Up, Out, and Away:

Modeling the Personnel Decisions and Labor Structure of Baseball's Minor League System

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Abstract

In order to understand potential sources of inefficiency in player personnel decisions in minor league baseball, it is necessary to examine historical trends in this area of the industry. Minor league baseball bears a strong resemblance to an up-or-out labor system, where workers are screened for their ability to perform at the next level following a promotion, and there exist models of the up-or-out system that can be used in this effort to gain a clearer perception of typical career trajectories in the minor leagues. In this paper, I use data from over twenty years of minor league play in an application of an up-or-out model in order to examine player movement patterns within this system and discern potential differences between observed and optimal behavior on the part of both major league organizations and professional baseball players. I show that this model significantly underestimates the exit and promotion rates of players in the minor leagues. I provide various explanations for these differences, in particular as they pertain to the sport's antitrust exemption and the resulting low wages for players throughout minor league baseball. I then examine several proposed alterations to the existing system, and their potential consequences, in an attempt to better align player performance with predicted exit and promotion rates.

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1 Introduction

Minor league baseball has historically been an area of professional baseball in the United States that has experienced significant yet underacknowledged downstream effects from structural shifts and broader decisions affecting the sport. From Major League Baseball's decision amidst the COVID-19 pandemic to reduce the number of minor league teams by 26% (Cooper, 2019b) to the sport's antitrust exemption and associated legislation keeping the annual wages of minor league players around the federal poverty line (Ghiroli, 2021), the minor leagues often bear the brunt of larger-scale issues that affect the landscape of American professional baseball, which can result in players at these levels having playing careers that are shorter or more arduous than expected. However, the degree to which this has held true over time has typically been considered as a purely qualitative question, so by examining empirically the shape minor leaguers' career paths take, it is possible to gain a sharper understanding of the effects these policies may have on the minor league system in general.

This paper uses two decades of minor league player performance, exits, and promotions to fit a model of an up-or-out labor system developed by O'Flaherty and Siow (1992), enabling a comparison between predicted and observed player career patterns and providing a basis for an assessment of the impact of baseball's unique labor environment on the sport itself. In fitting the model both across the minor league system overall and also on a level-by-level basis, I find that this model gives a significant underestimate of both exit and promotion rates within the minor league system and propose that this underestimate is driven in tandem by adverse working conditions via baseball's antitrust exemption and unique behavior and risk preferences of minor league players in determining their career path and expected future earnings.

This paper contributes to past work by expanding the application of this up-or-out model to an industry with a robust collection of performance data and personnel decisions, while also connecting the findings of this work to trends and behaviors observed within that industry over recent years. The discrepancies between the model's

predictions and actual player behaviors provide avenues for potential improvements to the O'Flaherty and Siow model. Additionally, evidence of the possibility of actors on both sides of the minor league labor market acting non-optimally gives an opportunity for a variety of solutions to address this issue, working both within the confines of the existing minor league system and also altering some of its more essential structural components.

2 Background

Before estimating the degree to which baseball functions as an up-or-out system, I present a general introduction to the minor leagues, give an overview of prior work on the up-or-out system, and discuss how this work connects to baseball, particularly within the context of structural trends and past legislation pertaining to the sport.

2.1 Minor League Baseball

American professional baseball is structured such that in order for a player to play at its highest level, they typically must show repeated strong performance over the course of several seasons. The thirty member organizations of Major League Baseball (MLB) each have a hierarchical collection of teams that compete against other teams at that same level while also serving as environments for player development. Players typically begin their careers playing for an organization's team at a lower level, such as Rookie or Low-A, competing against the teams at the corresponding level for other organizations, and are generally promoted level-by-level up to the top level of MLB, assuming strong performance. Although the parent MLB organizations own the contracts of all players within their system and can assign players to the different major and minor league teams within their organization at their discretion, they typically only have full operational ownership over the team at the top level of the major leagues. When coupled with the fact that major league teams also generate significantly larger rev-

enue when compared to those in the minor leagues, this implies that organizations as profit-maximizing firms have strong incentives to prioritize the major league level when considering how to allocate player talent within their systems, assuming a connection between team performance and economic success. This incentive may be lessened in the game's modern form, as team revenues have grown in recent years ("The Business of Baseball", 2021) while player salaries have decreased (Badenhausen, 2021), in part due to league-wide economic structures like team revenue sharing, but for now the assumption is that teams are incentivized to promote their best players, an assumption that will be revisited later.

The minor league system has historically been a very challenging environment within which players try to develop: from 1975 to 1988, over half of pitchers who began their careers in Single-A, a typical starting level for young players three full levels below the major leagues, were neither promoted nor demoted in the following season, but instead left the sport entirely (Spurr & Barber, 1994). This implies that the lowest levels of the minor leagues experience significant turnover, which could be attributed to organizations' screening processes, the unique labor environment of the minor leagues, or some other combination of factors. This also indicates that the prior likelihood of any one individual becoming a major league player is very low, so organizations are also incentivized to evaluate as many candidates as possible in order to maximize their chances of employing a productive player at the major league level.

Furthermore, the difference in talent level between minor league players, even those viewed to have potential major league ability, and major league players is stark, as exhibited by performance of MLB Rule 5 draft picks. The Rule 5 system is one in which teams select qualifying minor league players from other organizations and must keep them on the major league roster for the entire season, often utilized by weaker teams trying to acquire players who have potential of strong future performance but are still in need of further development. These players in 2021 were broadly below replacement level (Megdal, 2021), as measured by Wins Above Replacement, a statistic

that normalizes major league player performance to a league and position level. This indicates that even minor league players with potential that are a year or two removed from capable major league performance are still substantially inferior to replacement-level major league players, though the subpar performance of these players does suggest that the possibility of teams under-promoting top prospects has been mostly arbitraged away as a result of this rule. Nevertheless, the existence of Rule 5 provides in and of itself further motivation for organizations to implement an effective worker screening mechanism in order to avoid cases of mistaken promotion that negatively impact team performance at the major league level, and baseball's current system bears significant similarities to one possible process: the up-or-out system.

2.2 The Up-or-Out System

Firm personnel decisions, particularly those involving hiring, firing, or promotion, typically use worker performance as the most straightforward and applicable metric with which to inform their decision-making. Assuming that firms are rational and profit-maximizing, this means that unproductive workers will be dismissed and replaced with new employees, and those who are productive will either stay in their current role or be promoted, depending on which position gives the firm a higher expected profit ex ante.

There are certain types of firms who instead employ an "up-or-out" system, where personnel decisions are based not just on performance but also fit for higher-level roles. Industries such as the military, law, and academia have varying forms of this system, and in each lower-level workers have two functions for the firm: production, and screening for potential at higher-level roles (Waldman, 1990). In fields in which an up-or-out system is employed, the firm's profit is more reliant on performance of these higher-level workers. Firms therefore are focused on screening the lower levels of their workforce for those employees who will perform best in these higher-level roles that more directly impact the firm's profit, often using heavy workloads as the primary component of this screening mechanism; the firm will also offer higher wages at higher levels of this system, while

maintaining the threat of dismissal, in order to increase worker productivity (Barlevy & Neal, 2019). This aligns workers' incentives with those of a profit-maximizing firm, while also preserving the dual purpose in lower-level roles of screening and performance.

Under this definition, professional baseball appears to bear a strong resemblance to an up-or-out system, as organizations prioritizing player performance at the major league level constantly evaluate players in the minor leagues in their process of determining who will eventually succeed in MLB. The hierarchical structure of this specific system is supported by past work that demonstrates that a key component of an up-or-out system is both the specification of future wage in the case of promotion, and the fact that this retention wage is set above a worker's next-best alternative wage: this means that workers both know the benefits from promotion and also stay within the firm to seek promotion as opposed to switching firms to earn a higher wage (Kahn & Huberman, 1988), exemplified by players staying in the minor league system to try to reach the major leagues and receive the $700,000 minimum annual salary that comes with it.

Building on the theoretical foundation of the up-or-out system, much of the recent literature has attempted to address more rigorously the structure and implementation of such a system. Demougin and Siow (1994) model hierarchical employment systems more generally, looking at how firms decide the optimal proportion of their junior workers they train to become managers in the future. In the scenario where the firm needs a skilled employee to fill a recently vacated role, the firm will practice up-or-out, choosing to train and screen all of their junior workers. In another up-or-out model, Barlevy and Neal (2019) link the up-or-out system explicitly to the heavy workloads faced by junior workers in professional service firms such as consulting and investment banking, which serve as a productivity screening mechanism that exposes differences in performance between skilled and unskilled workers. In tandem with those firms' partner-based promotion structure, this provides a mathematical basis for these firms' incentives to implement an up-or-out system featuring this sort of workload emphasis.

Much of the existing empirical work uses as its underpinning a simplified model of up-or-out by O'Flaherty and Siow (1992), where workers have either high or low ability and give strong or weak performance signals. In this model, workers are promoted or fired once their cumulative signals either surpass or fall below certain thresholds. This model has formed the basis of several other analyses, including that of this paper, and will be more thoroughly explained in Section 4. Applying this model to historical law firm promotion decisions in a 1995 paper, O'Flaherty and Siow also find firms to be over-promoting unable workers, suggesting that firms may not have a sufficiently rigorous threshold for worker promotion. The model has also been expanded to a broader environment with regards to both population and industry, with an analysis of 45,000 research and manufacturing workers by Walker (2005) finding that the O'Flaherty and Siow model surpassed a standard time series Cox regression in predicting the survival rate of hourly employees. In turn, this indicates that this model may indeed hold applicability beyond law firms, which provides partial motivation for this paper and its application of this model to baseball.

2.3 Baseball's Economic System

There are several key features of baseball that make the sport particularly well-suited to serving as an assessment mechanism for the up-or-out system. One key difference with baseball when compared to not just other sports, but to industries such as law where up-or-out analyses have already been conducted, is that the sport has a heavily individualized structure of the batter-pitcher matchup that makes it easier to isolate the performance of individual players, whereas it may be more difficult to accurately determine the performance of workers in more standard industries. Moreover, professional baseball in the United States has a robust history of statistical record-keeping at all levels, which when combined with the nature of the sport itself creates a labor environment that lends itself more easily to empirical analyses, including potential applications of aforementioned up-or-out models, than other fields.

There are also several recent changes to baseball's minor league structure that are relevant in the up-or-out context. MLB has been pushing in recent years to restructure the current state of the minor league system, reducing the total number of minor league teams at Low-A, High-A, Double-A, and Triple-A from 162 to 120 as part of an ongoing effort to reduce costs associated with minor league player development (Cooper, 2019b); they have also proposed to reduce the number of minor league playing jobs as part of recent collective bargaining negotiations with the MLB Players Association (MLBPA), the MLB players' union (Passan, 2022b). An examination of the strength and weaknesses of the historical promotion structure within this system could give a lens into the benefits and drawbacks of different formats this minor league system has taken and could take in the near future.

Additionally, baseball's labor environment has another significant difference with not just other up-or-out industries, but almost every other company in America: its antitrust exemption. This exemption, which in essence permits Major League Baseball to operate as a legal monopoly, was instituted in 1922 via a Supreme Court ruling that deemed baseball to not be a form of interstate commerce, saying in part that "personal effort, not related to production, is not a subject of commerce" (*Federal Baseball Club v. National League*, 1922). This ruling has survived several challenges over the past century, and notably other professional sports have attempted to obtain similar exemptions but have been rebuffed, under the argument that modern professional sports do, in fact, constitute interstate commerce (Greenberg, 2002). As it pertains to this ruling, there is no material difference between baseball and other sports that do not have antitrust exemptions, but the survival of the ruling to this point instead serves as an example of *stare decisis*, where points of litigation are decided according to precedent. Specifically, this antitrust exemption explicitly permits collusion among owners to suppress player wages in a manner illegal in other areas of employment (Janes, 2021b), and while 1998's passage of the Curt Flood Act prevents major league players from falling under the jurisdiction of this exemption, the bill explicitly outlines that it still applies

to minor league players (105th Congress, 2nd Session, 1998). This means that in the current environment, organizations can actively keep minor leaguers' wages below what would exist on the open market, which has held true over recent years to a surprisingly large degree.

The Supreme Court has not been the only branch of the federal government to have affected the pay of minor league players. Congress' 2018 passage of the Save America's Pastime Act, which exempts minor league players from overtime pay laws present in other industries and classifies them as seasonal workers (114th Congress, 2nd Session, 2016), has led to the maintenance of an industry with very low levels of compensation. Despite recent wage increases after the dissolution of 42 minor league teams, minor league players are still paid about $10,000 to $15,000 annually, with the federal poverty line in the middle of this range at just under $13,000, and minor league players have consistently reported that these low wages have proved extremely taxing for their own career development (Ghiroli, 2022). In using an up-or-out model to predict career patterns of minor league players, it is possible to compare modeled exit and promotion rates to those that were actually observed, and in doing so potentially glean insight into any effect these low wages may have on players' ability to keep playing in the minor leagues. For example, if the empirical exit rate is much higher than what the model predicts, this could serve as an indication that there are external, non-performance factors affecting minor league career trajectories.

Notably, unlike their counterparts in the hockey and basketball minor league systems, minor league baseball players are not members of a union. This gives players minimal ability to collectively bargain for improvements in working conditions, which are rife with subpar living and workplace environments both at and away from the ballpark (Ghiroli, 2021). This has led to increased pressure from players and labor advocates to revamp the support structure surrounding the minor leagues, which has been particularly heightened since the return of minor league baseball amidst the ongoing COVID-19 pandemic (Lee, 2021). Given that players experience not just low

wages, but poor conditions in general, modeling the up-or-out system quantitatively could then also inform views on the impact of baseball's antitrust exemption, as the exemption not only explicitly permits wage suppression but also implicitly makes teams less motivated to improve working conditions, as they cannot be sued for antitrust violations of workplace standards. This means that potential takeaways from this model can apply to not just the low wages of minor leaguers, but also this larger structural force enabling its existence.

Moreover, when applied within a baseball context, the up-or-out model devised by O'Flaherty and Siow (1992) also gives the ability to understand the true talent level of the minor league system: by using the predicted exit and promotion rates, the model can also determine the percentage of a population that is capable of strong performance, which here is the percentage of professional baseball players who perform at a major league caliber of play. In concert with the aforementioned focus on minor league living conditions, determining the proportion of minor leaguers capable of making MLB has the potential to inform broader policy on the level of support necessary to provide these players throughout their careers. For example, if there are only a fraction of minor leaguers actually playing at a level that would indicate major league ability, it could lend support to MLB's recent unilateral decision to reduce the number of minor league teams; however, if the reverse were true and there are actually more minor leaguers capable of major league play than end up making it, that would suggest an alternative rationale to this contraction of the minor leagues.

In addition, the last quarter-century has seen professional baseball subject to a significant paradigm shift in organizational priorities, with the popularity and cultural resonance of the 2003 book *Moneyball* emblematic of the sport's shift towards a form of more heavily quantitative analysis and decision-making dubbed "sabermetrics." This shift has resulted in not only a decoupling of team performance with spending as teams find success via greater efficiency (Jaffe, 2013), but has also shed light on new ways for organizations to maximize the value of the talent they have in their systems. Under

classic up-or-out models, a firm's optimal decision comes from promoting the workers most likely to succeed at the next level, as there exists a strong connection between a firm's performance and its profits. However, differences in baseball as an industry lead to an examination of the strength of this connection in reality: is a team's profit-maximizing decision necessarily a performance-maximizing one?

Major league teams have a system of revenue sharing, where 48% of each team's local revenues, as well as all national revenues, are collected into one pool of money divided equally amongst the thirty teams, which in practice means that there is essentially a transfer of money from the teams generating the most revenue to those generating the least ("Revenue sharing", 2020). With television contracts signed years in advance typically composing over half of this common pool (Paine, 2020), most team revenues are thus secured years in advance. The MLBPA has filed grievances against select teams for not using redirecting this money towards player spending, as required by MLB's collective bargaining agreement (Axisa, 2018), and with the concept of tanking — purposefully spending less money in order to construct a subpar team, with the aim of that team's present futility making it easier to acquire cheap assets to build a team that will be successful in the future, and at a much lower cost — becoming both increasingly prevalent throughout the sport while drawing the ire of fans and players alike (Rosenthal, 2021), there is a distinct possibility that there is a disconnect between team behavior that maximizes profit and maximizes competitiveness.

This is further supported by recent organizational manipulation of players' service time, or the amount of time a player spends at the major leagues before he is eligible for free agency. The MLB regular season lasts for 187 days, and if a player is rostered at the major league level for 172 of those days, he earns a year of service time; after six years of service time, he becomes a free agent ("Statistics Glossary", n.d.). However, this also means that a player who has fewer than 172 days on a major league roster remains under contractual control of that team for another season, which provides teams a strong incentive to wait to promote top prospects until they can ensure an

additional year of control at what is typically the league-minimum salary while the player produces at a performance level commensurate with greater pay, with teams deeming this extra year of control of greater value than the team performance benefit gained from promoting a player sooner (Weaver & Adler, 2022). This is one specific example of a possible disconnect between team profit- and performance-maximization, and an empirical analysis of optimal team promotion behavior with this possibility in mind has the potential to yield more robust insights into the degree to which this disconnect currently exists.

3 Data

In the following section, I first offer an overview of the data used to analyze professional baseball performance. I then define several key metrics used to evaluate player performance and put forth some descriptive statistics of the data.

3.1 Structure and Source Information

The data collected for this research and for all following figures and tables was scraped via Python from Baseball Reference, an online encyclopedia that contains historical performance data for minor and major league baseball, the code for which can be found in my GitHub repository.[1] The data is separated into batting and pitching data, as position players and pitchers tend to be evaluated on a different set of metrics, with the intention of combining the two sets of data when applying the O'Flaherty and Siow model on a common set of variables. The scraped data run from 1998, the first year in which MLB expanded to its current size of thirty organizations, through 2019, the last full year of minor league data unaffected by the COVID-19 pandemic. For the purposes of this paper, the model will use up to ten years of data for players who debuted from 1999 through 2009. This lower bound of 1999 is to ensure that all players new to the data in this year did in fact debut in American professional baseball that year, given

[1]The URL address is https://github.com/tjhuffman4246/senior-thesis.

that 1998 was the first year any data was collected and thus categorizes it as the debut year for all players for whom data exists in that season. The upper debut year bound of 2009 is chosen as the latest year where players could collect ten years of playing data, plus an extra year in order to determine whether a player ended up exiting professional baseball after their tenth season. Data is obtained from seven different levels, listed here from highest to lowest: MLB, Triple-A, Double-A, High-A, Low-A, Short-Season A, Rookie.

While some organizations have occasionally had multiple teams at lower levels of the minor league system simultaneously, typically each major league organization has one team at each level, each of which had 25 players on the team at a given point in time over the period spanned by the data. These data contain statistics describing playing time, player performance, and team played for, with expanded definitions of the key variables in the following section, with a unique row for each player at each level for each team in each year. This means that if a player plays at multiple levels in the same year, or for multiple organizations, even at the same level, they will have multiple entries in the data in a given year. The performance data can also be used to determine whether or not a player produced a "good signal" during that season. This is done via percentiles, so that a 50^{th} or greater percentile performance relative to the rest of the primary level that player played at that season is deemed a "good signal", and a worse performance a "bad signal." This was chosen as the cutoff because the average MLB player performs at a level worth approximately two wins per year (Slowinski, 2010), which is also in the middle of the distribution of the 20-80 scouting scale most commonly used in player evaluation (McDaniel, 2014). Additionally, given how baseball's randomness as a sport lessens the predictive power of any one sequence of events — as sabermetrician Voros McCracken once said, "Anyone can hit anything in 60 at-bats" (McCracken, 2000) — having a relatively more forgiving threshold for producing a good signal is likely a prudent decision in developing a more accurate empirical analysis of player performance within baseball's up-or-out system.

3.2 Statistical Definitions

Below are descriptors of the primary variables scraped from Baseball Reference's database, with definitions coming from the official MLB website ("Statistics Glossary", n.d.). Recall here that one observation for a player corresponds to their performance at that level of the minor or major leagues that season for that given organization, so one player's observations for a given year may cover multiple organizations or multiple teams within an organization.

Age The player's age at midnight of June 30 on a given year.

Year The year of the observation period.

Level The minor league level of the period (denoted as "MLB" if the level is MLB).

Org The three-letter abbreviation for the major league organization that player was playing for in the given period.

G The number of games appeared in by the player in the given period. This does not require that they started the game in question.

PA/BF The number of plate appearances by a batter, or number of batters faced by a pitcher.

OBP On-base percentage, or the percentage of plate appearances in which a batter reaches base. It is typically presented as a ratio instead of a true percentage; i.e., as .400 instead of 40.0%.

SLG Slugging percentage, or the total number of bases a player records per at-bat (where at-bats are equivalent to plate appearances, but exclude walks, hit-by-pitches, sacrifices, and interference calls). The numerator is thus 1B + 2×2B + 3×3B + 4×HR (with these terms corresponding to singles, doubles, triples, and home runs, respectively), and the denominator is the number of at-bats.

OPS On-base plus slugging, or the sum of OBP and SLG. While it does not exactly weight the true value of different aspects of offensive production, it has a higher correlation to runs scored than either of its two components and the best of any offensive statistic calculated purely from in-game statistics (Law, 2017, p. 131).

ERA Earned run average, or the number of earned runs allowed by a pitcher per nine innings. Earned runs exclude runs that score with the aid of an error or passed ball. While imperfect, similar to OPS, it is a solid measure of pitching performance that is readily available and computationally inexpensive.

3.3 Descriptive Statistics

Below are descriptive statistics of the data over the time period covered by the data. To account for player injuries and instances where pitchers had a non-zero count of plate appearances, let n be the total number of players in the data, and let n_{min} be the number of players who met the qualifying criteria of either twenty plate appearances or twenty batters faced in each season they are in the data. The means, 10^{th} and 90^{th} percentiles, and standard deviations are computed for both all seasons where a player took a plate appearance or faced a batter and all seasons where a player had at least twenty plate appearances or batters faced.

Table 1: Career Summary Statistics, 1999-2009 Debut (n = 17,497, n_{min} = 14,699)

	No PA/BF Minimum				PA/BF $\geq$ 20			
Measure	M	10%	90%	SD	M	10%	90%	SD
Years Played	4.54	1	10	3.69	4.42	1	10	3.63
Organizations	1.85	1	4	1.60	1.74	1	4	1.48
Levels	3.21	1	6	1.83	3.22	1	6	1.82
PA/BF per Year	302.12	72	581	195.78	305.38	89	576	187.17

From Table 1, there are a broad range in key statistics across the player pool.

Of particular note is that the standard deviations for years played and organizations played for are nearly as large as the mean, suggesting that the distribution of these two metrics is strongly right-skewed (this trend is the same across both batters and pitchers). This supports the intuition that within the up-or-out system, many players have brief careers, but a select few play at the major league level for an extended period of time. Additionally, players without a yearly plate appearance or batters faced minimum had a higher average number of years played and organizations played for than those who met the playing time minimum.[2]

Table 2: Career Summary Statistics, 1999-2009 Debut and Played in MLB (n = 2,438)

Measure	M	10%	90%	SD
Years Played	8.93	7	10	1.80
Organizations	3.08	1	5	1.52
Levels	5.78	5	7	1.10
PA/BF per Year	394.00	147	648	194.51

Another important exercise is replicating the previous summary analysis, but for players in this debut window who ended up playing in MLB, in order to discern potential differences between the career patterns of these players and the professional baseball population as a whole. As expected, the career patterns of this group of players in Table 2 are substantially different from Table 1: players in this period who made the major leagues played for an average of nearly nine years (likely an underestimate of their careers as a whole, given that data after ten years of play were not used), while playing for more organizations and at more levels. This may indicate that players deemed

[2]While counterintuitive, a potential explanation is that players may not have reached the plate appearance or batters faced minimum in a given season due to injuries stemming from overuse, so players who did not reach the playing time requirement in every year may have had greater volume in years prior to injury. In turn, players had to recover from these injuries before they could play again, meaning that they may have played in more unique seasons as an artifact of their recovery timeline, and certain teams may have been more willing to take the chance on these recovering players, so they "bounced around" professional baseball at a higher rate. In contrast, those players who met the playing time threshold in each season may have been less likely to have experienced such injuries during their playing career.

to be major-league caliber are relatively more coveted by teams and are given more opportunities to succeed in different organizations, whether by trade or free agency. Additionally, these players who made the major leagues had significantly higher average playing time, though a similar standard deviation. This is likely a combination of several factors: those who eventually make the major leagues have likely showcased their talents for several minor league seasons prior to reaching the top level, and this strong level of performance makes teams and managers more inclined to give them increased playing time in response. Moreover, some pitchers who make the major leagues as relief pitchers begin their professional careers as starting pitchers, only transitioning to the higher-intensity, lower-workload relief role at the top levels of the minor leagues, while many players who begin their professional careers as relievers find it more difficult to make the majors; this would tilt the balance of playing time throughout the minor leagues towards these players who end up serving as relief pitchers in MLB.

Figure 1: Professional Baseball Player Count, 1998-2019

To get a sense of the degree to which the patterns in this data are dictated by hitters

compared to pitchers, Figure 1 depicts the number of unique players within the time period over which these data were scraped, from 1998 through 2019. The increase in unique player count overall is due to the increase in number of minor league teams in general, up to 162 by the end of 2019 (Cooper, 2019b). More interesting is the relative increase in proportion of pitchers. This is potentially due to the increase in pitcher injuries, particularly the ulnar collateral ligament (UCL) over recent years: with an uptick in injuries requiring surgeries that keep a player out for a year or more (Erickson et al., 2015), followed by their return to professional baseball after an extended absence, it could be that the number of unique players in a given year has been increasing rapidly, but these same players return to baseball later on and therefore do not markedly affect the total unique pitcher count.

With the potential of injuries and player exits affecting the unique player count year-by-year, it may be useful to see what players' playing patterns at the start of their career look like. Table 3 depicts the transition matrix for all players debuting in the 1999 to 2009 window used for this work, by taking the level at which each player started their career and investigating what level they played the most in during the following year. Notably, the vast majority of players began their careers at either the Rookie or Short-Season A levels of the minor leagues, and after even just one year a large contingent of these players exited the system (21.98% and 17.27% for these two levels, respectively). Looking at the Rookie level in particular, 34.39% of all players who began their career at that level returned to that same level in the following year, which, when taken together with the significant first-year rate of exit for that same cohort, suggests that there may exist some sort of minimum performance threshold players need to clear in order to be able to return the following season, as well as another level of performance required in order to earn a promotion to a higher level of the minor league system.

However, these $T + 1$ exit rates were significantly lower than those of players who begin their professional careers at higher levels of the minor leagues, who exited after their first season over a third of the time in this cohort, though were also more likely

Table 3: $T + 1$ Player Transition Matrix (First Season 1999-2009)

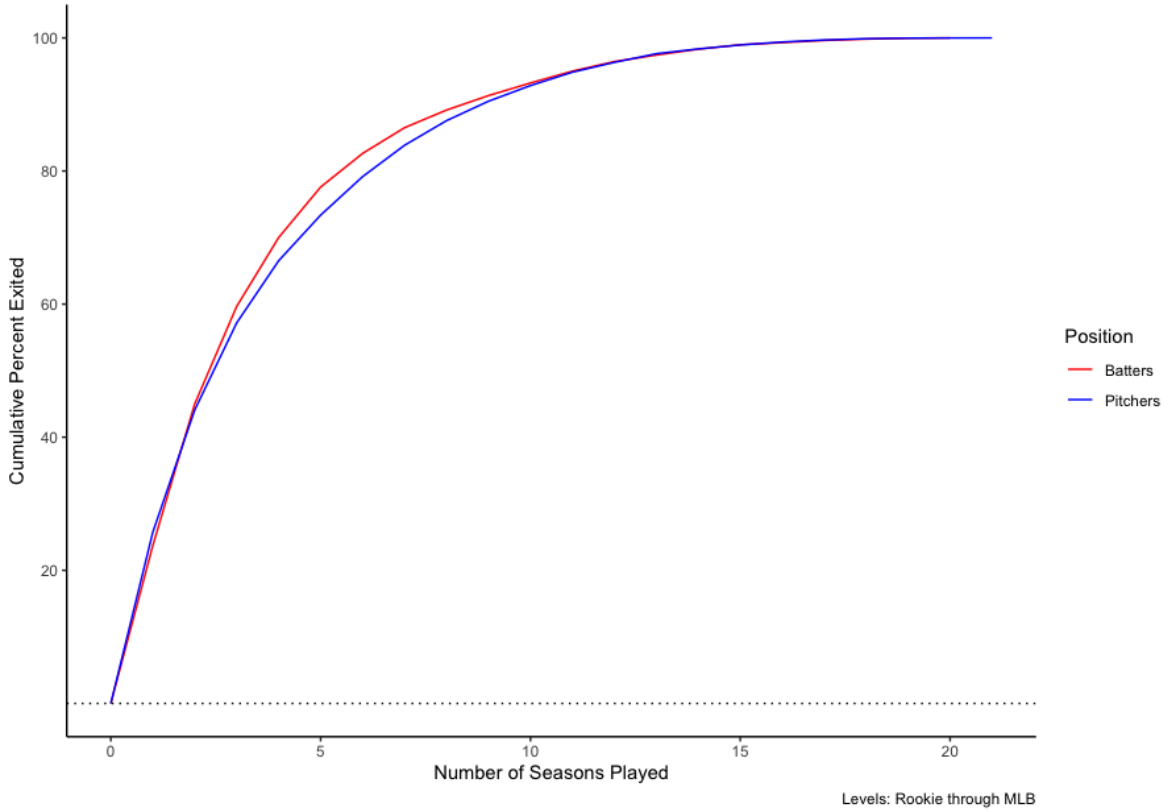
T		$T+1$ (Percent)							
Level	n	Rookie	Short-Season A	Low-A	High-A	Double-A	Triple-A	MLB	Out
Rookie	10,875	34.39	14.62	24.59	3.94	0.37	0.10	0.02	21.98
Short-Season A	4,111	5.72	13.72	47.51	14.77	0.90	0.12	0.0	17.27
Low-A	670	4.63	3.13	17.46	36.27	9.10	0.75	0.45	28.21
High-A	418	2.87	0.96	3.59	22.01	24.40	7.89	1.67	36.60
Double-A	783	0.64	0.13	0.26	1.79	39.85	19.41	0.38	37.55
Triple-A	548	0.18	0.0	0.36	0.36	9.31	39.23	1.28	49.27
MLB	58	1.72	0.0	0.0	3.45	3.45	15.52	41.38	34.48

to make the upper levels of the minor leagues. After Rookie and Short-Season A, the initial level with the greatest number of players was Double-A, just two levels below the major leagues. As Double-A is often viewed as the first minor league level decently representative of the major leagues' higher caliber of play (Moore, 2013), this level can serve as a debut platform for top prospects, foreign professionals transitioning to North American baseball after careers in other professional leagues, or older players who may have recently exited college. The difference in approaches for these player populations, therefore, means that there could be a meaningful difference in how teams treat players who begin at different levels, which may in turn require different estimates of or approaches to estimating an up-or-out model within the system of minor league baseball while posing the interesting question of how consistently organizations apply their promotion standards across levels, in association with prior perception of ability.

To investigate this further, an examination of the exit patterns of professional baseball players via the hazard rate may be helpful. The hazard rate is defined here as the percent of the total playing population that exits professional baseball in a given period of time, and for ease of interpretability, Figure 2 illustrates one minus this hazard rate, such that the cumulative total on the y-axis is the percent of the starting population that has exited baseball by the year in question. This metric is a useful

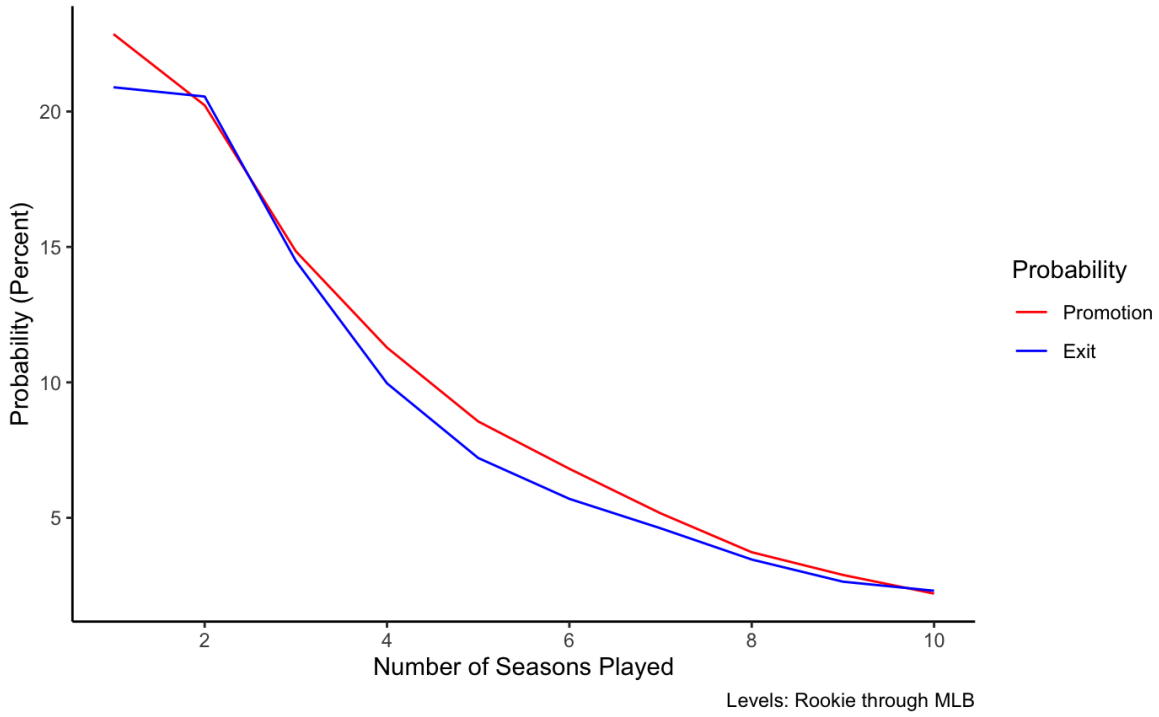
tool that by indicating the frequency of player departures and dismissals could both potentially lend credence to the use of an up-or-out system in analysis of minor league baseball and also provide color as to what complicating and noticeable differences, if any, may exist between batters and pitchers in such an analysis. However, in looking at the frequency of player exits year-by-year in Figure 2, there appears to be limited significant difference in hazard rates between the two player populations, apart from a small discrepancy in exits about five years into one's career, where 73.4% of pitchers have exited, as opposed to 77.6% of batters. This implies that while this work could theoretically treat these player populations as two distinct entities, there exist enough similarities between the two that they can be combined into one for purposes of this up-or-out empirical analysis. However, the question still remains of whether this hazard rate is what should be expected given player performance in the minor leagues, or if there are still inefficiencies prevalent in the system that could be revealed through a more quantitative examination of the promotion and exit patterns of minor leaguers.

Figure 2: One Minus Professional Baseball Hazard Rate, by Year of Career



Further examining this point, Figure 3 depicts the probabilities of exit and promotion for each of the first ten years of a player's career for players who debuted from 1999-2009 and met the playing time thresholds of twenty plate appearances or batters faced per season. This threshold serves to exclude from the data players who appear in only a handful of games before getting injured, as well as occasions where hitters pitch or pitchers hit. The curves follow similar patterns, which makes intuitive sense, as those who are dismissed or released by teams are replaced by players promoted to fill their spots. There do exist more minor differences: a slightly larger proportion of players were promoted in the midst of or after their initial seasons than exit, and were promoted at slightly higher rates than they exited in the middle of their careers. Nevertheless, both curves follow a similar trend of decreasing exit or promotion probabilities over time, which suggests that an up-or-out model fit to these observed patterns could show whether teams' optimal behavior in their personnel decisions is indeed to follow this trend, or whether they have other motivations in their decision-making should there exist a marked discrepancy between modeled and observed behavior.

Figure 3: Observed Promotion and Exit Probabilities, by Year of Career



4 Model

Here, I detail the motivation and mathematical specification for the O'Flaherty and Siow up-or-out model and outline alterations to the model needed in order to properly apply it to minor league baseball.

4.1 Setup

Under the up-or-out model proposed by O'Flaherty and Siow (1992), profit-maximizing firms are collections of junior and senior workers that combine to produce output for the firm over a sequence of periods. All workers begin as junior workers, and they have one of two types: type A (indicating an able worker) or type B (indicating an unable worker). In order for the combination of junior and senior worker to produce output, the senior worker must be of type A, though not necessarily the junior worker. Moreover, firm profits are both linear and nondecreasing in direct proportion to fraction of the workforce composed of type A workers. As firms do not know ex ante whether the junior worker is type A or type B, their profit-maximizing incentive is to screen their junior workers for these type A workers. At the onset of each period, firms can choose one of three options:

1. Keep the junior worker in their current role and observe them for at least one more period.

2. Dismiss the current junior worker, replacing them with a randomly chosen new worker.

3. Promote the junior worker to a senior role, replacing them with a randomly chosen new worker. If the newly promoted senior is type B, the firm loses the start-up cost associated with this promotion; if they are type A, the worker is productive and the process repeats itself under the new senior worker.

As the firms are profit-maximizing, they will choose the option of these three that maximizes their expected discounted returns. Moreover, under the optimal solution

to this optimization problem, O'Flaherty and Siow (1992) also showed that when a firm engages in a process of Bayesian updating of the probability a worker is type A at the conclusion of each period, the firm will promote a junior worker when θ, the posterior probability that the worker is type A, rises above a given standard θ_u, where $\theta_0 < \theta_u < 1$, with θ_0 the ex ante probability of a worker being type A. The firm will therefore dismiss the worker when θ becomes less than θ_0. When taken in conjunction with the prior statement, this suggests that a firm's optimal approach in the up-or-out system is to retain the junior at their current level until their internal probability of that worker being type A either exceeds a given threshold, resulting in the promotion of that worker, or falls below the prior probability that a random new worker will be type A, resulting in the dismissal of the original worker.

Table 4: Signal Probabilities for Type A and Type B Workers

	Type A	Type B
Good Signal	α	τ
Bad Signal	$1-\alpha$	$1-\tau$

In setting up this model, let α be the probability a type A worker produces a good signal in a given period, and let τ be the probability a type B worker produces a good signal in a given period. Thus, the probabilities of each type of worker producing a certain signal in a given time period can be conceptualized via Table 4. The basic form of this model assumes that all new workers share the same values of θ_0, α, and τ. Additionally, as θ_u is bounded by θ_0 and 1, it is proposed that its distribution across junior workers follows a beta distribution with mean μ and standard deviation σ. This θ_u value varying across the working population is an important one, as it allows for different performance standards across the labor system (as would be expected in professional baseball, where some players are high draft picks and expected to play in the majors at some point in time, and others may have been signed as undrafted free agents and are unlikely to play more than one or two seasons in the minor league system).

Assume there are n periods in this model, each corresponding to one year in the data, and let there be a total of $2n$ cells in the data. Let cell i denote workers who exited in year i, and let cell $i + 10$ denote workers who were promoted in year i. As an example, in year two, the probability of a worker exiting the firm would fall into cell $i = 2$, and the probability of their promotion would be contained in cell $i = 12$. The dismissal and promotion observations are stacked in this manner in order to properly estimate the values of the aforementioned parameters. Additionally, let the vector Ω_1 be a collection of α, τ, and θ_0, such that $\Omega_1 = (\alpha, \tau, \theta_0)$. This Ω_1 vector is the same for all workers. This makes the probability that a given worker is observed in cell i (i.e., exits or is promoted in the corresponding period) $\tilde{\pi}_i(\Omega_1, \theta_u), i = 1, \ldots, n$, where θ_u varies across workers. Because there exists a distribution of θ_u, which has a constant mean of μ and constant standard deviation of σ, the probability of a worker falling into cell i, with $\Omega = (\alpha, \tau, \theta_0, \mu, \sigma)$ is

$$\pi_i(\Omega) = \int_{\theta_0}^{1} \tilde{\pi}_i(\Omega_1, \theta_u) g(\theta_u; \mu, \sigma) d\theta_u \tag{1}$$

where $g(\theta_u; \mu, \sigma)$ is the aforementioned beta density with mean μ and standard deviation σ.

As constituted in the data, solving this above expression is difficult, as π_i is typically not continuous: players can only exit after a given season, as any exit in the middle of the season would appear identical to seasons where players got injured partway through or saw their playing time reduced, so there do not exist probabilities of players exiting continuously throughout the season. Similarly, the data also do not contain dates of mid-season promotions, so the exact amount of time players spend at different levels in a given season cannot be measured via time, as would be necessary to construct continuous promotion probabilities throughout a season. This lack of continuity in π_i thus poses a problem for integration purposes. However, note that in the data, there are players who play their last season in every year up to the maximum possible value of n, which means the above formula can be altered to look at only the regions where a

sufficiently bad signal in a player's first n periods results in their exit. This means that discrete values for π_i can be accepted and the term pulled out of the integral, leaving only the beta density within. Making this modification to the formula, the probability of an exit in period i becomes

$$\pi_i = [\theta_0 \alpha^{i-1}(1-\alpha) + (1-\theta_0)\tau^{i-1}(1-\tau)] \int_{\theta(i-1,i-1)}^{1} g(\theta_u; \mu, \sigma) d\theta_u \tag{2}$$

and the probability of a promotion in period i becomes

$$\pi_{i+n} = [\theta_0 \alpha^{i} + (1-\theta_0)\tau^{i}] \int_{\theta(i-1,i-1)}^{\theta(i,i)} g(\theta_u; \mu, \sigma) d\theta_u \tag{3}$$

where $\theta(a, b)$ is the probability a junior worker is type A after producing a good signals in b periods. Letting P_i be the observed probability of an exit in period i or promotion in period $i - n$, as above, the values of Ω are chosen via least squares to minimize the function

$$Q = \sum_{i=1}^{n} [P_i - \pi_i(\Omega)]^2 \tag{4}$$

Therefore, this model will give estimates of α, τ, and θ_0, the interpretation of which can give insight into the likelihood of strong performance by type A players.

4.2 Baseball-Specific Modifications

The O'Flaherty-Siow model is based on a theoretical firm with a certain personnel construction that differs from professional baseball in several ways, so some modifications to the model's structure must be made in order to properly adapt it to this system. As initially proposed, the model sets up the firm as a collection of independent units, and by promoting a junior worker to the senior level a new work unit is created to be led by this newly promoted worker. However, in application, this model is impractical as it assumes the possibility of infinite firm expansion. Note, though, that nothing outlined in the above model necessarily assumes that there must be the creation or dissolution

of worker units in order for promotion or dismissal, but instead this firm hierarchy just serves as a more structured mechanism by which to create an environment for workers to either exit or be promoted. Therefore, as O'Flaherty and Siow (1995) and Walker (2005) both did in their empirical analysis of this model, I eliminate this independent unit requirement and instead apply the model to firms employing a typical promotion and dismissal mechanism, of which minor league baseball is one.

Additionally, a difference between minor league baseball and other firms that have been the subject of an empirical analysis of this model is that the minor leagues employs a sequential promotion system. As outlined above, players typically begin their careers at the minor leagues' Rookie level, or at some level of Single-A (i.e., Short-Season, Low, or High). They are then promoted sequentially throughout the different levels based on their performance, up to and potentially including the major leagues. In this system, unlike the law or manufacturing firms examined in previous empirical analyses, players can be promoted repeatedly. This has the benefit of expanding the sample size of the data over time: instead of the data corresponding to a given individual stopping after either a promotion or dismissal, performance is continually observed following a promotion, and it is then observed what level of performance is necessary to be promoted to the next level. However, this also implies that there could be different standards for promotion at different levels, which increases computational complexity and decreases interpretability. A potential solution to this issue is to estimate parameter values and compute promotion standards on a level-by-level basis: i.e., to compute $\Omega_{X\to Y} = (\alpha_{X\to Y}, \tau_{X\to Y}, \theta_{0X\to Y}, \mu_{X\to Y}, \sigma_{X\to Y})$ for the transition from level X to level Y. This application of the model will come after its initial test across the minor leagues as a whole.

5 Results

Below, I present my results, for both a general model of minor league promotions and exits, and also an implementation where the model is fit to the data level-by-level.

5.1 General Model

For the initial analysis of the model, much of the form of the computations came in its simplest form. I let $n = 10$ in order to look at statistics from the first ten seasons of each player's career. This is the same period of time that O'Flaherty and Siow (1995) used, and as shown in Figure 2, a significant majority of players in the data exit professional baseball by this time, so it is an adequate representation of the promotion system. As mentioned in Subsection 3.1, performance benchmarks are normalized on a year-by-year and league-by-league basis, as player production can differ significantly depending on the ballpark (Weinberg, 2015), league environment (Inaz, 2010), and even the type of baseball used (Davis, 2021). The rationale behind at least a 50^{th} percentile performance qualifying as a "good signal" was similarly outlined in that section. Hitters were required to have at least twenty plate appearances in the seasons in question, and pitchers were required to have at least twenty batters faced.

Most significantly, as opposed to going through several iterations of this model to estimate the parameters $\Omega = (\alpha, \tau, \theta_0, \mu, \sigma)$ for each individual transition period (e.g., Rookie to Low-A, or Triple-A to MLB), this initial empirical analysis looks at all exits and promotions over the course of a player's first ten seasons. This means that while that player may only have one exit, they can have multiple promotions. Interpreted within the sequential promotion system, this means that while θ_0 remains the ex ante probability of a player being major league-caliber, the other parameters of Ω are related strictly to the next level in the system. For example, α is the probability of a type A player producing a good signal, but in this aggregate reinterpretation, this is the mean probability of a player who is capable at the next level producing a good signal; i.e., a mean of the probability of a Low-A player capable at High-A producing a good signal, a

High-A player capable at Double-A producing a good signal, etc. The only constraints given to this model were the that the shape parameters of the beta distribution had to be greater than zero, and that the probabilities α, τ, and θ_0 were bounded by zero and one. μ and σ were not calculated directly, but instead the shape parameters a and b in a beta distribution Beta(a, b), from which the mean and standard deviation can be calculated via:

$$\mu = \frac{a}{a+b} \tag{5}$$

$$\sigma^2 = \frac{ab}{(a+b)^2(a+b+1)} \tag{6}$$

where $\sigma = \sqrt{\sigma^2}$. Running the model with the outlined bounds, in addition to the constraint that $\alpha \geq \tau$ (as a type A player must be at least as likely to produce a good signal as a type B player), the following results are obtained.

Table 5: Parameter Estimation, General Model

	α	τ	θ_0	a	b
Lower Bound	0	0	0	0	0
Upper Bound	1	1	1	∞	∞
Estimate	0.943	0.805	0.276	45.625	87.408

Using the above formulas and our estimates of a and b to calculate μ and σ, values of $\mu = 0.343$ and $\sigma = 0.041$ were found, which when taken with the results in Table 5 gives an initial estimate for Ω

$$\hat{\Omega} = (0.943, 0.805, 0.276, 0.343, 0.041) \tag{7}$$

Some of these results make intuitive sense. The mean of the type A probability promotion threshold θ_u is 0.343, meaning that on average, a player is promoted once

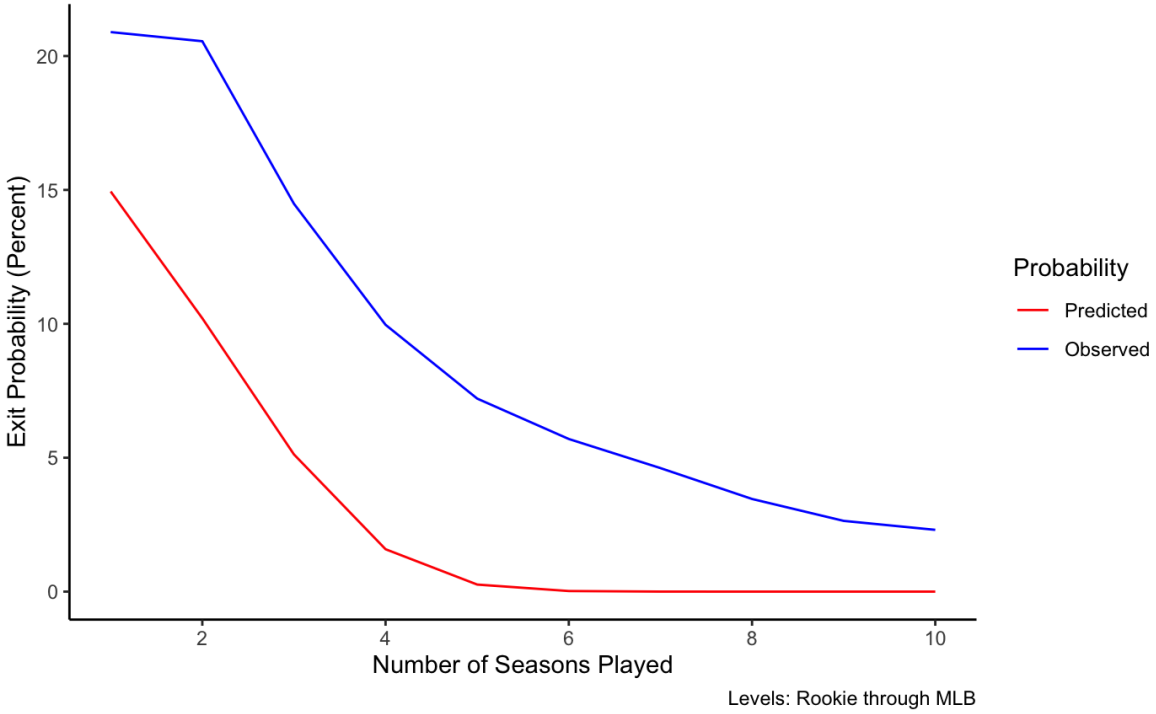
the team believes that individual has a 34.3% chance of becoming a major league player. Additionally, players categorized as type A are predicted to produce a good signal 94.3% of the time, which is greater, though not markedly so, than the 80.5% mark for type B players. While this discrepancy may seem too small to accurately be able to distinguish between type A and type B players, it makes more sense within the larger context of baseball's repeated promotion system, given that players have to perform well over several different levels and seasons in order to be promoted to the major leagues. For example, assuming that performances at each level season-by-season are independent, a type A player would have an 83.8% chance to produce four good signals in four seasons, whereas a type B player would only do so 52.2% of the time.

Nevertheless, this still poses problems for differentiating between type A and type B players: the estimate of θ_0 is 0.276, which implies that 27.6% of minor league players have the potential to become major league players. This stands in stark contrast to reality: from 1981 to 2010, only of 17.6% of drafted and signed players ended up making the major leagues (Cooper, 2019a), and in the collection of data used for this model (professional debuts from 1999 through 2009, with playing time minimums), 14.7% of the population played in MLB at some point. Not only does this imply that significantly more players are capable of playing at the major leagues than actually do so, but it also means that it may not be as easy to distinguish type A and type B players based on good performance as one would expect. Using θ_0 as the prior probability that a player is capable of making the major leagues, Bayes' Theorem implies that the probability that a player is type A, given that they had produced four good signals in four seasons, is 38.0%, which is not much higher than θ_0. This could be an explanation as to why empirical promotion patterns do not exactly match the model's predictions, which will be examined in more detail later.

Now that the parameters for the model have been estimated, they can be used to calculate $\pi_i(\hat{\Omega})$ and compare the predicted exit and promotion probabilities with what was actually observed in the data. In Figure 4, the shape of the predicted exit

hazard is a near-exact match to what was actually observed. However, the values of those distributions are markedly different, with the predicted exit probability of players within the minor leagues consistently seven to ten percentage points lower than what was actually observed. This difference decreases at the end of the ten-year period, but primarily because the predicted exit probabilities converge to zero after the fifth season of a player's career.

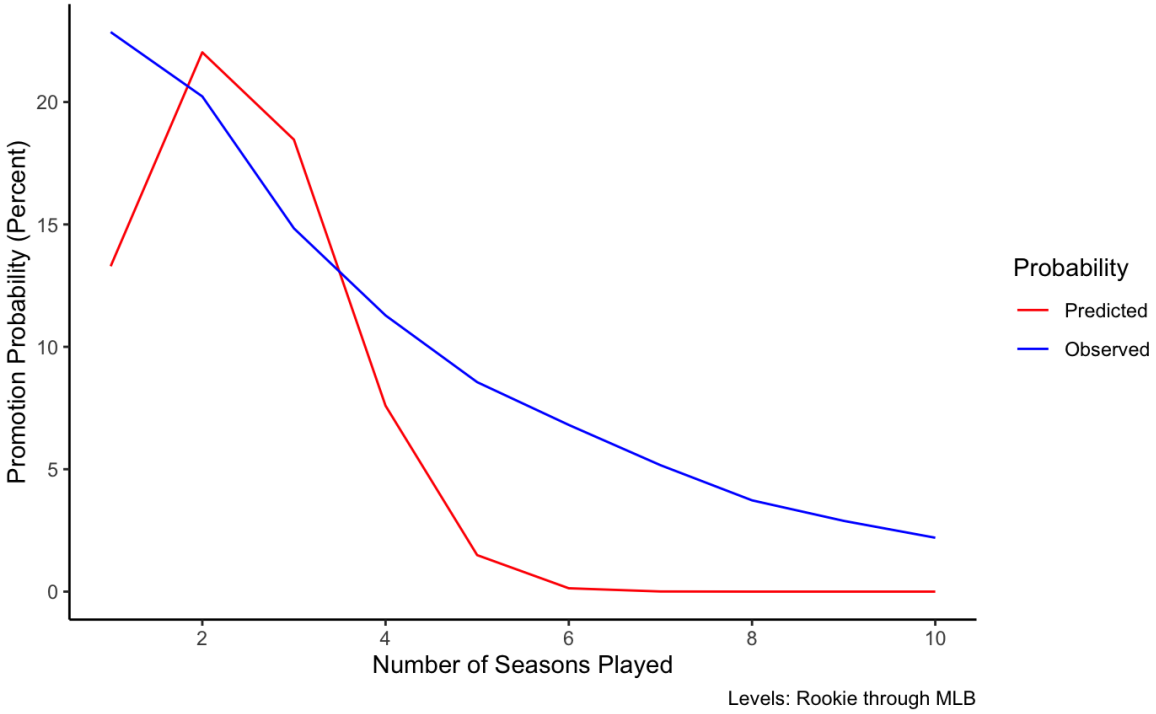
Figure 4: Professional Baseball Exit Hazard, by Year of Career



While Figure 5 suggests a similar underestimation issue for promotions later on in a player's career, this comes with an overprediction of promotions at the start of a player's career: that is, based on performance at the start of players' careers, this model predicts more player promotions in their second and third seasons (on aggregate) than actually observed. While there exist potential explanations for this trend that will be further investigated in Section 6 — namely, that teams may in certain cases be incentivized to not promote their top minor league players — these results, when viewed in conjunction with the results seen in Figure 4, are primarily motivation to alter the form the model is currently taking. As mentioned in Subsection 4.2, these results could be a manifestation

of fitting a dataset of exits and promotions that is too generalized and does not take into account the possibility of different promotion standards at different levels of the minor leagues. Before drawing larger conclusions about team behaviors as a result of running this model, examining it again with the increased specificity that comes from running it on a level-by-level basis is likely necessary.

Figure 5: Professional Baseball Promotion Hazard, by Year of Career



5.2 Level-by-Level Implementation

The focus now turns to implementing the O'Flaherty and Siow model for several different transitions. Instead of fitting all exits and promotions across the entire minor league system, there will be six different models implemented: one modeling exits and promotions from the minor leagues' Rookie level, another from Short-Season A, and so forth, up to and including Triple-A, the second-highest level, to ensure that promotions are still possible. Each model is fit via the same implementation as described earlier and the same player population (with identical playing time requirements); the only difference is that each transition uses players who have not yet played at a level higher

than the one the model is being fit on. For example, for the model fitting the exit or promotion transition from Double-A, the model will use only Double-A players who are yet to play above Double-A.

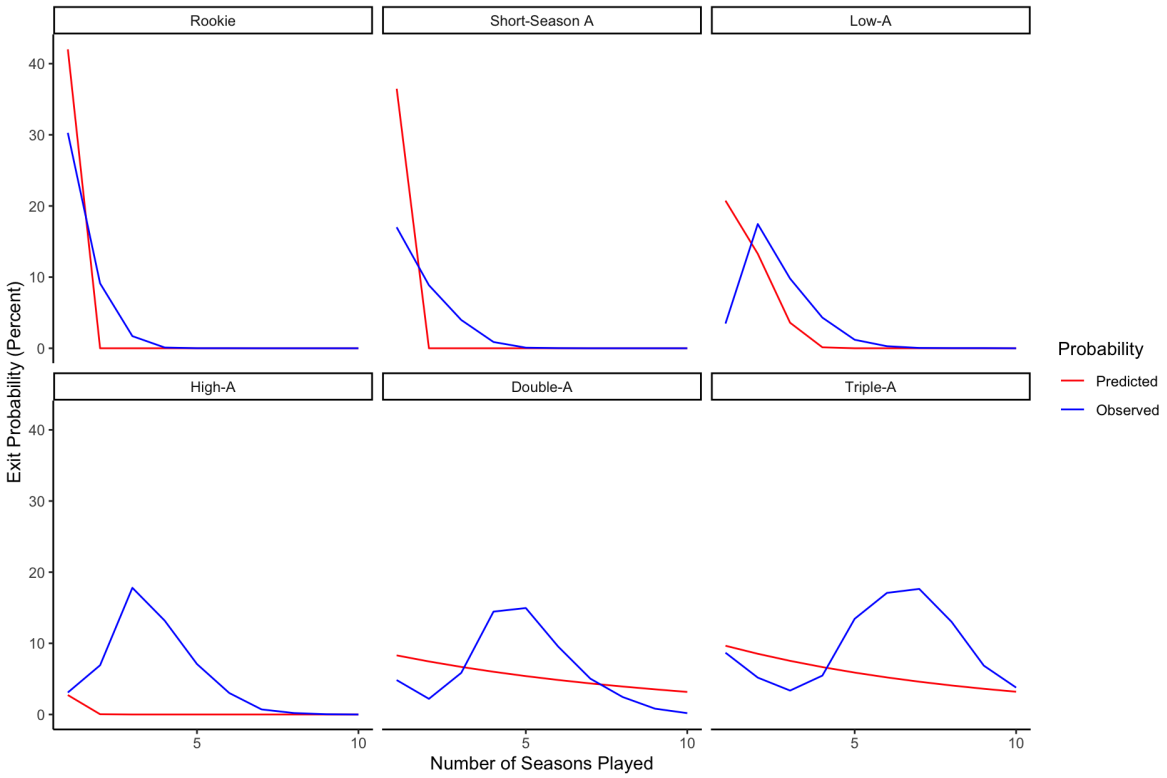
Table 6: Parameter Estimation, Level-by-Level Model

	α	τ	θ_0	μ	σ
Rookie	1	0.227	0.270	0.295	0.037
Short-Season A	1	0.148	0.239	0.248	0.046
Low-A	0.988	0.710	0.296	0.429	0.048
High-A	0.864	0.626	0.258	0.208	0.036
Double-A	0.982	0.891	0.283	0.620	0.055
Triple-A	0.993	0.882	0.196	0.776	0.036
Mean	0.971	0.581	0.257	0.429	0.043

Running this model on each level on its own yields several interesting results. Most notable is the shrinking disparity between α and τ as players progress through the minor leagues: at the lowest levels of Rookie and Short-Season A, type A players (i.e., those believed to be productive at the next level) are estimated to always produce a good signal with their play, whereas type B players are drastically less likely to produce at these levels. In contrast, while the parameters derived at higher levels still suggest that type A players are extremely likely to be productive, type B players at these levels are also more likely than not to produce strong performance signals, particularly at Double-A and Triple-A, the levels closest to MLB. This provides support for the common conception of the upper levels of the minor leagues, and Double-A in particular, as the critical point at which true major league talent is forced to emerge from a playing population tightly packed in terms of skill (Skillin, 2015), whereas the lowest levels are more of a testing grounds for capable players to get their feet wet, and a place where those less capable serve as instruments in these players' development. Additionally, the

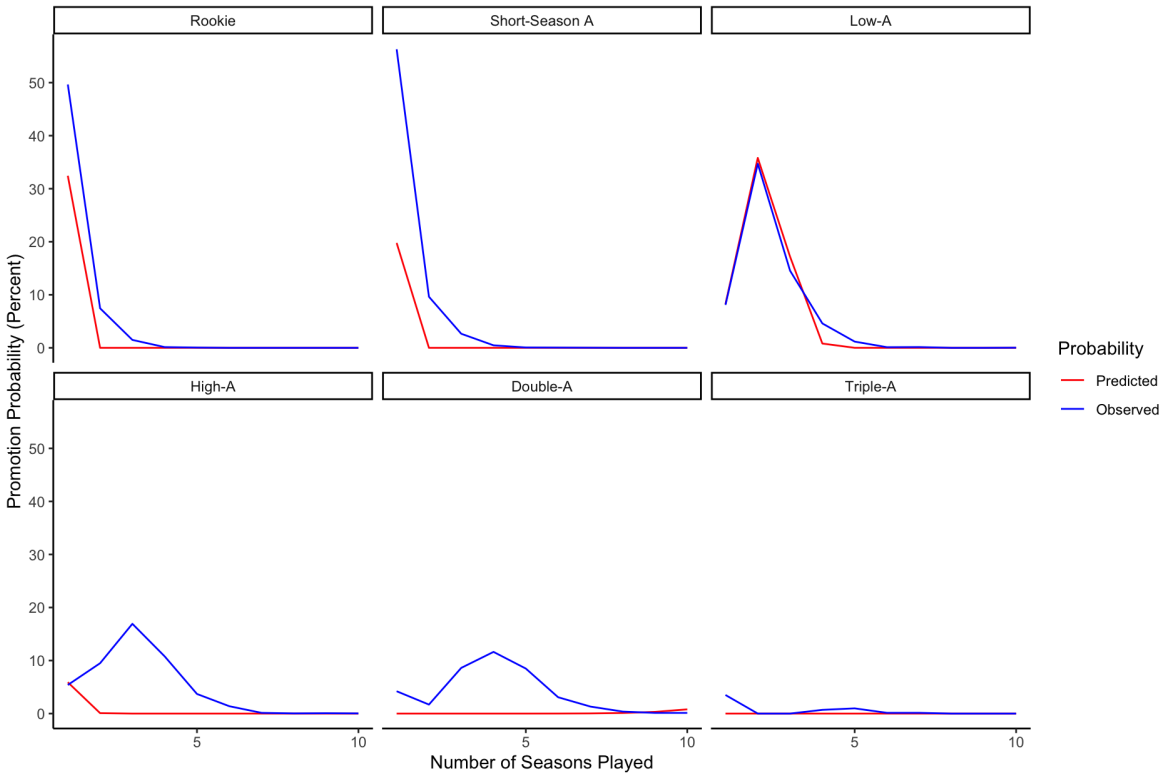
closeness of α and τ at these levels may also suggest an increased level of difficulty in discerning whether or not these players are capable of playing at the next level, complicating teams' personnel decisions. Intuitively, the mean μ of the distribution of θ_u generally increases with level, meaning that the closer players get to the major leagues, the stronger their performance has to be in order to warrant promotion to the next level.

Figure 6: Professional Baseball Exit Hazard, by Level and Year of Career



The parameters of these various versions of the model in Table 6 appear to make sense at each level, supporting intuition and existing knowledge of professional baseball while initially lending credence to the idea that such a revision may draw benefits from reducing the generalization present in the initial version. However, there is limited support for this notion when visually inspecting the results of the model across the different levels. Figure 6 shows the model's fit in comparison to observed exits at each level, and while the fit at the lowest levels is not exactly inaccurate, this is largely due to the high rate of exit by these players, resulting in a unique shape of the observed

Figure 7: Professional Baseball Promotion Hazard, by Level and Year of Career



distribution that requires a less granular exit model for a proper fit. This loss of complexity becomes particularly clear when the exit distribution's shape becomes more complex at higher levels, as the model shows little nuance in capturing the variations of player exits over time and instead follows a general downward trend. A similar and arguably more drastic pattern exists in the models' fit of promotions at a level-by-level basis in Figure 7, where apart from the same trend at the lowest levels and strong predictions at Low-A there appears to be little, if any, connection between the predicted rate of promotions and what was actually observed. This has several implications that will be discussed in the next section, but one of the primary ones is that it does not appear as if running the model level-by-level results in significant improvements in modeling team personnel decisions at the minor league level. Overall, the primary takeaway from these two editions of the model, neither of which has a particularly strong fit, is that there are large disparities between predictions and reality, as player turnover is higher than expected.

6 Discussion

Before concluding the paper, I examine potential modifications that could be made for future versions of this model, then walk through the implications of different policies and behaviors on the minor league system, working under the assumption that the results above from the model's general implementation are an accurate reflection of player promotion and exit patterns.

6.1 Revisiting the Model

In order for the theoretical up-or-out model of this paper to be able to be used for empirical purposes, some modifications had to be made to its structure, as discussed when it was outlined in Subsection 4.1. One of these, which was initially introduced in the original empirical application of the O'Flaherty and Siow model, is that because there are exits in each year of the data, any bad signal in the first n periods results in a dismissal (where n is the number of periods in the data), though this was a decision also made because the data were not continuous, a situation shared by this paper. Given how performance data in baseball can be noisy, as previously mentioned, assuming that one poor season should result in a player's exit is likely a faulty one: over half of the players who ended up making the major leagues in the dataset used for the model had at least one season in the minor leagues where they produced a bad signal under the definition posed above (where a 50^{th} percentile performance or above is a good signal, and below that a bad signal). Given that under the current conception of the model players can produce only good or bad signals, addressing this within the current application of the model would mean implementing a modification in which workers could also produce neutral signals, which would simplify categorization of performance but may also complicate estimation of the model parameters.

One significant observation from O'Flaherty and Siow (1992) is that they focuses predominantly on the firm's agency in these personnel decisions, abstracting away from the limited agency held by workers with respect to exits and categorizing worker-driven

exits as equivalent to those dictated by the firm. Given that promotion and retention decisions are made largely by firms alone, reducing the number of agents in these decisions makes sense. However, by including a worker's own optimization decisions into the model, there is potential for a more complete illustration of the labor dynamics at play in these personnel decisions. In the current model, workers are evaluated after each period, their future potential evaluated, and a decision made about their role at the firm based on this updated probability of them becoming a contributor to the firm at the following level. Similarly, a theoretical addition to the model could feature a sequential component to these personnel decisions. As an example, firms may first decide promotions, retentions, and dismissals following the conclusion of the evaluation period. Just as firms update their views on workers, workers who remain within the firm update their expected discounted future wages as a result: those whose future wages fall below the predetermined threshold of this same metric outside of the firm will exit (this threshold may vary across individuals within the firm, just as the model's promotion threshold varies). As an empirical exercise, this would not be possible with the current dataset of minor league baseball personnel patterns, as there exists no differentiator between demand-based and supply-based worker exits. However, as a theoretical extension and a possibility for work within a more robust set of data, this addition to the existing model could be useful.

6.2 Baseball's Labor Structure

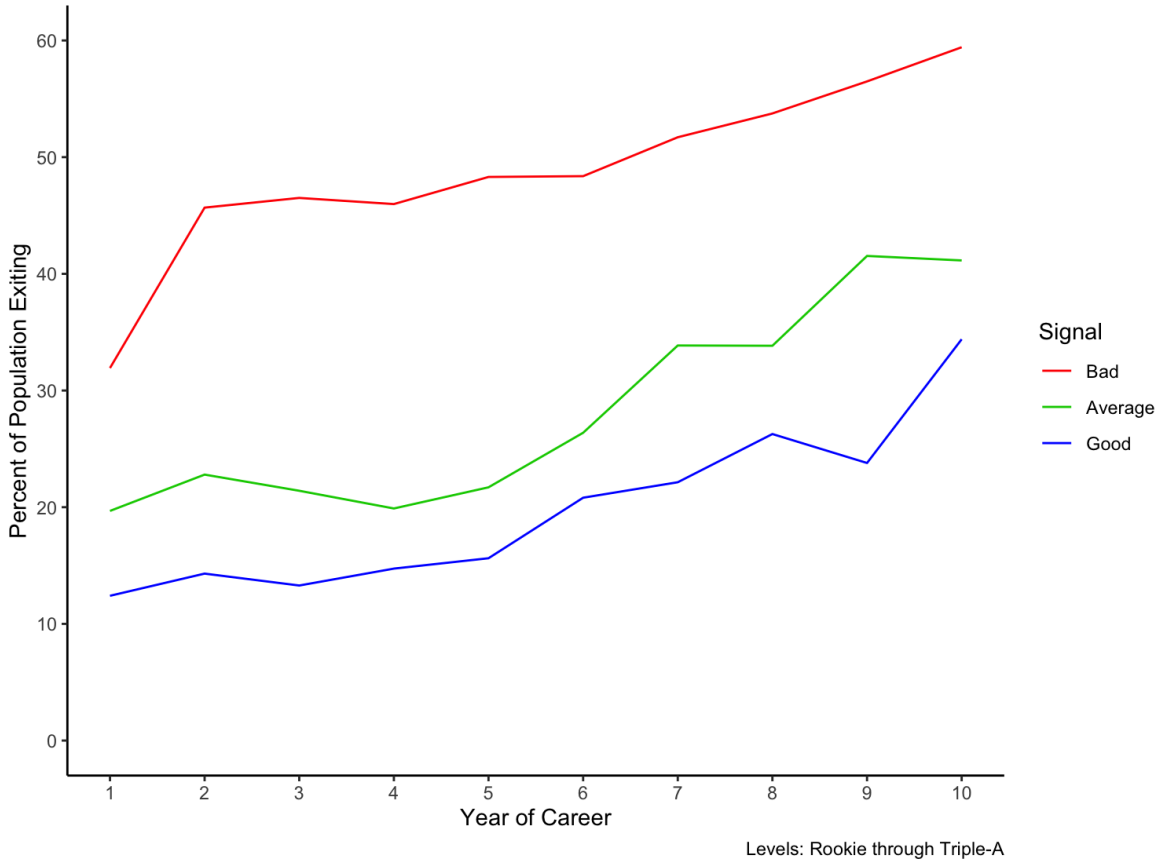
For the purposes of this section, the focus will turn to the general model from Subsection 5.1, with the assumption being that the model as constituted therein is working as intended. This means that, based on the performance of minor league players and the structure of the minor league system as a whole, the predictions given by the model are ones that give an accurate depiction of the firm's profit-maximizing strategy. In this scenario, teams are behaving inefficiently in their dismissal and promotion decisions. In particular, the significantly higher exit rates of players seen in Figure 4 in

comparison to predictions generally suggests that teams are much too quick to dismiss players after subpar performance, though this could also be driven by players exiting at a drastically higher rate than would be allowed for by the model. In turn, whether it is driven by suboptimal decision-making or compensation for a greater-than-expected exit rate, Figure 5 indicates that teams generally over-promote players, though they may not be giving enough credit to players who perform well at the beginning of their careers, or struggling to differentiate between type A and type B players. In general, however, the high observed exit and promotion rates in comparison to the predictions from the general version of the model suggests that professional baseball is exhibiting significantly more turnover than would be expected on performance alone.

This leads to the question of why, apart from personnel management inefficiency, minor league baseball experiences such a high rate of player turnover. In theory, no player who produces a good signal in the given season should ever exit the minor league system, as a strong performance would result in the probability of that player making the major leagues being greater than or equal to that same probability prior to the season. However, this is not the case: Figure 8 divides player signals in the minor leagues into three tiers, such that the upper third of performance (by percentile) is categorized as a good signal, the middle third as average, and the bottom third as bad, and depicts the percentage of the players producing those signals who exit that year. While about half of players who produce bad signals each year exit the system, there are still non-negligible exit rates for higher-performing players that see increases over time, with about a fifth of players producing average signals and ten to fifteen percent of those producing good signals exiting after these average or above-average seasons at the start of their career, and a higher percentage as their careers progress. Notably, this trend of increasing exit rates season-by-season is observed throughout the minor leagues, even when controlling for player performance. Thus, it is likely that there are other factors common to all minor leaguers driving these player exits, and as outlined in Subsection 2.3, there is a strong possibility that one of the primary factors is the low

wages of the minor league system.

Figure 8: Signal of Exiting Players, by Year of Career



In particular, one key component of the O'Flaherty and Siow model is that workers do not have a motivation to leave their current role for one with another firm, as the wage they recieve at the next level of the system is higher than their next-best alternative wage, and that hiring costs are non-trivial, such that firms are incentivized to promote workers within their own system as opposed to from other firms. In baseball, the fact that minor league players are typically contracted to parent organizations for seven years almost entirely eliminates the problem of hiring costs (given that most careers are not long enough to reach this point), but the highest-alternative wage issue is not remedied and instead takes on a different form: this next-highest wage comes not from another playing role within minor league baseball, but from other, less specialized industries both related and unrelated to baseball. As an example, DeAngelo Mack was an outfielder drafted by the New York Yankees out of the University of South Carolina in

2009, and in each of his first three seasons within the Yankees organization he produced a strong signal ("DeAngelo Mack Minor and Independent Leagues Statistics and History", n.d.), yet in 2013 he had exited baseball and begun working as a leasing consultant ("DeAngelo Mack", n.d.), a role with an estimated yearly salary of slightly over $51,000 ("Salary: Leasing Consultant (March, 2022) — Glassdoor", 2022), significantly above the low five-digit annual salaries minor league players typically receive. Exits such as these do not make sense from the perspective of major league teams, as nearly half of all players who perform this well in their first three seasons end up making the major leagues (48%, to be exact), so in combination with aforementioned anecdotal evidence of the economic challenges faced by minor leaguers and previous empirical work suggesting a higher-than-expected rate of player exits, it stands to reason that instances such as these are in large part driven by players' economic incentives.

Before considering alternatives to baseball's current economic structure, it is first worth considering what the goals of such changes would be. While as previously mentioned revenues across the sport have grown markedly over the past three decades, the television ratings of the World Series (MLB's championship series) have declined steadily over the same period, while the NFL and NBA have seen larger revenue growth than MLB while maintaining or increasing viewership, indicating that industry growth does not necessarily tie to the sport's popularity (Draper, 2021). Given that pundits and popular sentiment agree that baseball's most significant fundamental area for long-term revenue growth when compared to its peer leagues is both the quality and quantity of its top talent ("The State of Baseball: Inside the biggest questions MLB is facing with the future of the sport at stake", 2021), baseball has an incentive to maximize the development potential of its players within the minor league system as a key component of its future growth. In doing so, teams would reduce the number of good players exiting the system for non-performance-related reasons, so a straightforward solution would be addressing the low wages for those within the system and the antitrust exemption that has codified such a salary structure.

6.3 Potential Revocation of the Antitrust Exemption

MLB's antitrust exemption has survived a century's worth of challenges, and it remains the only American professional sport to retain one. However, the recent Supreme Court opinion determining that the NCAA had violated antitrust law in restricting name, image, and likeness payments to student-athletes has been seen as an indicator that MLB's exemption, which has only been preserved to this point via repeated precedent-based rulings, is less solid than it has appeared historically (Janes, 2022). Justice Brett Kavanaugh's concurring opinion in this case states in part that "price-fixing labor is ordinarily a textbook antitrust problem because it extinguishes the free market in which individuals can otherwise obtain fair compensation for their work" (*National Collegiate Athletic Association v. Alston*, 2021), which is commonly acknowledged to be an implicit invitation for baseball's exemption to be challenged, whether via the judicial or legislative processes, and to this end Senator Bernie Sanders of Vermont recently announced his plan to introduce the "Save American Baseball Act", which would revoke MLB's antitrust exemption (The Athletic Staff, 2022).

A revocation of the antitrust exemption would impact Major League Baseball in a variety of ways, including an increased ease of team relocation and entry that would have the potential of boosting the number of minor league teams and players, as well as increased difficulty for MLB to make broad changes to the number of teams in the minor league system without approval (Belth, 2001). For the purposes of this paper, the most relevant is the impact on the minor league system. Were the exemption to be revoked, the owners of MLB organizations, which pay the salaries of minor league players, would no longer be able to collude amongst one another to pay minor league players the same salary. However, teams now determining their minor leaguers' salaries without colluding with one another would not necessarily lead to wage increases across the minor league system, as 2018's Save America's Pastime Act would still exempt these players from federal minimum wage laws and regulations around overtime pay (114th Congress, 2nd Session, 2016), and players would still be bound to their MLB

organizations for the duration of the standard minor league contract, so there would not be a free market for players' services until their contracts expire after seven seasons. Teams have also shown limited willingness to act in players' best interests when those interests are not completely aligned with their own — one team executive, when asked about the problem of service time manipulation mentioned in Subsection 2.3, said, "It's horrible... But what are we supposed to do? Not take advantage of them?" (Passan, 2022a) — so significant, widespread improvements are not likely to come of teams' own volition.

This means that the most straightforward way for minor league players to maximize the potential benefits of a revocation of the antitrust exemption would likely be via collective bargaining. Minor league players are not part of the MLBPA, so they lack the bargaining power of their major league counterparts, and there is limited incentive for MLB to collectively bargain with minor leaguers. However, should MLB be forced to operate without their antitrust exemption, they would become vulnerable to antitrust lawsuits for, among other standards, widespread wage suppression, and the threat of such litigation would likely increase the league's motivation to negotiate with a minor league union in order to have some input into their new labor standards (Janes, 2022). This would emulate the existing systems in the minor leagues of the NBA and NHL: the players in the former's G-League formed a union in 2020, collecting a minimum salary of $35,000 with covered housing costs; meanwhile, the AHL, a hockey minor league, also has a union, and while housing costs are not covered, their minimum salary of $51,000 is 70% greater than the highest minor league baseball minimum salary (Ghiroli, 2021).

Thus, the revocation of MLB's antitrust exemption has the potential of increasing player salaries, improving working and living conditions, and reducing the high degree of player exits, perhaps leading to a system of professional baseball where the talent present at each level more accurately reflects players' true abilities and not just their ability to make it through a uniquely challenging and economically burdensome labor environment. As the system is currently constituted, minor league baseball players

do not have this level of security and are instead left to determine for themselves the amount of uncertainty in expected earnings they can tolerate, a calculation that has significant potential for suboptimal decisions.

6.4 Minor Leaguers and Rational Behavior

Popular media has typically depicted the lifestyle of minor league baseball in a heavily romanticized manner, from documentaries on NBA star Michael Jordan's brief time in the minor leagues to cult classic films like "Bull Durham." But as the aforementioned circumstances of many minor league players (and their associated salaries) indicate, this is not warranted by much of their lived experience, and it is more reflective of a larger glamorization of "the grind" on the road to MLB, a glamorization that along with the images of wealth and fame of major league players may give minor leaguers skewed perspectives on their own chances of making the major leagues.

In illustration of this point, players in the data spent an average of 4.08 years in professional baseball, of which over a year was at the lowest minor league level of Rookie ball, and the remainder evenly split across the other minor league levels, including an average period of one-sixth of a year spent in the major leagues. Taking the minor league weekly wages from 2019, the end of the period of time covered by the data and the only available data for the minor leagues ("MLB raising minimum salary for minor leaguers in 2021", 2020), as well as the major league minimum salary of $400,000 from the middle of this time period ("Major League Baseball Minimum Wage", 2021), the expected weekly salary for a professional baseball player over their four-year career is approximately $450, inflation-adjusted to $527.60 in 2019.

This is well below the expected weekly wages for the minor league population based on their education levels: just under three-quarters of minor league players come from the domestic amateur draft, which sees nearly 80% of players selected out of college programs and the remainder from high school, from which a diploma is required in order to enter the draft (Cooper, 2018). Even working under the dual assumptions that

the entire international amateur population in the minor leagues has not completed high school and that all domestic amateurs drafted out of college are selected without completing their degree, the expected weekly salary outside of baseball for minor league players in 2019, the last year of the data, is slightly over $750 (U.S. Bureau of Labor Statistics, 2020), over 40% greater than their average salary from baseball. Allowing for domestic players to have graduated college in this calculation sees estimated weekly salaries increase to nearly $1,000, a value that would increase even further if international amateurs completed high school, though the relevant data are not readily available. Regardless, the expected weekly wages for even those without a high school diploma is $592, which is still 12% higher than the expected weekly salary for a minor leaguer over their average four-year career and greater than the weekly pay at any minor league level over the course of the data (Bureau of Labor Statistics, 2020). While it is possible that professional athletes are less risk-averse than most individuals, and research by Buccetti (2012) has shown this to be the case for former athletes, this nevertheless indicates that minor league players are making decisions that do not maximize their expected wages. This raises the question of what the effect on the minor leagues would be if players were more realistic about their chances of eventually reaching the major leagues and were more risk-averse or risk-neutral in choosing a job that would maximize their expected earnings.

In a situation where minor league players acted in a manner more reflective of standard risk preferences, the most likely outcome would be a significant reduction in the supply of minor league labor, as the players with the lowest chances of making the major leagues ex ante would not start careers in baseball to begin with. This would by extension decrease the number of minor league teams in each organization, which could have the effect of increasing the concentration of resources for each MLB team and lead to a stronger support system and potentially higher level of play throughout the minor leagues. This is the explicit rationale outlined by MLB in their 2021 reduction in the total number of teams in Low-A through Triple-A to 120 from 162, citing reduction

in travel, higher facility standards, and weekly salary increases ranging "from 38 to 72 percent" as the primary benefits that will arise from this top-down reorganization of the minor league system (Janes, 2021a), a process that has also seen MLB mandate organizations to provide housing for all of its minor league players as part of "a multi-year effort to modernize the minor league system" (Passan, 2021).

However, this concentration of talent to a smaller number of teams would make more sense if the quality of minor league play was worse. As the model predicts that 27.6% of players should make the major leagues, yet only 17.6% do, the implication is that the talent level of the minor leagues is actually higher than is reflected in the number of players who do eventually reach MLB. This makes MLB's decision to cut the number of minor league teams seem counterintuitive: if there are more capable players than expected, the natural decision would be to increase the number of minor league teams in order to enable the development of the maximum number of major league-caliber players, who can accrue value for an organization even if they do not end up playing for that team, as they can serve as components of trades for even more skilled players. As an example, throughout the period of time covered in data, the Astros, Cardinals, and Yankees, who while just a tenth of MLB combined for nearly a third of the championships won, all tended to field nine minor league teams per year, while other organizations had six or seven, an indication of the potential benefits of larger minor league systems.

While MLB's move to provide housing for all players was met with widespread praise from minor league advocacy groups, the decision to cut the number of minor league teams received a much more tepid response. Research suggests teams may already face incentives to properly support and compensate their players without having to eliminate existing minor league teams, as Russell Carleton of Baseball Prospectus estimates that an estimated $4 million annual investment in the improvement of minor league conditions could result in surplus value beyond that investment of up to $6 million per year (Carleton, 2021). Though there are varying perspectives on the effects

these two changes will have, they both provide an indication that MLB is aware of the inefficiencies that may exist within its minor league system, some of which are illustrated in this paper's results, and is adopting a variety of new policies in an effort to counteract them.

There exist some alternative mechanisms that could result in increased financial security for minor league players over the course of their career without requiring a drastic change in the number of available roles, or for a large portion of them to not enter the minor league system in the first place. One solution already put into practice is the income share agreement, where an individual in search of immediate income pledges a percentage of their future income over a certain period to investors, providing present-day income security to the individual and future upside for the investor (Garcia, 2020). Given the low wages at the minor league level and player uncertainty regarding future success, this sort of solution seems well-suited to baseball's economic structure, and companies like Big League Advance have already signed these agreements with prospects and reaped rewards, most notably when San Diego Padres star Fernando Tatis Jr. signed a $340 million extension prior to the 2021 season (Diamond, 2021). However, these agreements are also prone to exploitation on both sides, whether via companies taking advantage of young athletes with low education levels or a moral hazard problem with misaligned player and investor incentives, though proper regulation has the possibility to mitigate these issues (Garcia, 2020).

Another market-based solution comes via the structure of professional baseball contracts themselves: upon signing their initial contract, players are under team control (and their component minor league teams, by extension) until they can negotiate a new contract as a six-year minor league free agent, typically after their seventh season ("Frequently Asked Questions — The Business of MiLB", n.d.). Given that the average career length in this data is just over four years and 83.2% of players play for seven years or fewer, this means that only a select group of the playing population has the ability to enter free agency and engage with the free market for their services.

Coupled with the fact that not only are minor league salaries fixed ("Frequently Asked Questions — The Business of MiLB", n.d.), but also that this wage fixing is explicitly permitted by baseball's antitrust exemption, minor leaguers' wages are essentially fixed until they make the major leagues, a goal only achieved by a select few. A straightforward solution is to mandate higher minimum salaries for minor league players, but an interesting alternative is to shorten the standard length of a minor league contract, which is the subject of a bill recently introduced in the California state legislature that would shorten minor league contracts to four years (Baggarly, 2022). This could have a similar effect as above with MLB organizations reducing the number of minor league teams and players under their control, but it also has the potential for the free market to dictate higher salaries for minor league players — and even if the former scenario were to come to pass, the players who would be the first to exit the system after the expiration of their contract would likely be the ones whose expected earnings calculation would most strongly be in favor of seeking more stable forms of employment.

7 Conclusion

In this paper, I used data from minor league baseball from 1999 through 2019 in an effort to more quantitatively determine the degree to which professional baseball resembles an up-or-out labor system, and to be able to draw sharper conclusions about the effects of various policies and programs on the careers of minor leaguers. After establishing the general resemblance of baseball to an up-or-out system, and providing an overview of some of the nuances of the sport that make it worthwhile to examine in greater detail, I used observed player career data to further motivate an empirical approach to the minor leagues. Following a walkthrough of the model used for this work, I implemented multiple versions of the model in a manner appropriate for its novel application to professional baseball. I found that the results from these various implementations reflect inefficiencies within baseball's minor league system, and I examined potential remedies to amend these inefficiencies through revocation of the sport's antitrust exemption or

changes in behavior from minor league players, considering the various consequences such changes would bring in the process.

This work could be improved with a thorough revision of the O'Flaherty and Siow model used for this paper, as outlined in Subsection 6.1, that could incorporate some more baseball-specific details. In doing so, the model would be better tailored to the industry to which it is being applied, which could provide more accurate and perhaps more revealing results. Future work will be able to leverage the broader changes happening throughout the minor leagues, such as the aforementioned reductions in number of minor league teams, wage increases, and mandated team-provided housing: revisiting this exercise several years from now, after the impact of these changes (should they exist) have been felt in the minor leagues, may reveal how significant these changes are in lowering the exit rates of minor leaguers, and whether they serve their intended purposes of raising the level of play throughout professional baseball and increasing the financial security of the players involved.

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