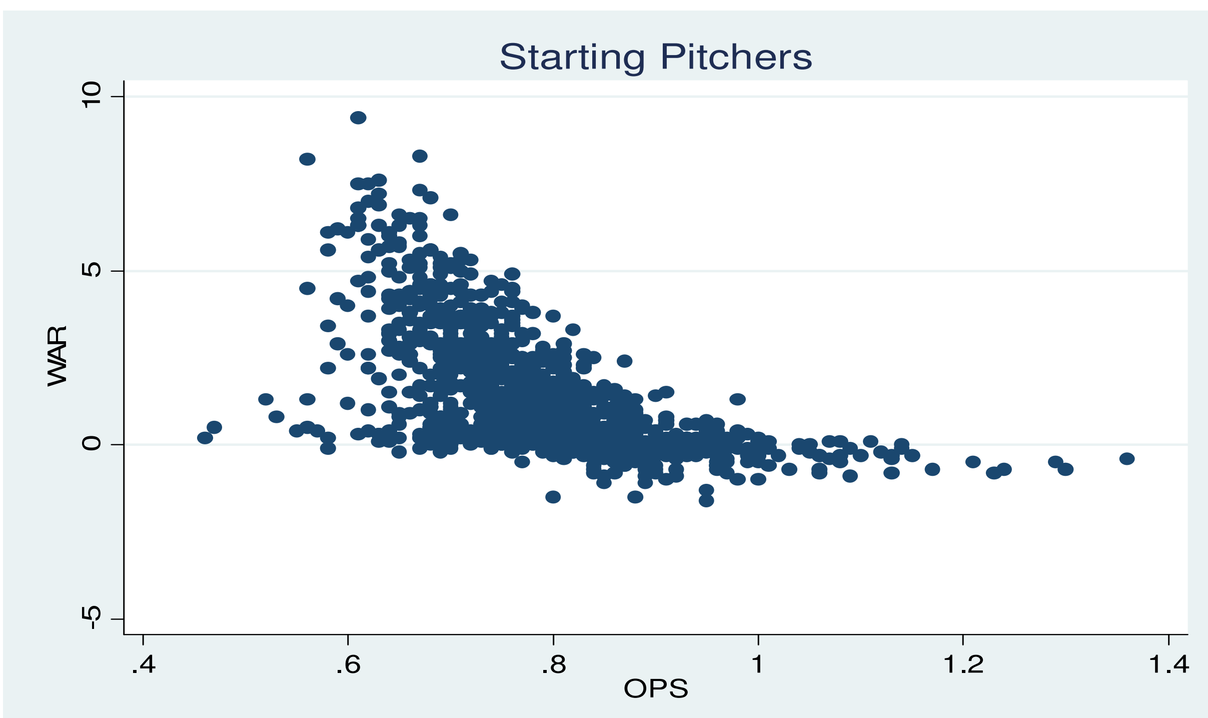
Results	t	df	Two-tailed p-value	Standard Dev
OPS	2.27	645	0.023	0.808

Table 8: T-Test: Difference in Fastball Use between Starting Pitchers and Relief Pitchers

Starting Pitchers		Relief Pitchers
Fastball %		Fastball %
0.60 0.100904 1040	Average Variance Count	0.615541 0.12554 1357

Results	t	df	Right-tailed p-value	Standard Dev
FB%	3.2649	2395	.00055	0.005

Graph 1: Starting Pitcher's WAR vs. OPS



Graph 2: Relief Pitcher's WAR vs. OPS

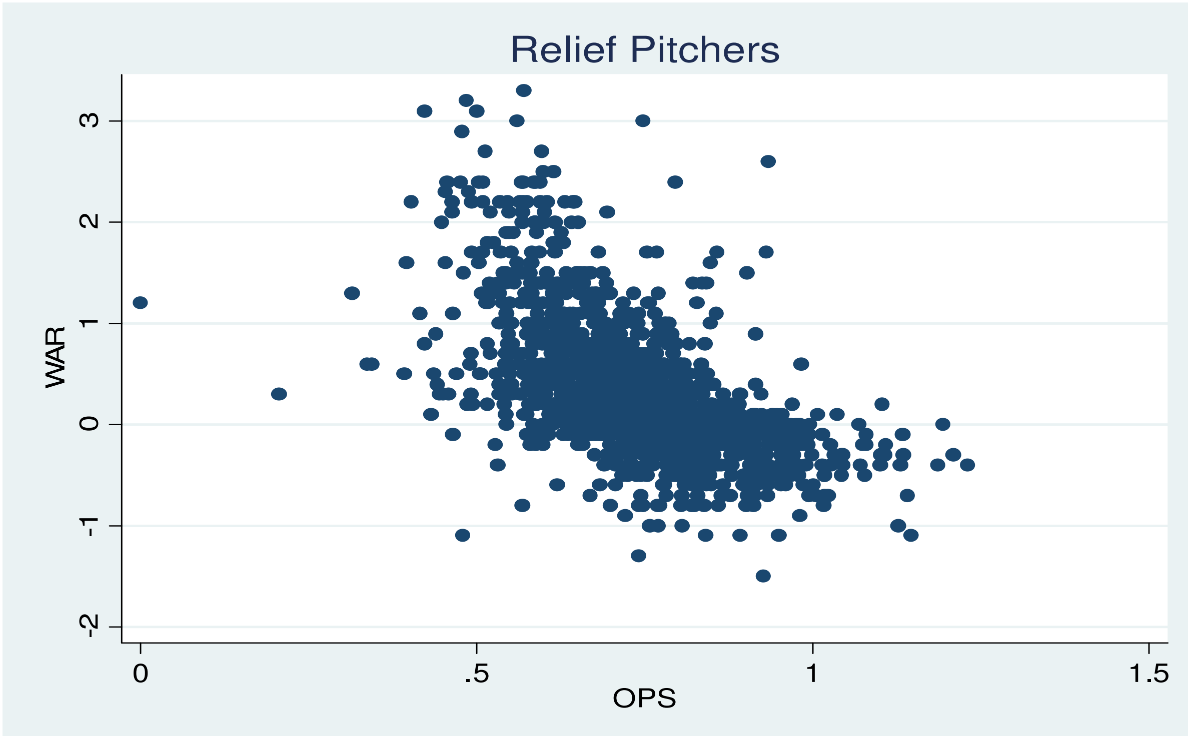


Table 9: Regression Analysis of WAR vs. Other Predictor Variables for Starting Pitchers

	(1)	(2)	(3)
OPS	-9.764578***		-6.227705***
	(.384067)		(.3934314)
K/BB			.5488333***
			(.0431176)
IP		.019386***	
		(.0004611)	
Pitch Speed			.016445
Differential			(.012003)
Max velocity			.108701***
			(.0166157)
SwStr%			6.017285**
			(2.310465)
Fastball %			-1.377262**
			(.4196499)
Constant			-4.415718**
			(1.417009)
R^2	0.3838	0.6301	0.5333

Notes: The dependent variable is a pitcher's WAR. Standard errors are shown in parenthesis. The number of observations is equal to 1,040 in all columns.
* p= <.1, **p = <.01, *** p<.001

Table 10: Regression Analysis of WAR vs. Other Predictor Variables for Relief Pitchers

	(1)	(2)	(3)
OPS	-3.030339***		-.7480672***
	(.1129083)		(.1459109)
IP		.0136603***	
		(.0007845)	
K/BB			.120852***
			(.0132164)
HR/9			-.3941003***
			(.027985)
% Strikes			3.725498***
			(.5213681)
Max Velocity			.015737**
			(.0051231)
Pitch Speed			.0099467*
Differential			(.003961)
SwStr%			4.584408***
			(.6252883)
Fastball %			.0357626
			(.1114758)
Constant			-3.297502***
			(.5752681)
R^2	0.3471	0.1828	0.5183

Notes: The dependent variable is a pitcher's WAR. Standard errors are shown in parenthesis. The number of observations is equal to 1,358 in all columns.
* p= <.1, **p = <.01, *** p<.001

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