The Financial Implications of Tommy John Surgery: The Actuarial Value of Major League Baseball Pitchers

Aaron Hartman

Robert Morris University

Abstract

General Managers (GMs) have the most challenging job in professional sports: predicting player value. Player value is measured by Wins Above Replacement (WAR) which is defined by the marginal increase in wins an individual adds to a club over a replacement level player. These wins correlate with the compensation a player should be paid. A major factor to the overall calculated player value is a player's health status. Players who are physically unable to perform do not add value to a team in terms of wins. From an economic standpoint, there is an opportunity cost associated with reserving salary space for a non-performing player. Ulnar Collateral Ligament (UCL) tears, the most common pitching injury, pose significant injury concerns for Major League Baseball teams. The research conducted in this thesis determined pitcher age and fastball velocity as the two most significant variables contributing the likelihood of a UCL tear. With this knowledge and a logistic regression model created using pitching data from 2008-2012, a GM can more accurately predict his pitching prospects' injury risk. Past pitching data provides an estimate of a player's expected value when the injury risk of UCL tears is considered. MLB GMs can use this pitching data to estimate a pitchers value in the present and determine an estimated expected salary for the members of the pitching staff.

Introduction

In Major League Baseball (MLB), an exorbitant amount of money is invested on pitching. Currently, pitchers hold five of the top ten spots on the list of highest paid players in the MLB (Link & Yosifov, 2012). General Managers (GM) generally pay a proportionally equal amount of their overall salary to pitching and hitting. Unlike hitters, however, pitchers face a common catastrophic arm injury risk with the potential to be on the disabled list for over a year. This specific injury is an Ulnar Collateral Ligament (UCL) tear which requires Tommy John Surgery (TJS) to correct. Because of this devastating injury, GMs need to account for the possibility of losing a pitcher for an extended period of time.

Players are paid to win games. The players who significantly contribute to the probability of their team winning games are compensated at a higher level. This compensation may come in the form of salary, bonuses, contract incentives, or any combination of the three. Wins Above Replacement (WAR) are the units used to value how much a player contributes to each individual win for his team throughout each season. WAR can be defined as the number of wins a player contributes to a team over a "replacement level" player. Replacement level means a player of lesser ability who could easily be added to a roster, generally through a minor league transactions, a free agent signing, or in some cases, a trade. Wins are defined as either ten runs contributed, in terms of batting, or ten runs defended against, in terms of pitching and fielding. A batter can increase their WAR by batting in runs, scoring runs individually, and/or contributing in other ways to the number of runs his team scores. A pitcher can increase their WAR by striking batters out, getting batters to ground out, and preventing the opposing team to score in any other way. Conversely, a players WAR will decrease if they contribute to their team at a level lower than replacement level.

In theory, a player should be compensated with a dollar amount correlating to the contribution to his team, in terms of WAR. However, in practice, contracts are negotiated for a dollar amount based on the predicted player performance during the life of the contract. As with any prediction, some of the variables contributing to player's value are uncertain. Generally uncertainty exists in contracts, therefore risk exists in MLB contracts. When a GM signs a contract with a player, the GM risks this player may not perform at the anticipated level of WAR to compensate for his salary. This may potentially result in the GM enduring an economic loss on this player. There is an opportunity cost associated with investing salary dollars into players, and when a GM endures a loss, the opportunity cost will be greater than the performance of the specific player. To mitigate the risk of enduring a loss, GMs must accurately predict the WAR their players will provide in a given year. Using a probability distribution, the GM could find the expected value of WAR for each player and strategize to pay them according to the league standard conversion of dollars per WAR. With effective modeling and a large enough sample space, the GM can significantly hedge the risk of enduring a loss on his pitching staff.

The GM's main goal is to pay each player a competitive market salary to assemble a roster of quality players and minimize losing key players to free agency signings with other teams. The player must be adequately compensated at a fair market rate to prevent him signing with another team, but not more than he is worth, in terms of WAR, to prevent enduring a loss for players. If a pitcher were to incur a UCL tear, the GM would likely endure a loss on that particular pitcher. The pitcher would still receive the guaranteed money in his contract, but would provide at least one year less than expected in WAR. Injury risk will be defined as the risk of enduring a loss for an injured pitcher because he is physically unable to perform. The focus of this thesis will be to identify methods to assess the probability of injury risk in determining competitive salaries for MLB pitchers.

Pitchers can be modeled similarly to clients for life insurance products. The goal is to determine the players expected present value (EPV), in terms of WAR. In general, EPV is calculated using three components, an amount, a probability, and a discount factor. On an annual basis, the players WAR would be predicted for every season of pitching. The WAR of the player will exist as the amount component of this calculation. WAR can be predicted using previous experience of the pitcher combined with historical data from similar pitchers in the MLB. If a player were to undergo TJS, there would need to be a new prediction model designed using the experience of players who had also undergone TJS. This second model would have a value attached on it based on age and the level of WAR the pitcher had achieved before incurring a UCL tear. The probability of actually succumbing to a UCL tear in each year would be multiplied by the new value given to a pitcher who has undergone TJS. These two steps would calculate the expected value of WAR the player would earn in his career. However, GMs are more willing to pay for WAR occurs in the present rather than the future, so a discount rate must be applied to WAR that is predicted to happen in future years to value it at the present time. Once the EPV is found, the expected salary of that pitcher would be the EPV of War multiplied by a Dollar per WAR factor which can be determined using current salary data.

Literature Review

As of the 2013 season, over one third of all current Major League Baseball (MLB) pitchers have undergone Tommy John Surgery (TJS). Over 100 out of about 300 current pitchers in the MLB have torn their Ulnar Collateral Ligament (UCL) (Cain et al, 2010). Such a staggering number deserves the attention of General Managers (GM) across the league. Since 1974, TJS has evolved to effectively repair UCL tears. What was once a career ending injury has evolved into just a season ending injury due to Dr. Frank Jobe, the inventor of TJS (Gillespie & Cowder, 2003). With the available pitching injury data, GMs should adjust their player valuation methods to protect their clubs from injury risk. The player valuation can provide a value of performance that the GM may select to determine a contract including salary dollars, contract length, bonuses, incentives, etc.

Currently, it is unclear what exactly causes UCL tears. Commonly cited contributing factors are poor mechanics, throwing sliders or curveballs, pitching at high velocity, and other risk factors (strikeout rate, groundball rate, overall pitcher condition, etc…) (Lyman, Fleisig, Andrews, & Osinski 2002). Some believe the UCL tears violently as the result of a particularly stressful overhead throw, while other believe the constant stress of accumulating overhead throws slowly breaks down the UCL until it loses function. Biomechanics are studied to assess the injury risks baseball pitchers face. In medical journals, several studies on youth pitchers have been conducted to determine the injury risk of breaking pitches (Stodden, Fleisig, McLean, & Andrews, 2005). Objective statistics and their correlation with pitching injury have been studied in significantly less depth, possibly because statistical analyses need not be peer reviewed. An in depth analysis of pitching statistics may lead to a better understanding of the causes of UCL tears.

Players are evaluated in different ways by GMs. Each MLB team has a unique budget due to market size and team salary. Subsequently, roughly 30 unique strategies exist for MLB player valuation. A relatively standard metric for player value is Wins Above Replacement (WAR). WAR measures the number of runs contributed offensively (batting and base running) as well as the number of runs saved (defense and pitching) and applies a conversion of 1 win per 10 runs that a player contributes over the number of runs that a Minor League player or readily available free agent could contribute (Pitching, 2013). Whatever the metric, GMs must use a method to convert on the field contributions tofuture player compensation.

The Cost of Tommy John Surgery

Before Frank Jobe developed the TJS procedure, a UCL tear was considered a career ending injury. Today, an MLB pitcher who tears his UCL will be physically unable to compete for the next 12 to 18 months. If a pitcher tore his UCL on opening day, he would be unable to pitch by the end of the season. Generally, a UCL tear is viewed as a season ending or potentially career ending injury, with many players returning to action sometime in the following season after a UCL tear (Magra, Caine, & Maffulli, 2007). Therefore, pitchers who undergo TJS miss a significant amount of playing time.

During the 2008-2012 seasons, pitchers recovering from TJS missed 14,232 games. A combined $193,500,000 was spent on their salaries during the time they were recovering (Maclean, 2007). The salary paid to recovering pitchers is a significant cost a club must anticipate for pitchers who have had TJS.

There is a moderate risk of surgical repairs being ineffective. However, a MLB club is still obligated to pay the pitcher the guaranteed money on the remainder of their contract if he does not recover from TJS. According to Jobe (2007), the success rate of TJS is roughly 85% for all recipients of the surgery (Maclean, 2007). However, the success rate of 85% for TJS is a very conservative estimate for MLB pitchers. Some pitchers having the surgery early in their career may not have the financial motivation to recover completely, thus bringing the success rate down. An estimated 92% of MLB pitchers return to the level of competitiveness before the injury (Maclean, 2007).

Over a large enough sample, a success rate may be determined by finding how many pitchers have had TJS and determining the percentage returning to action for a significant amount of time (Jones et al, 2013; Magra, Caine, & Maffulli, 2007). A major limitation in this research is the difficulty in finding a complete list of MLB pitchers who have undergone TJS. Another limitation is defining whether a pitcher has returned to the pre-injury level of performance. In this case, assumptions can be made to determine whether a pitcher’s performance is indicative of a successful surgery.

Risk factors of UCL Tears

As stated previously, the exact causes of UCL tears are unknown, but it is generally accepted that this injury is primarily limited to baseball pitchers due to the overhead throw motion of the arm when pitching (Stodden, Fleisig, McLean, & Andrews, 2005). The injury is not limited to professional players; a 2008 study showed more than half of all high-school pitchers have experienced elbow pain after pitching (Dun, Loftice, Fleisig, Kingsley, & Andrews, 2008). There are multiple theories about the main causes of UCL tears such as: pitching mechanics, the pitcher's physical conditioning, pitch velocity, pitch types, high innings pitched per season, and high pitch counts per game (Lyman, Fleisig, Andrews, & Osisnski, 2002). While it is widely believed these factors contribute significantly to UCL tears, it is difficult to gather objective data on variables like conditioning and pitching mechanics.

There is significant information from analyzing pitching mechanics. The kinetic chain, which breaks down the pitching motion into six steps, has been cited to explain the possible points in a pitcher's delivery where an injury might occur. Studies have found the angular velocities as well as force applied to the UCL in each step of the kinetic chain (Magra, Caine, & Maffulli, 2007; Lyman, Fleisig, Andrews, & Osisnski, 2002). This does prove from a biomedical perspective, overhead pitching is a highly stressful activity for the elbow (Posner et al, 2011). These studies are not within the bounds of this study because it is difficult to measure the differences in mechanics for pitchers.

Since measuring the differences in mechanics is not feasible, confirmation bias is a major limitation with this factor for injuries. Some examples of poor pitching mechanics include submarine delivery, raising elbows higher than parallel with the ground during delivery, and planting the plant foot before delivery. Baseball aficionados point to pitchers like Stephen Strasburg to prove poor pitching mechanics cause UCL injuries. While they could possibly be correct, there is no explanation as to why pitchers with similarly poor pitching mechanics such as Tim Lincecum and Chris Sale, have never been injured (Truedson, Sexton, & Pettitt, 2012). This also gives little explanation for pitchers like Matt Harvey who have near flawless mechanics have incurred UCL tears (Zimmerman, 2013). It appears UCL tears occur randomly with some pitchers being more at risk than others.

Baseball is a unique sport because many aspects of the game can be quantitatively measured. Unambiguous statistics, kept for every game, are analyzed to determine reasonable outcomes (James, 1982). In the realm of UCL tears, pitch velocity, pitch type, and pitching volume are accurately measured statistics in MLB (Bradbury & Forman, 2012; Zimmerman, 2012). Additionally, minor factors such as strikeout rate (K %), walk rate (BB %), ground ball rate (GB %), and home run to fly ball ratio (HR/FB) can also be analyzed to determine an objective conclusion about the true causes of UCL tears (Zimmerman, 2012). Currently, little qualitative research have analyzed these specific statistics relating to UCL tears. There are mathematical methodologies existing to do this, so the fact there are no scholarly sources is not necessarily detrimental.

Evaluating Players

The beauty of baseball is every team has a different strategic formula to win. All GMs for NFL teams, for example, follow the same general strategy for building a successful team. They must build a core of players through the draft and bring in talent to fit specific team needs through free agency all while staying under the salary cap. Due to different economic models relating to the teams' market size, all 30 MLB teams have a different strategy as to how they fill out their 25 and 40 man rosters each year. For example the New York Yankees have a practice for paying a high price for the highest name free agents on the market, while the Oakland Athletics have a practice for finding undervalued players through drafting and player development, who can possibly contribute in different ways than normal (Sommers & Quinton, 1982; Soebbing, 2008). The Athletics manage their finances this way mostly out of necessity; they have a payroll of just over $60 million while the Yankees have a payroll of over $200 million.

Baseball clubs, like any financial entity, are interested in successfully generating revenue. Revenue is typically generated by three categories: fan revenue, television deals, and sponsorships. These categories are all related, but slight differences exist. Fan revenue covers the revenue made by selling tickets to games, as well per capita expenditures (concessions and other game day purchases). This can vary based on the location of the team, so teams in New York City will have a different economic model for fan revenue than teams in Tampa Bay (Soebbing, 2008). All MLB teams share revenue sold on jerseys, hats, and similar items. Even though 25% of MLB merchandise sold are Yankees merchandise, every team shares equal revenue from these sales (Cameron, 2011). Television deals are contracts with a local cable network to show the teams' games throughout the season and vary from market to market. Sponsorships include the advertisements in the stadium, game day promotions, any corporate partnerships the clubs have (i.e. an official health care provider).

A big name pitcher may increase the fan revenue for days they are scheduled to pitch (Sommers & Quinton, 1982). MLB teams also share 15% of all ticket sales revenue, so if a pitcher boosted attendance in a particular game, the marginal increase he created in attendance would only increase his team's revenue by a factor of 85% (Cameron 2011). It appears a popular player increases attendance in his first season with the team, but unless the team is winning significantly more games, the attendance regresses back to the average it was at before the free agency signing (Cameron 2011). This has a greater impact for teams having a smaller fan base, but with one or two popular pitchers who draw a lot of fans. There will be a very small impact for teams who consistently sell out games regardless of the starting pitcher that day, since the marginal increase of attendance would be minimal (Soebbing, 2008).

In MLB, the gold standard is club wins, which ultimately lead to postseason berths and eventually World Series Championships. A team's payroll can affect the probability of a team reaching the postseason. The main driver of attendance for an MLB team is their win-loss record. Each player individually provides a benefit to his team to improve their win-loss record. GMs invest money in their players hoping the performance will provide returns in terms of higher attendance due to a good win-loss record (Cameron 2011). The methodology that each GM uses to evaluate the talent of his players is different than the other GMs in the league, but a combination of metrics are described in Table 1 (Table 1).

Table 1

Metric	Initialization
Innings Pitched	IP
Strikeout Rate	K%
Walk Rate	BB%
Home Runs Allowed Per Nine Innings Pitched	HR/9
Opposing Batting Average	OBA
Opposing Batting Average of Balls in Play	OBABIP
Ground Ball Rate	GB%
Home Run to Fly Ball Ratio	HR/FB
Earned Run Average	ERA
Fielding Independent Pitching	FIP
Expected Fielding Independent Pitching	xFIP
Wins Above Replacement	WAR
Runs Against Per Nine Innings Pitched Wins Above Replacement	RA-9 WAR

Using regression techniques and considering market variables, it can be determined how important each of these statistics is to determine a player's expected salary. A weighted average will be used based on how important each of the statistics are to determine salary. A score may be applied to a pitcher, and pitchers with similar scores can be pooled together. For example, ground ball pitchers tend to have a shorter shelf life than fly ball pitchers. Because of this, pitchers with similar GB % would need to be pooled together because they are predicted to perform similarly in the future. From there, the only way to determine the future effectiveness of a pitcher would be to build a model based on age. Since age and experience are extremely important factors in determining pitching value, once the value of a pitcher is determined, a simple conversion factor can be applied to estimate the pitcher's salary. Of course, more complicated factors like contract length, performance incentives, bonuses, and guaranteed money would be present in actual contract negotiations (Link & Yosifov, 2012). In conclusion, there is significance in determining the present value of a pitcher based on performance.

Research and Conclusions

The Economy of the MLB

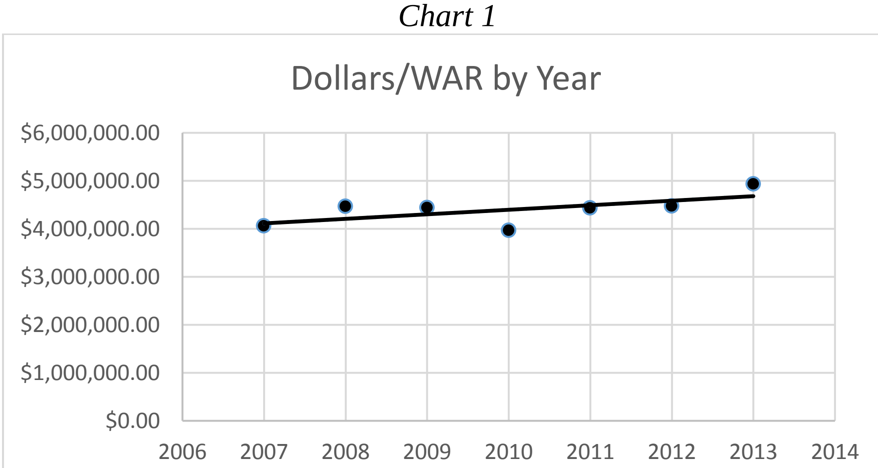
All players on an MLB roster are investments made by the GM. The GM invests an amount of money into each player by providing compensation in the form of a base salary, bonuses, and incentives. The GM will earn a return on his investment with each win that his team accumulates. Each win for a team generates interest from fans causing them to attend games or watch games on television. The team generates revenue from fans paying for tickets to attend the game and from the team's local broadcast network paying for the rights to show the team's games. The team generates revenue from merchandise sales, but all merchandise revenue is distributed evenly throughout all 30 MLB teams (Cameron, 2011). Teams share revenue from 15% of all ticket sales, leaving 85% of revenue from tickets for each team for each of the teams'

81 home games (Cameron, 2011). Generally speaking, television contracts are negotiated and usually involve long term deals ranging from three to ten years (Cameron, 2011). These revenue generating methods suggest the most affective technique for a team to generate revenue is to sell as many tickets as possible.

The primary driver for attendance is a team's win/loss record. Therefore, a player's individual contribution to the team's win/loss record will directly affect attendance (Denaux, Denaux, & Yalcin, 2011). A player's individual contribution to his team's win/loss record is measured in WAR. The higher a player's WAR, the more he contributes to his team's record. In theory, a team with an overall war of zero will still win roughly 48 games per season. A team made of free agents and minor league players would still win some games in the MLB, especially with a 162 game season, but not enough for a winning record and especially not enough for a postseason berth (Swartz, 2012). Since every team is guaranteed to acquire 48 wins, each team is also guaranteed to have about 48 losses. In the last 40 years, only one team has had fewer than 48 wins (the 2003 Detroit Tigers with a record of 43-119) and only one team has had fewer than 48 losses (the 2001 Seattle Mariners with a record of 116-44). This means there are 66 marginal wins for every MLB team.

Players' salaries are determined on a number of different variables, but generally follow a linear pattern relative to their WAR. The market price of one Win Above Replacement has risen slowly but steadily since 2007. In 2007, one Win Above Replacement was worth $4,061,228.45, and the price has risen linearly at a rate of $94,016.55 per WAR per year (Chart 1) (Swartz, 2012). In the future, it is safe to assume this upward trend will continue. Since every team in MLB has a different payroll, so using this scale for every team is unrealistic. This scale represents the average amount a player should earn given his value to his team's win/loss record. A player who generates no WAR would not be paid zero dollars, but theoretically, this player would be paid the league minimum (Link, & Yosifov, 2012). Using the scale in Chart 1 should allow teams to utilize their payroll to acquire the maximum amount of talent.

Chart 1



Injury Risk

Players are always at risk of succumbing to some type of injury, resulting in a loss of playing time, over the course of the season. When this happens, the GM will not be receiving the total value from that player over the duration of his injury, and therefore the GM may endure an economic loss for that player. In the event a pitcher goes an entire season without sustaining an injury, that pitcher will have just experienced a "healthy" season. In the scope of this research, a healthy season is defined as one season in which a pitcher does not sustain a UCL tear. If a pitcher does tear his UCL, then the pitcher will have experienced an injury season. The probability of a healthy season is the complement of the probability of an injury season (Figure 1). In each season, a pitcher must either tear his UCL or not tear his UCL, so the probability of a healthy season and the probability of an injury season will add to one. In statistics, this type of probability distribution is called a Bernoulli distribution. Each season a pitcher pitches will be an individual Bernoulli trial. In this research, the probability of an injury season is investigated, so an injury season will be deemed a success. It will be assumed that once a player tears his UCL, he joins a different pool of players and is no longer considered in the population of healthy pitchers.

Figure 1

p_k = probability of UCL tear in season k

q_k = probability of healthy season during season k

p = (1 – q)

Pr (2 healthy seasons) = $q_1 * q_2$

Pr (n healthy seasons) = $q_1 * q_2 * \ldots * q_n$

Pr (UCL tear within 3 years) = $p_1 + q_1 * p_2 + q_1 * q_2 * p_3$

Pr (UCL tear within n years) = $p_1 + q_1 * p_2 + \cdots + q_1 * q_2 * \ldots * q_{n-1} * p_n$

Determining a Pitcher's Injury Risk

To counteract injury risk throughout the whole team, GM would need to evaluate each one of his pitcher's individual injury risks. There are many factors playing a role in the probability of an injury season. For example, the age of a pitcher is certainly a variable to be considered when determining the probability of an injury season. Studies on youth pitchers have been conducted to determine whether sliders and curveballs are drivers of elbow injuries, so the percentage of breaking pitches a pitcher throws is a possible variable to analyze (Lyman, Fleisig, Andrews, & Osinski, 2002). To measure the percentage of breaking pitches that a pitcher throws, it is most affective to instead measure the percentage of fastballs that a pitcher throws and determine if it is significantly different for pitchers who tear their UCL in a season. Ground ball percent is a variable that has been investigated in the past, so a pitcher's ground ball percent should be studied to determine if it is a driver of elbow injuries (Zimmerman, 2012). A pitcher's ground ball percent could drive elbow injuries because pitchers who throw pitches that are more likely to be hit on the ground may throw the ball in a fashion that will apply more stress to the elbow. On top of all of these factors is the velocity in which a pitcher throws his fastball.

Fastballs thrown at a higher velocity will apply more force to the elbow, so higher fastball velocity would be expected to increase the probability of an injury season (Polster et al., 2013).

A logistic regression was developed to analyze the significance of these variables in relation to the probability of an injury season. Logistic regressions consider variables that can contribute towards the probability of an event to estimate the probability that said event occurs. A general logistic regression can be found in Figure 2 (Figure 2). In this general formula, p refers to the probability of an event occurring, the x values refer to variables that are determined before the regression is calculated, and each B refers to coefficients that are calculated by the regression. Each coefficient will be attached to a variable to determine a final formula to estimate p.

Figure 2

$$\ln\left(\frac{p}{1-p}\right) = B_0 + B_1 * x_1 + B_2 * x_2 + \cdots + B_n * x_n$$

Using pitching data from the 2008-2013 MLB seasons retrieved from Fangraph's PitchF/X database, a logistic regression was performed to analyze the variables mentioned above. The date range was chosen because 2008 was the earliest season in which complete PitchF/X velocity and pitch type data could be retrieved. Each of the seasons were assumed to be independent of the previous seasons for each pitcher, so the model measures the one-year failure rate of a pitcher's UCL. If a pitcher incurred a UCL tear in a season, the pitcher was assigned an indicator value of 1, and if they did not incur a UCL tear, the player was assigned an indicator value of 0. The logistic regression was then performed using the variables listed in Table 2 (Table 2). To measure the significance of each variable, the chi-squared value was also calculated. If a variable had a chi-squared value of less than .05, it was determined significant. This means that there is a 5% chance that a variable determined significant did not actually contribute to UCL tears, and the data coincidentally made it appear to contribute.

Table 2

Variable	Coefficient	χ^2 Significance
Intercept	-14.9205	0.00785
Age	-0.16135	0.01870
Years in MLB	0.05636	0.43347
Fastball Velocity	0.17029	0.00317
Fastball %	-0.48328	0.69589
Pitches Per Inning	-0.03500	0.64131
Ground Ball %	0.72191	0.62046

After the regression using all six variables was performed, the most significant variables were age and fastball velocity. All other variables were not within the bounds of the original chi-squared level of significance, so they were no longer considered in the study. Logistic regression models become more accurate with every addition of a significant variable, but the most efficient model involves only the most significant variables. The Akaike Information Criterion provides a trade-off between goodness of fit and complexity in the regression. Using the Akaike information criterion, it was determined that the most efficient model included only age and fastball velocity.

Understanding of the kinetic chain explains why the average fastball velocity variable is significant. The kinetic chain is essentially a system of joints allowing movement to flow through a mechanism. In the case of pitching a baseball, the kinetic chain follows a path through the legs providing the initial push, into the torso providing torque, and finally through the pitching arm propelling the baseball towards home plate (Stodden, Fleisig, McLean, & Andrews, 2005). The weakest spot in this kinetic chain happens to be the UCL (Polster et al., 2013). When excessive amounts of force are placed on the UCL, it has a higher likelihood to tear. Increases in fastball velocity correlate with increases in the force placed on the UCL, so it is understandable that increased fastball velocity will increase the likelihood of a UCL tear (Polster et al., 2013). An analysis of the data used for this regression reveals the average fastball velocity of a pitcher who tore his UCL that season was about 92.5 miles per hour, and the average fastball velocity of a healthy pitcher was about 91.2 miles per hour. This provides evidence supporting the notion that pitchers who throw fastballs at a higher velocity are more likely to tear their UCLs.

Using only the two significant variables, age and fastball velocity, another logistic regression can be performed to develop an equation predicting the probability of an injury season for all pitchers (Table 3) (Figure 3), starting pitchers (Table 4) (Figure 4), and relief pitchers (Table 5) (Figure 5). Each of the coefficients calculated have a variance attached to them. A range of values for each coefficient can be calculated using a normal distribution. One would expect the true value of the coefficient to fall within two times the standard error plus/minus the estimated mean of the coefficient. The equations in Figures 3, 4, and 5 provide a formula to calculate the expected probability of an injury season, but it should be noted that there is a variance attached to each coefficient.

Table 3

Logistic Regression Results for All Pitchers

Variable	Coefficient	Standard Error	χ^2 Significance
Intercept	-15.93501	5.19209	0.00215
Age	-0.11425	0.03940	0.00374
Fastball Velocity	0.16394	0.05264	0.00184

Figure 3

Expected Probability of Injury Season for All Pitchers

$$\ln\left(\frac{p}{1-p}\right) = -15.93501 - 0.11425 * (Age) + 0.16394 * (Fastball\ Velocity)$$

Table 4

Logistic Regression Results for Starting Pitchers

Variable	Coefficient	Standard Error	χ^2 Significance
Intercept	-19.60521	7.94472	0.0136
Age	-0.11323	0.05573	0.0422
Fastball Velocity	0.20616	0.08072	0.0106

Figure 4
Expected Probability of Injury Season for Starting Pitchers

$$\ln\left(\frac{p}{1-p}\right) = -19.60521 - 0.11323 * (Age) + 0.20616 * (Fastball\ Velocity)$$

Table 5

Logistic Regression Results for Relief Pitchers

Variable	Coefficient	Standard Error	χ^2 Significance
Intercept	-21.33077	8.33344	0.0105
Age	-0.06749	0.05746	0.2401
Fastball Velocity	0.20573	0.08295	0.00131

Figure 5
Expected Probability of Injury Season for Relief Pitchers

$$\ln\left(\frac{p}{1-p}\right) = -21.33077 - .06749 * (Age) + 0.20573 * (Fastball\ Velocity)$$

Using the above formulas, a GM could predict the probability of a healthy season for each of his pitchers. A standard error for each variable does exist, but the error is not high enough to claim any of the coefficients could equal zero. The negative coefficient attached to the age variable indicates younger pitchers are more susceptible to UCL tears compared to older pitchers. In the data used for this regression, the average age of a player who tore his UCL for a specific season was about 26 years, and the average age of a healthy pitcher was about 28 years. It is important to note at a significance level of 0.05, age was not significant in the relief pitcher cohort. Velocity is still significant in this cohort, however. One drawback to this model is there is no standard way to predict a pitcher's future fastball velocity. There are two recommended methods to counter this uncertainty: 1. The GM could assume the pitcher's velocity will remain constant at its current value in the future 2. The GM could use historical data to determine how velocity might change with age and apply these changes to the pitcher's current velocity for future predictions. The aforementioned Bernoulli formulas will allow the GM to predict the probability of an injury season for every year in the future.

The GM will need to consider that UCL tears are not the only decrement a pitcher is faced with. Other injuries could cause the pitcher to stop pitching before the pitcher tears his

UCL. The pitcher could leave baseball due to poor performance or opt the enter retirement later in his career. This notion of multiple decrements for a pitcher could possibly be explored in more depth, but as limitation of this study is it only considers the decrement of pitchers tearing their UCL.

Evaluating Pitchers

Since the annual probabilities of an injury season can be predicted, the GM may use these probabilities to determine the expected value of pitcher's value. Undergoing TJS will change the performance of a pitcher in different ways. Most notably, the pitcher must rest, rehabilitate, and recover from the surgery. This rehabilitation process can take anywhere from 12 months to 18 months (Cain, et al. 2010). During the rehabilitation process, the pitcher will produce no WAR for his team. Once the pitcher returns, he may pitch at a lower or higher level of WAR. The surgery may enhance the pitchers ability to pitch since it really is replacing an old worn out ligament with a brand new, functional ligament. The increase in function of the elbow would be expected to increase performance. The surgery may enhance the pitchers ability to pitch since the pitcher spent so much time focusing on improving form and conditioning the elbow. The surgery may diminish the pitchers ability to pitch since the pitcher spent so much time away from pitching in the rehabilitation process.

Using the same pitchers from the previous study (pitchers from 2008 to 2012), the expected WAR after Tommy John Surgery was determined. Only pitchers who averaged at least 0.5 WAR in their final three years before surgery were considered for this study. The pitchers with lower levels of WAR would make the data more sensitive to division, so they were not considered. If a pitcher did not have three full years before his surgery, all of their pitching data before surgery was considered. This data was still required to meet the 0.5 WAR per year threshold. Using this pitching data the expected ratio of earned WAR after the surgery compared to the average WAR per year before the surgery was determined (Table 6).

Table 6

Years After Surgery	WAR Ratio
1	0.2051655
2	0.7060576
3	0.9712401
4	0.8769231

GMs value one WAR during the current season as more valuable than one win in the next season. Similar to how dollars are valued using the time value of money, WAR in baseball can be discounted (Swartz, 2012). The expected present value (EPV) of WAR can be determined using a discount factor. For simplicity, a discount factor of 0.9 will be applied to the expected WAR to determine the expected present value of WAR for pitchers who have had TJS. This discount factor suggests GMs value one WAR in the next season as 90% as valuable as one WAR in the current season. The EPV of WAR for pitchers in MLB follows a relatively simple formula. For every year, multiply the probability of an injury season with the expected ratio of WAR for a pitcher who has had Tommy John Surgery and apply the discount factor.

Table 7 displays an example of the EPV of WAR calculation (Table 7). The hypothetical pitcher used in this example provided an average of one WAR per season in the last three seasons. The probability of an injury season can be calculated using the above formulas, but in this example, the probability of an injury season will be p_k for year k. Subsequently the probability of a healthy season for this pitcher will be q_k for year k. These values are subject to change based on the pitcher's age, and future velocity. The EPV columns are calculated using the assumption that the player performs exactly how the averages in Table 6 suggest a pitcher who has undergone TJS will perform and the assumption that the pitcher will continue to pitch at a level of one WAR per season if he is not injured. With each year, the WAR levels are discounted by a factor of 90%. The total EPV column is simply the sum of the before and after TJS columns.

The formula below shows the calculation of a pitcher who is about to begin the first year of a four year contract and is currently averaging one WAR per season with probability of an injury season equal to q (Table 7) (Figure 6).

Table 7

Season	Probability of UCL Tear	EPV of WAR (After TJS)	EPV of WAR Earned (Before TJS)	Total EPV
1	p_1	2.2666	0	2.2666
2	$q_1 * p_2$	1.6327	1	2.6327
3	$q_1 * q_2 * p_3$	0.8406	1.9	2.7406
4	$q_1 * q_2 * q_3 * p_4$	0.2052	2.71	2.9152

Figure 6

$$\mathbf{EPV(WAR)} = (\mathbf{p_1}) * (\mathbf{2.2666}) + (\mathbf{q_1} * \mathbf{p_2}) * (\mathbf{2.6327}) + (\mathbf{q_1} * \mathbf{q_2} * \mathbf{p_3}) * (\mathbf{2.7406}) + (\mathbf{q_1} * \mathbf{q_2} * \mathbf{q_3} * \mathbf{p_4}) * (\mathbf{2.9152}) + (\mathbf{q_1} * \mathbf{q_2} * \mathbf{q_3} * \mathbf{q_4}) * (\mathbf{3.4390})$$

There are five total possibilities in this scenario. The pitcher can incur to a UCL tear in season 1, 2, 3, 4 or not succumb to a UCL tear at all. The probability of not incurring a UCL tear is equal to the product of a healthy season for years 1, 2, 3, and 4. The EPV of WAR of a pitcher who does not tear his UCL is the sum of the discounted seasons where the pitcher produced one WAR per season (in this case that EPV is equal to 3.4390). Once the EPV is calculated, it can be scaled based on whatever level of WAR the pitcher is actually performing at when evaluated.

Using this formula, a GM can find a pitcher's EPV in WAR in respect to the risk of a UCL tear. Once this value is found, a conversion of actual salary dollars should be made using the formula in the Economy section. The GM may find it more valuable to negotiate different aspects (length of contract, bonuses, incentives, etc…) into a contract, so the GM should include these based upon the comparison of these aspects and actual salary dollars. This estimate will provide a baseline for the GM to follow when negotiating salaries. It should be noted that the above formula is specifically for a pitcher who is about to begin a four year contract. Necessary changes must be made to the formula when determining the EPV of a different length of contract. It should also be noted that the formula only determines the player's value based on

WAR, and the signing team may or may not determine salaries based upon that statistic. A free agent pitcher is not required to sign this contract either, so if another team offers a more appealing contract, the player will be more likely to sign with the other team. Overall, this formula should provide the GM with a good estimate to work towards in the salary and contract structure negotiation process.

Applications of this Research

Obviously, the main application of this research is to aid GMs in determining a salary for their pitchers. However, there are other facets of baseball that this research can be applied. Physicians and athletic trainers can determine more effective treatments with the knowledge that age and fastball velocity are the significant variables for UCL tears. Managers and pitching coaches can apply the same knowledge to help prevent UCL tears. This research also confirms why some cases of UCL tears happen to pitchers with no obvious risks. Matt Harvey seemed to have flawless mechanics, but his average fastball velocity was 95.4 miles per hour in the 2013 season. Pitching coaches and managers can use this information to use new preventative measures for their younger pitchers.

A secondary audience to benefit from this study is fantasy baseball team owners. These owners are trying to maximize their team's performance during a season in order to beat other fantasy teams. If an owner were deciding between two pitchers, but determined that one of the pitchers was at a higher risk to tear his UCL, the fantasy owner would have an advantage over his competitors. Since pitchers provide fantasy teams with value in a similar fashion to the way they provide their teams value, this research translates well to the fantasy world.

Many disciplines within baseball are involved with injuries, so the understanding of how injuries happen is extremely important. If a GM can hedge his injury and investment risk well, he can give his team an advantage over the rest of the MLB. The research done in this study can apply to many different aspects of the game in order to help pitchers prevent such a devastating injury.

Discussion and Recommendations for Future Research

Some variables may be significant in determining the likelihood of a UCL tear, but are difficult to objectively measure. This study does not take into account delivery style, changes in velocity throughout the season, pitcher size, overall conditioning of pitcher, and many other variables. Perhaps a biomechanical study can be done to investigate these variables more in depth.

Also, this research only includes pitching data from 2008 to 2012 because that is the only data with PitchF/X. As more data becomes available, a study with more observations may be done to increase the degrees of freedom in the study.

The value based on WAR is estimated in this research, but many teams evaluate, and ultimately pay players an amount different than what they are worth according to WAR calculations. If all players are being paid an amount much greater or much less than what the formula claims, a change in the $/WAR conversion assumption may be necessary. Along these same lines, some teams will be willing to pay more than market value for specific players for many reasons. One common reason teams pay at higher rates than their WAR reflects for players is simply because they have a higher payroll than other teams (Link, & Yosifov, 2012). A method to still apply this research to a team that pays its players drastically different than their $/WAR would be to manipulate the formula to more closely match that team's spending patterns. Furthermore, pitchers may have a different value based on what league they pitch in. In the National League, pitchers have to bat, so it may be easier for a player to have a higher WAR in the National League. In this case, a factor based on what league the pitcher is being evaluated for could be applied.

A factor not discussed in the economy section was the "superstar" factor, or the ability of one player to increase attendance on any given day. This is observed when a high profile starting pitcher is scheduled to start for a team that does not always sell out (Denaux, Denaux, Yalcin, 2011). Usually, an increase in ticket sales can be observed when these pitchers start games. Since it was determined that attendance is the easiest way for teams to generate revenue, a study based on this "superstar" factor could add to the value of a player.

All of these recommendations add complexity to a relatively simple model. These additions could enhance the model, but may not necessarily enhance the model enough to justify adding more complexity. In conclusion, it would be important to study the Akaike information criterion with these new additions.

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