What's New in the New NHL?
A Comparison of the Effect of Team Performance on the Probability of Winning and Goal Scoring Efficiency in the Pre- and Post-Lockout NHL

by

Andrew Vesper

(Under the direction of William Lastrapes)

Abstract

The National Hockey League became the first North American professional sports league to lose an entire season to labor disputes when the league canceled the 2004-2005 season. The NHL emerged from the lockout with a new collective bargaining agreement and a new set of rules. This study uses the logit framework to model the impact of team performance factors on the probability of winning to determine differences in play between the pre-lockout 2003-2004 season and the post-lockout 2005-2006 season under the new rules. In particular, the results of the logit estimation reveal that special teams play is significantly more important to determining game outcome in the "New NHL." Stochastic frontier modeling is also used to further differentiate between the two seasons in terms of NHL goal scoring efficiency by team.

Index words: NHL, efficiency, stochastic frontier, wins

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Dedication

To my parents.

Acknowledgments

First, I am most indebted to Michael Guillemette, without whom I would never have come to know the beauty of hockey. While Mike introduced me to the game, it was Ilya Kovalchuk, Henrik Zetterberg, Jaromir Jagr, Brendan Shannahan, and all the rest that made me a fan. Mike also provided critical analysis of historical hockey trends, game play, and strategies necessary for a full understanding of my results.

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Lastly, I should say that without having Brooks Andrews along for the ride, I would never have made it this far.

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Chapter 1

Introduction

1.1 The Lockout

On September 15, 2004, the collective bargaining agreement between the National Hockey League and the NHL Player's Association expired. The following day, the owners began a lockout of the players that lasted 310 days until the ratification of a new collective bargaining agreement in July of 2005. In the mean time, an entire season consisting of 1230 regular season hockey games and the Stanley Cup Playoffs was canceled. Prior to this drastic move by the NHL owners, a complete season had never been lost due to labor issues in the history of the major professional sports in North America.

During the years leading up to the lockout, NHL franchises and the NHL itself reported alarming operating losses. For the 2002-2003 season, NHL teams reported losing a collective $273 million on hockey related activities. The following year, they reported operating losses of $224 million on $2.08 billion in revenue, with 75% of revenues paid out to players in compensation. It is worth noting that *Forbes* magazine independently estimated league-wide operating losses of only $124 million and $96 million in those years respectively[1]. The differences in these estimates are due to the fact that the NHL reports only hockey related financial information, while the Forbes estimate included non-hockey related operations in its data. Regardless of which numbers are under consideration, it became obvious to the owners that they could not continue to pay 75% of revenues in labor and maintain long term financial sustainability. Believing that they must restructure the collective bargaining agreement in

[1] These numbers were collected from both Andrew's Dallas Stars Page and the annual Forbes NHL report.

order to become profitable, the NHL began discussions with the player's association. NHL commissioner Gary Bettman demanded "cost certainty"[2] for the owners, or in other words, a salary cap limiting what teams could spend on players' salaries. The players association initially refused to consider any form of salary cap, causing the negotiations between the NHL and the players association to stall prior to the start of the 2003-2004 season, and essentially forcing the owners to lockout out the players.

After nearly a year of talks between the league and the players, a new agreement was reached that allowed the owner's to achieve "cost certainty" and put the players back on the ice. The main term of the agreement was a salary cap that limits the players' share of league wide revenues to approximately 55%, with a first year payroll of no more than $39 million per team. The agreement also established a maximum individual player salary of 20% of the total team salary (approximately $8 million) and a minimum individual player salary of $450 thousand, significantly higher than the $185 thousand under the previous agreement. Other notable terms of the new agreement included restrictions on performance based salary bonuses, an immediate 24% roll back of all salaries, a new commitment to revenue sharing amongst the owners, a free agency policy to account for the lost season, a new free agency system that allows players to become unrestricted free agents at a younger age, a ruling on salary arbitration, a reduction in the number of rounds of the NHL entry draft, the implementation of a system to conduct the NHL entry draft lottery and the draft itself in 2005, limits on salaries and contracts for entry level players, an agreement to allow NHL players to participate in the 2006 and 2010 Olympics, and the establishment of a performance enhancing drug policy. After reaching the agreement, the commissioner released the following statement on July 22, 2005[3].

[2] "Cost certainty" became a buzz-phrase used a number of times in quotes from the commissioner to the press during labor discussions.

[3] This quote is an excerpt of the remarks made by the commissioner accompanying the press release to announce the new CBA, the quote is reproduced on the same webpage.

> Today, our Board of Governors gave its unanimous approval to a Collective Bargaining Agreement that signals a new era for our League – an era of economic stability for our franchises, an era of heightened competitive balance for our players, an era of unparalleled excitement and entertainment for our fans.
>
> — Gary Bettman, *NHL Commissioner*

The financial effects of the agreement were immediate and profound. During the 2005-2006 season, the first season after the lockout, the Forbes report estimated league-wide operating incomes in excess of $125 million on revenues of $2.27 billion.

1.2 NHL Rule Changes

While the lockout was the result of the business side of hockey, the labor dispute also had a significant effect on the game of hockey. Perhaps feeling indebted to the fans for sacrificing a full season of games, the NHL hoped to unveil a full slate of new rules that were intended to "emphasize entertainment, skill and competition on the ice," according to a press release issued by the league. Following the lockout season, the league established a Competition Committee which is now responsible for proposing rule changes to meet these objectives. At the time, the NHL approved several significant rule changes for the game of hockey that would take effect immediately for the upcoming 2005-2006 season, the beginning of what would become known as the "New NHL." The following is a brief outline of these rule changes and some discussion of the league's intended consequences of the changes.

Though not a rule change in the game, it is important to first recognize that the establishment of a salary cap should create more parity among the teams in the league. Theoretically, small market teams will have the same financial ability to sign talented players to contracts as the big market teams. While it is certainly not clear that parity is necessarily a positive characteristic of a professional sports league, the NHL hoped that more competitive games would make for more exciting hockey.

The NHL also decided to revamp the league's schedule of games in an attempt to emphasize divisional rivalries and hopefully provide more compelling television matchups, especially toward the end of the season when teams fight for playoff berths within the division. Like the salary cap, this rule change does not affect the way the game is played, but it obviously has a big impact on the structure of the league.

According to a statement released by the NHL[4],

> One primary objective of the new rules will be to reduce the scope of defensive 'tools' a team may effectively employ, and to create a corresponding benefit to the offensive part of the game – thus allowing skill players to use their skills and increasing the number and quality of scoring chances in the game.
>
> — NHL Press Release

In order to accomplish these objectives, the league established a zero-tolerance policy for specific tools, namely hooking and holding penalties (in past seasons there was some leeway given to defenders to "clutch and grab"[5] offensive players). The league also made additions to the scope of the delay of game penalty to include goaltenders handling the puck outside of the designated territory, goaltenders unnecessarily freezing the puck, and the intentional clearing of the puck by a defensive player out of play from his own defensive zone. All of these rule changes have a negative effect on the ability of a defense to combat the attack of the opposing team, which should certainly increase the quality of scoring chances. Also, by calling more penalties, there will necessarily be more power play opportunities (time spent with a one man advantage), and in turn more goal scoring opportunities. Clearly these rules should enhance the offensive aspect of hockey.

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[4]This statement was taken from an NHL press release concerning the new rule changes (NHL Press Release, 2005).

[5]"Clutch and grab" is common terminology within the league to refer to deliberate use of hands or sticks to impede the progress of the opponent.

Further, the league reduced the maximum allowable size of goalie equipment by approximately 11%. Less equipment to make saves should translate into fewer saves, and thus more goals, again increasing the ability of teams to produce offense under the new rules.

Also in an effort to increase offensive play, the league changed the dimensions of the rink and the location of the blue lines, which mark the offensive zones. While the NHL made several minor changes to the dimensions, the most significant change was the addition of 4 feet to each offensive zone, positioning the blue line 64 feet from the end line instead of 60 feet. Because time spent in the offensive zone is crucial to generating scoring opportunities, the league believed that a larger zone would translate to more time in the zone and thus more scoring chances, especially on the power play.

The NHL also wanted to increase the flow of play with fewer stoppages and more open ice action. To accomplish this goal, they removed the center line as part of the two-line pass rule, which essentially eliminated this infraction from the game. The league also modified the offsides rule to allow for "tag-ups." Under the old rules, when a player preceded the puck across the blue-line into the offensive zone, as soon as the puck entered the zone, the offside infraction would be called. The new rule allows such players to return to the blue-line, thus "tagging" it, and then re-enter the offensive zone to try to play the puck, with offsides only being called if a player from the attacking team interferes with the play of the puck prior to any players "tagging-up." Because offsides and the two-line pass are very common infractions in the game of hockey, reducing the number of calls per game can significantly decrease the number of stoppages and make for a faster pace of the game.

With a similar goal of increasing the flow of play in mind, the NHL also decided to modify the icing rule. Icing the puck is the act of shooting the puck to the end line from beyond the center line; icing the puck results in a face-off near the penalized team's goal. Icing is often employed by a defensive team under heavy pressure in an effort to simply clear the puck out of a dangerous area. In order to deter teams from icing, the NHL decided that a team that ices the puck will be prevented from making a line change; or in other words, they must continue to use the same players already on the ice. The idea is that a team that ices the puck to avoid offensive pressure should not benefit from the infraction by being able to substitute fresh players into the game. In addition to this modification, the officials were given more discretion on when to call icing, adding a clause to the rule that an intended pass that unintentionally results in what otherwise would be called icing can be waved off by an official. This change should then result in fewer stoppages and better flow to the game.

For the sake of completeness, it is worth briefly mentioning that the league also established more formal policies and procedures for players who instigate fights, commit unsportsmanlike conduct, and feign injury or embellish a fall or reaction in effort to induce a penalty against the other team.

Finally, the NHL established procedures to determine a winner in a tie game by creating a shootout procedure. While this rule change does not affect the play of the game of hockey, it does affect how the winner of the game is ultimately decided by the NHL. After a five minute sudden-death overtime period, if the game is still tied, three shooters from each team participate in the shootout (skating one-on-one against the goalie). If the shootout is tied after those six shooters, it proceeds one shooter at a time from each team in a sudden-death format. This rule was likely created in an effort mainly to increase fan excitement at the end of games.

All of these rule changes have a similar goal in mind. After the lockout, the NHL wanted to create a "New NHL" and enter into a new era of professional hockey in North America that would appeal to its fans and create a more exciting game of hockey with more competitive games, fewer stoppages, more goals, and a clear winner at the end of the game.

1.3 Goals of this Paper

Clearly the new business structure and the rule changes of the league raise plenty of interesting economic questions. It is natural to consider how salaries are affected by both the salary cap and the rule changes; e.g., will certain types of players make more money under the new rules designed for faster and more skilled players? Other interesting questions include how attendance will be affected by the lockout, how team strategy and success will respond to the new rules, how league-wide revenues will change, how the value of franchises will change, and what will be the effect of the shootout on overtime games. While all of these issues certainly merit investigation, this paper seeks to examine the differences in the actual play of the game of hockey in the NHL between the pre-lockout and the post-lockout eras. Specifically, this paper asks whether the rule changes created a significantly different game of hockey (is the "New NHL" really new?), and whether the league accomplished its goal of "increasing the number and quality of scoring opportunities." To examine the difference in game play under both sets of rules, we estimate and compare the effect that various elements of play, such as shooting percentage, power play percentage, and face-off percentage, have on the probability of winning a game in each of the seasons. Next, using stochastic frontier models to estimate efficiency, the ability of teams to perform at or near their goal scoring potential will be measured under each set of rules, and again comparisons can be made between the two seasons.

1.4 Literature Review

Of the four major North American team sports, the academic literature surrounding the NHL is probably the sparsest, especially with regard to production efficiency. Typical studies concerning the NHL involve wage and employment discrimination of French Canadians (Lavoie et al., 1987; Lavoie, 2000; Longley, 2000; Kahane 2005; Curme and Daugherty, 2004), the role of violence and fighting in the NHL as it is related to employment (Jones et al., 1997), team incentives to win given rule changes concerning the overtime period (Abrevaya, 2004; Easton and Rockerbie, 2005), and studies on attendance with respect to violence and scoring (Paul, 2003).

All of these significant articles were published prior to the continuation of play after the lockout. This paper intends to be the first study examining the "New NHL." The ultimate goal is to model the relationship between team performance and the probability of winning using individual game data and the logit framework for both the season immediately preceding the lockout and the season immediately following the lockout. McGoldrick and Voeks (2005) applied a similar strategy to analyze differences in play between the WNBA and the NBA using a logit model and game-by-game data for each of the leagues. Indeed, they found significant differences between the leagues in how team performance in the basketball games affected the probability of winning.

Heyne et al. (2006) created one of the first production functions using NHL data for five pre-lockout NHL seasons. The study estimated the production of team points accumulated throughout the season based on various performance factors, including goals allowed, assists, shots, face-offs, and majors. The most interesting result of this study was that major penalties actually help teams win games. The logit model that will be used here to predict wins will contain many of the same explanatory variables as in the model employed in the Heyne et al. study. Of particular interest in the logit results will be the effect major penalties have on the probability of winning in the pre- and post-lockout seasons.

In addition to the construction of the appropriate logit models, this paper also intends to use simple stochastic frontier models to measure the efficiency of goal production in the NHL. Stochastic frontier models are very common, especially in the sports literature. Such models have been employed to analyze rugby (Carmichael and Thomas, 1995), basketball (Zak et al., 1979; McGoldrick and Voeks, 2005), football (Hofler and Payne, 1996), and soccer (Carmichael,et al., 2001). In this paper we will employ a simple stochastic frontier model for goal scoring using season long data in the NHL, most similar to the strategy employed by Zak et al.

While the statistical models to be employed in this paper are not new to the literature, the application to the NHL, particularly with respect to the post-lockout era, is novel. The logit model is used as an especially effective way to determine whether the game of hockey has significantly changed after the lockout. If the new business structure and the rule changes have affected the way the game of hockey is played in the NHL, we would expect certain performance factors to be more or less important in determining the probability of winning. For example, we might predict that home ice advantage is less valuable after the lockout since there is more parity in the league due to the salary cap. In response to the Heyne, et al. study, we will take special notice of the role of major penalties in this model. Further, using the stochastic frontier models to measure the efficiency of goal scoring in the "New NHL" as compared to the pre-lockout NHL is a fairly common strategy in the sports literature. It will allow us to determine if the league succeeded in its goal of allowing skill players to use their skill to increase the quality and number of scoring opportunities. In other words, we will be able to answer the question of whether goals are produced more efficiently under the new rules.

Chapter 2

Data

In order to make comparisons between the NHL pre- and post-lockout, we collected data for a number of recent NHL seasons. From the NHL.com website (the official website of the NHL), game-by-game data were collected for every team in the league for all NHL seasons from 2001-2002 until 2005-2006. The NHL publishes a number of statistical reports on its website for each game played in the NHL; these reports are sortable by team. By cross referencing the Game By Game, Penalties By Game, Penalty Shots, and RTSS Reports published on the NHL Web Site, a data set for all 1230 games for each season was created. The data for each game includes the date of the game, overtime/shootout status, home team, away team, attendance, and statistics for each team for goals scored, power play goals scored, penalty minutes, power play opportunities, major penalties, face-off percentage, and penalty shots. Beginning with the 2005-2006 season, the NHL decided to begin keeping track of a number of new statistics for each game, specifically takeaways, giveaways, hits, blocked shots, and missed shots. However, the NHL did not establish rigid guidelines for these statistics, and they are kept on location by a scorekeeper at each arena. As such, the numbers tend to vary between teams and arenas, making comparisons across games difficult. While it would be interesting to include these new statistics in the analysis presented here, because they are not available for pre-lockout seasons and because they are not uniform across teams, they will not be considered.

At the time the data was gathered only one season had been completed after the lockout (2005-2006). For the sake of symmetry, the methods of this paper will primarily be concerned with comparing the season immediately prior to the lockout (2003-2004) and the season immediately following the lockout (2005-2006). The data for the previous seasons (2001-2002 and 2002-2003) is offered with the intent of establishing a pattern for pre-lockout NHL game play. Because they are not necessary for the analysis and collection is time consuming, statistics for penalty shots, major penalties, and face-off percentage were not gathered for these two seasons.

In the following discussion we have used a significance level of 0.01 for all statistical tests. With a sample size of 1230, this relatively small significance level is necessary because at that sample size comparisons of means will often be statistically significant at higher significance levels without any practical significance simply due to the large sample size.

First, we examine the data for the 2001-2002, 2002-2003, and 2003-2004 seasons, the final three seasons prior to the lockout. The NHL imposed no significant rule changes during this time period and the league functioned under the previous collective bargaining agreement. We use these three seasons to characterize hockey under the old NHL rules, when the league freely allowed the use of certain "defensive tools" which have now been eliminated from the game. It is immediately apparent that there are clear patterns in the statistics across all three seasons.

Table 2.1 provides means and simple statistical tests for differences in mean for the NHL data collected over all four seasons. All of the statistics presented in this table are per game averages (not per team averages). As the table shows, the average number of goals per game was 5.24 in 2001-2002, 5.31 in 2002-2003, and 5.14 in 2003-2004. In a typical game over these three seasons, approximately 5.22 goals were scored. Using the F-test we find that there are no statistically significant differences between the average numbers of goals scored per game across these three pre-lockout seasons. There is no statistical evidence to suggest that goal scoring varied between these seasons. In practical terms, we would expect game scores like 3-2 to be very common in the pre-lockout NHL.

Just as with goals, the per game averages for power play goals, penalty minutes, power play opportunities, and shots are all very similar for these seasons. There were approximately

Table 2.1: Descriptive Statistics

	2005-2006		2003-2004		T-Test
Variable	*Mean*	*Std. Dev.*	*Mean*	*Std. Dev.*	*Difference*
Goals	6.0512	2.3567	5.1366	2.2328	9.8808*
Power Play Goals	2.0691	1.4626	1.3959	1.2230	12.3831*
Shots	59.9593	8.9302	56.1057	8.7656	10.8007*
Penalties in Minutes	31.6024	15.7846	29.2496	22.9314	2.9641*
Power Play Opp.	11.6992	3.4611	8.4772	2.9790	24.7444*
Penalty Shots	0.08374	0.2858	0.0463	0.2141	3.6728*
Major Penalties	0.7797	1.4030	1.3073	2.0534	7.4410*

	2002-2003		2001-2002		F-Test
Variable	*Mean*	*Std. Dev.*	*Mean*	*Std. Dev.*	*Difference*
Goals	5.307317	2.2297	5.237398	2.2041	1.8349
Power Play Goals	1.45122	1.2579	1.301626	1.1854	4.7092*
Shots	56.7252	8.2807	55.18049	8.7094	10.0785*
Penalties in Minutes	28.53252	19.6451	30.03171	23.2094	1.4304
Power Play Opp.	8.847154	3.1911	8.252033	2.9087	12.1069*

Note: F-Test statistic is a test for the difference in means between all pre-lockout seasons including 2003-2004, * Significant at 1% level

1.38 power play goals per game in the NHL during that time period. While there were a statistically significant higher average number of power play goals scored in 2002-2003 season than in the 2001-2002 season, in practical terms the difference of 0.15 power play goals per game between the seasons is not particularly large. Shots per game averaged around 56 during these three seasons. As with power play goals, there were statistically significant differences in average shots between the 2002-2003 season and the 2001-2002 season. With a mean difference of 1.54 shots per game, this difference is again not especially significant in practical terms since some 56 shots are taken in an average game. Regarding penalties, the three seasons are almost identical. Over the course of all three seasons, there was an average of 29.27 penalty minutes per game, with no significant differences in the averages between the seasons. These penalty minutes translated to approximately 8.52 power play opportunities per game during the same time span. While there were statistically significant differences in power play opportunities between these seasons (the 2002-2003 season had significantly more power plays than the other seasons), in practical terms the difference of less than 0.60 power plays per game is not significant. Overall, it is safe to say that in terms of offensive output (goals, power play goals, and shots) and penalties (penalty minutes and power play opportunities) that there are clear statistical patterns in the data that uniformly characterize pre-lockout hockey.

Because there are no major practical differences in the per game averages among the three seasons preceding the lockout, it is reasonable to use only the 2003-2004 season as the basis of comparison for the "New NHL" against the pre-lockout NHL. We use this season in the analysis because it is chronologically closest to the 2005-2006 season, which means there are most likely not differences between the two seasons due to factors that naturally change over time such as the talent of players in the league, different coaching or training strategies, and better equipment technology. While the previous statistical results are provided mainly to establish a pattern of results in the NHL under the old rules, here we conduct the more crucial statistical tests to detect differences in pre- and post-lockout game play.

As the table shows, there are significant statistical differences for all per-game averages that were measured, which suggests that the rule changes imposed by the league after the lockout significantly altered the way the game of hockey is played in the NHL. Goal scoring increased dramatically from 5.13 to 6.05 per game (an 18% increase); however, approximately 74% of this increase in goals can be attributed to the increase in power play goals. In fact, power play goals increased an even more remarkable amount in percentage terms from 1.39 to 2.07 per game, a 49% increase. Further, power play goals accounted for 34% of goals in 2005-2006, as compared to only 27% in the pre-lockout season. These results are not very surprising when taking into consideration the fact that power play opportunities also rose 38% from 8.47 to 11.69 per game. The data suggest that the NHL did indeed increase the number and quality of scoring chances (shooting percentage jumped from around 9%

before the lockout to just over 10% after the rule changes), but in some sense this increase is very artificial. By encouraging officials to call more penalties, particularly the hooking and holding penalties intended to reduce the use of "defensive tools," the league created a huge increase in power play opportunities (about 4000 over the course of the season). With a man advantage on the ice, teams on the power play would necessarily have higher quality scoring chances, and would thus score more goals. It is not immediately clear that in even-strength situations the scoring opportunities were better. However, goals not scored on the power play increased by about 0.24 goals per game, some evidence that the rule changes affected even-strength play as well. A statistical comparison of non-power play goals reveals a statistically significant difference in average non-power play goals scored per game between the pre- and post-lockout seasons. Even though much of the goal scoring increase comes on the power play, there are still significant differences in goals per game accounting for the increase in power play opportunities and goals. We should also point out that shots increased dramatically as well, from 56.11 to 59.96 per game. Again, a similar argument could be made that teams generate more shots on the power play than they otherwise would, and that this increase is largely due to the increase in power plays. Since power play shot data are not readily available, there is no way to statistically test this claim. Nonetheless, since every shot is a scoring opportunity, the rule changes clearly resulted in a significant increase in scoring chances.

Though they are less crucial for our analysis, we also consider the effect of the rule changes on penalty shots, penalty minutes, and major penalties. In the 2005-2006 season there were nearly twice as many penalty shots awarded than in 2003-2004. With more penalties, it is only natural that there will be more penalty shots. Hooking players on a breakaway is a common defensive strategy to try to save goals, since a breakaway is a better scoring opportunity than a power play. Because more hooking penalties are called in the "New NHL" there are also many more penalty shots. Finally, we consider the effects of the new rules on penalty minutes, specifically in regard to major penalties. In the "New NHL" there are far fewer major penalties, with 1608 majors in the 2003-2004 season and only 959 in the 2005-2006 season. A major penalty is typically the result of a fight, and all players involved in a fight are assessed with a major penalty. However, under the new rules with more severe penalties for instigators of fights, there are more incentives not to fight. Further, since the rule changes were intended to place more of an emphasis on using skill to win games, many teams replaced big, violent "enforcers" with smaller, faster skilled players who are less likely to fight. Hence, there have been far fewer fights under the new rules and thus fewer major penalties. Because there are fewer majors, which result in five penalty minutes, but many more minor penalties, which result in two penalty minutes, there was only a slight increase in penalty minutes after the lockout from 29.25 to 31.60 per game. There is also a much smaller variance in penalty minutes under the new rules since there are fewer fights. A fight typically adds ten minutes of penalty time (five for each player), which contributes greatly to the variance of average penalty minutes in a game especially considering that games tend to have either multiple fights or no fights at all.

The bottom line is that while the NHL did indeed succeed in increasing the number and quality of scoring chances in each game after the lockout, most of these increases can be accounted for by the large increase in power play opportunities. By more strictly enforcing certain penalties the league has artificially generated scoring chances by placing teams in power play situations more often. However, non-power play goals also increased by 0.24 goals per game (a statistically significant increase), and it is likely that much of this increase is due to the other changes, including a decrease in the size of goalie equipment, a faster pace of play, harsher penalties for icing the puck and delaying the game, and larger offensive zones.

Chapter 3

The Logit Model

3.1 Empirical Model

In order to model the differences in play in the "New NHL" we use the logit framework to estimate how team performance affects the probability of winning. There are, of course, other models available that we could similarly employ, notably the probit model. Here, we have chosen the logit model due to the simplicity of interpreting coefficients as log-odds ratios, the fact that the logit model tends to be used more frequently than the probit model, and the fact that the logit model has superior likelihood criterion scores when compared to the probit model.

We proceed with the logit model. However, as previously outlined, the NHL changed its process for determining a winner after the lockout. Under the old rules, if the game was tied after the overtime period it ended in a tie. Post-lockout games tied after overtime continue to a shootout which ultimately decides a winner for every game. The 2003-2004 season presents special problems for the logit model because a game can end in a loss, a tie, or a win, but we would like to consider the logit model of a binary response (win or loss only). If we wish to be able to compare the logit models for the two seasons, we must rectify the differences in how each season determines a winner.

We consider two possible solutions. First, under the assumption that two teams in a shootout have equal probability of winning regardless of inherent talent or prior game performance, we could simply randomly assign a winner (with each team having a 50% chance of being selected) to the games that ended in ties in the 2003-2004 season. Using this method, the new shootout rule is essentially simulated into the 2003-2004 season, which allows us to consider all 1230 games and imposes a parallel overtime and shootout structure on both seasons. However, this simulation creates data, which can be dangerous. If the coin flip assumption for the shootout is incorrect this method is probably not very good. In fact, the assumption almost certainly fails. Teams with more skilled players or excellent goalies are probably more likely to win a shootout, and teams that have performed better in a game are similarly more likely to win the shootout based on their superior skill on that day. On the other hand, players convert only about 33% of their shootout attempts. With only three shootout attempts per team, there will be a quite a bit of variation in shootout results, making the coin flip assumption seem fairly reasonable.

Another solution would be to consider only the games in both seasons which determine a winner in regulation time or overtime, and not those games that end in either a tie or a shootout. Like the alternative presented above, this method imposes a parallel process for determining a winner on both leagues. Rather than simulating data, however, this solution eliminates data but does not require us to make any assumptions about the play of NHL games. Unfortunately, this method limits the scope of our results to apply only to certain types of games (those that do not end in a tie or shootout). Rather than choose between either of these methods, results will be offered for the logit estimation using both of these techniques.

We have data for 1230 games for the last season before the lockout and the first season after. In order to model the probability of a team winning against various characteristics of play for that team, we must choose a team from each game whose performance we will consider. Rather than always modeling the performance of the away team (as do McGoldrick and Voeks), we randomly assign a number 0 or 1 (with equal probabilities) to the home team for each game, and we then model the performance of the home team if they are assigned 1 and the away team otherwise for that particular game. In this way, we can include a home/away indicator variable in the logit model which will allow for the estimation of the effect of playing at home on the probability of winning.

Having addressed these issues, we now proceed with the estimation of the logit model[1]. In particular, the relationship between winning and team performance can be expressed by the following latent variable model:

$$y_i^* = x_i\beta + \epsilon_i$$

$$y_i = 1[y_i^* > 0]$$

Then, the logit binary response model for the probability of winning is

$$P(y_i = 1|x_i) = \frac{e^{x_i\beta}}{1 + e^{x_i\beta}} .$$

Where $y_i = 1$ if the team wins in the ith game, β is the vector of parameters to be estimated, y^* is a latent variable for team performance, and x_i is a matrix of explanatory variables of team performance for the ith observation consisting of save percentage, shooting percentage, power play percentage, penalty kill percentage[2], major penalties, difference in penalty shots between the teams, difference in power play opportunities between the teams, and an indicator for playing at home.

3.2 Predictions

Save percentage is the percentage of times a shot on goal against the team does not result in a goal. Save percentage is both a measure of the performance of the goalie and the defense. A high save percentage indicates the of quality goalie saves as well as poor scoring chances for the opposition, which would suggest quality play from the defense. Shooting percentage, similarly, is the percentage of shots on goal for the team that result in goals. Likewise it is an indicator of both quality of scoring opportunities and the play of the opposing goalie. If

[1]See Wooldridge chapter 15 for detailed maximum likelihood estimation procedure for the logit model.

[2]For both power play percentage and penalty kill percentage, if a team has no power play opportunities, this value is undefined since these statistics are ratios. It is extremely rare that a team has no power play opportunities in a game, and in the few cases that it did occur, a team was assigned a power play percentage of 0 or a penalty kill percentage of 1. We have thus assumed that the failure to create a power play indicates the worst possible power play performance.

a team gets a number of good scoring chances, we would expect a high shooting percentage and higher likelihood of victory. Thus, both save percentage and shooting percentages are expected to have highly positive effects on the probability of winning.

Power play percentage is a measure of the efficiency of a team's power play opportunities; it is simply the number of power play goals per power play opportunity. Penalty kill percentage is the number of times a power play for the opposition does not result in a goal per power play opportunity allowed. A team that performs well on the power play typically generates goals, and a team that performs well on the penalty kill prevents goals against. Often times, excellent performance in these special teams situations can generate team chemistry, fan noise and support, and momentum that will improve results when play returns to even strength hockey. Clearly, power play percentage and penalty kill percentage are expected to have a positive effect in the model.

In the NHL play stops a number of times in a game; when penalties are assessed, the puck goes out of play, the puck is frozen, an infraction is committed, and the period begins. Play is always restarted with a face-off. Face-off percentage shows how often a team gains possession of the puck after play is resumed. Moreover, certain infractions (icing especially) and the goalie freezing the puck result in an offensive zone face-off in a dangerous area near the goal. The ability to win such face-offs is extremely important for both teams given the immediate threat on goal when the puck is dropped. Because possession of the puck, particularly near the goals, is necessary to score goals and prevents the opposition from scoring, face-off percentage should increase the probability of winning.

The difference in penalty shots is simply how many more penalty shots the team gets than its opposition. Because players typically convert on about 32% of penalty shots, a penalty shot is one of the best goal scoring opportunities in all of hockey. Though rare, we would expect penalty shots to contribute positively to the chances of winning. Similarly, power play opportunity difference measures how many more power play chances a team gets than the opposing team. Because power play opportunities provide a team with a one man advantage on the ice, they typically consist of one-sided play with the power play team dominating the possession of the puck and generation of scoring opportunities. Again, we would expect power play opportunities to have positive effects on wins in this logit model.

While the effects of all of these factors are fairly obvious, the impact of major penalties on the probability of winning is much more ambiguous. A major penalty is almost always issued for fighting and is typically assessed to both teams simultaneously, which means no power play opportunity results for either team. Teams that fight more often would likely incite fan support and energize their team. In turn, they may be more likely to win hockey games. Players can also receive non-offsetting major penalties for certain more violent infractions of the rules, which would result in an elongated power play chance for the opposition. These types of penalties would obviously reduce a team's odds of winning. While the Heyne et al. study found positive season long effects of major penalties on winning, it is not clear what the effects of majors on a single game will be. Because major penalties are usually given to both teams in equal numbers at the same time, the effects of majors in a single game is likely indistinguishable between the teams and thus it is expected that the majors variable is not significant in predicting the probability of winning, regardless of whether it contributes positively or negatively to the probability of winning.

3.3 Results

The results for the logit models for both seasons under both shootout correction techniques are shown in Table 3.1 and Table 3.2. We begin by noting that we could spend time trying to decide which of these techniques is superior for our model; however, this endeavor is unnecessary because both of our procedures reveal the same information about the play of hockey in the seasons under consideration. As shown in the tables, the parameter estimates generated using either technique are similar. It is worth briefly pointing out that when we estimate the same logit model for only the 2005-2006 games that ended in a shootout, the model is not significant predictor of the probability of winning (with a P-Value of 0.779

for the test of overall model significance). In other words, this shootout model provides no significant information about the likelihood of victory for games that end in a shootout. This result would then suggest that the coin flip assumption for the probability of a shootout victory is quite reasonable. For simplicity, the following discussion will refer to the model that simulates with a coin flip the shootout for tied games from the 2003-2004 season (Table 3.1); though, we can draw the same conclusions in the model that eliminates tied or shootout games from consideration. Also, note that we use a 10% level of significance[3] in comparing the seasons in this model. Further, when we refer to the partial or marginal effects of an input on the probability of winning (as in the following tables), this value is the expected change in the probability of winning due to a one unit change in the input value when all inputs are originally evaluated at their average value. For example, for the average game performance in 2005-2006, when save percentage falls by 10% we expect the probability of winning to fall by about 0.366. This result is plausible since a save percentage of 0.80 (0.10 less than the average save percentage of 0.90) is relatively poor and will result in a much smaller probability of winning. In fact in a typical NHL game when teams face approximately 30 shots, the difference between a save percentage of 0.90 and 0.80 is equivalent to the difference in allowing three goals and six goals. Obviously, a team allowing three additional goals is far less likely to win.

First, consider shooting percentage and save percentage. Both variables attain extreme levels of significance in both the 2003-2004 season and the 2005-2006 season. Clearly, greater shooting and save percentages increase the probability of winning. Because creating scoring chances and preventing the opponent from generating scoring opportunities are obviously crucial to winning, this result is not surprising. More notably, these variables have significantly larger coefficients in 2003-2004 than in 2005-2006. This result is likely due to the fact that prior to the rule changes scoring chances were more difficult to create. When the league

[3]Although we used a 1% level of significance for the comparison of means, here we use a 10% level because in the presence of shooting and save percentage (which are highly significant) the other variables are likely to be practically significant even at attained levels of statistical significance as high as 10%.

Table 3.1: Logit Model with shootout simulated for 2003-2004

2003-2004 Season				
Parameter	*Estimate*	*t-Stat*	*P-Value*	*Partial Effects*
Constant	-55.8423	-15.0902	≈ 0	-4.45701
Save Percent	52.8448	14.4509	≈ 0	4.21777
Shot Percent	48.6437	14.443	≈ 0	3.88246
Power Play Percent	0.810841	1.54412	0.123	0.064717
Penalty Kill Percent	-0.143916	-0.277252	0.782	-0.01149
Face-off Percent	6.05582	4.01388	≈ 0	0.48334
Major Penalties	-0.040203	-0.34671	0.729	-0.00321
Penalty Shot Diff.	0.408373	0.827871	0.408	0.032594
PP Opp. Diff.	0.131447	2.80224	0.005	0.010491
Home	0.520962	2.47778	0.013	0.04158
Pseudo R^2	0.69440			
Percent Correct	0.89268			
Log Likelihood	-315.75			
N	1230			

2005-2006 Season				
Parameter	*Estimate*	*t-Stat*	*P-Value*	*Partial Effects*
Constant	-36.1516	-15.2116	≈ 0	-3.9462
Save Percent	33.5645	13.7562	≈ 0	3.6638
Shot Percent	35.845	14.1216	≈ 0	3.91273
Power Play Percent	0.861001	1.55974	0.119	0.093984
Penalty Kill Percent	1.04648	1.77255	0.076	0.11423
Face-off Percent	2.46291	1.91283	0.056	0.26884
Major Penalties	-0.077223	-0.559098	0.576	-0.00843
Penalty Shot Diff.	0.653025	1.93097	0.053	0.071282
PP Opp. Diff.	0.175881	5.33101	≈ 0	0.019199
Home	0.308488	1.7455	0.081	0.033674
Pseudo R^2	0.59765			
Percent Correct	0.86504			
Log Likelihood	-422.77			
N	1230			

Table 3.2: Logit Model with tied and shootout games excluded

2003-2004 Season

Parameter	*Estimate*	*t-Stat*	*P-Value*	*Partial Effects*
Constant	-76.3877	-12.7366	≈ 0	-3.33094
Save Percent	72.431	12.2852	≈ 0	3.1584
Shot Percent	65.8062	12.3581	≈ 0	2.86953
Power Play Percent	1.15506	1.51168	0.131	0.050367
Penalty Kill Percent	0.262841	0.350172	0.726	0.011461
Face-off Percent	6.71608	3.20375	0.001	0.29286
Major Penalties	0.064299	0.376464	0.707	0.0028038
Penalty Shot Diff.	0.987873	1.32443	0.185	0.043077
PP Opp. Diff.	0.273431	3.85345	≈ 0	0.011923
Home	0.886894	2.84567	0.004	0.038674
Pseudo R^2	0.84196			
Percent Correct	0.94717			
Log Likelihood	-157.16			
N	1060			

2005-2006 Season

Parameter	*Estimate*	*t-Stat*	*P-Value*	*Partial Effects*
Constant	-43.0846	-14.2885	≈ 0	-3.57262
Save Percent	39.4273	13.0235	≈ 0	3.26935
Shot Percent	42.0535	13.3681	≈ 0	3.48712
Power Play Percent	0.803519	1.17987	0.238	0.066629
Penalty Kill Percent	1.07829	1.5015	0.133	0.089413
Face-off Percent	4.51028	2.84648	0.004	0.374
Major Penalties	-0.071588	-0.43475	0.664	-0.005936
Penalty Shot Diff.	1.30871	3.03217	0.002	0.10852
PP Opp. Diff.	0.22545	5.52726	≈ 0	0.018695
Home	0.324989	1.5053	0.132	0.026948
Pseudo R^2	0.72068			
Percent Correct	0.92166			
Log Likelihood	-292.83			
N	1085			

emphasized the enforcement of certain penalties in order to remove "defensive tools" from the game, scoring chances became less valuable because they came in much greater numbers. In essence, in the "New NHL" creating quality scoring chances is not as important as simply putting the puck on net. Alternatively, prior to the lockout, teams were forced to work hard to generate excellent chances on goal because any goal scoring opportunities at all were much harder to find. One could then argue that the rule changes have hurt the game in the sense that goal scoring now has more to do with the number of opportunities than the quality of those opportunities.

As discussed previously, the rule changes and the officiating points of emphasis on hooking and holding resulted in 4000 additional power play opportunities in 2005-2006. Not only were there more power plays in 2005-2006, but teams scored on a higher percentage of those power plays. In 2003-2004 teams converted on 15.42% of power plays as compared to a 16.60% success rate in 2005-2006. Therefore, it is not surprising that the logit models reveal striking dissimilarities in terms of special teams situations before and after the lockout. In both the pre- and post-lockout seasons power play opportunities difference has a significantly positive impact on the probability of winning. However, as the marginal effects show, in 2005-2006 for each additional power play earned, and for every one less power play allowed, the probability of winning rises by nearly 0.02 as opposed to only 0.01 in 2004-2005. Simply, a power play opportunity is worth twice as much in the "New NHL" toward the probability of winning. It is also of note that the parameter estimate for the power play opportunities difference coefficient is much larger in 2005-2006 than in 2003-2004, which would confirm the result that power play opportunities are more valuable in the "New NHL."

In addition to the differences in the contribution of the number of power play opportunities to the probability of winning, the performance in special teams situations also has a very different impact on winning between the two seasons. In fact, a likelihood ratio test of the joint significance of power play and penalty kill percentages in the logit model reveals that these variables are together significant in determining the probability of winning in the post-lockout season, but not in the pre-lockout season. While the power play percentage parameter estimates are fairly similar for both seasons, there are substantial differences for penalty kill percentage. Power play percentage is not significant in either model and the partial effects estimates are similar for both models, both are positive with 2005-2006 slightly higher at 0.093 as compared to 0.065. On the other hand, the pre-lockout model estimates the penalty kill percentage coefficient to actually be slightly negative, but with such a large standard error relative to the estimate, it is essentially zero. Comparatively, in 2005-2006 the penalty kill percentage is significantly positive. Such a wide difference in the impact of this variable on the model of the probability of winning reveals a large disparity in the importance of team performance in special teams situations. Before the lockout because fewer penalties were called in a typical game, a team could succeed without stellar performance in odd-man situations. In the post-lockout era the power play is such a big part of the game that quality performance has become much more important for team success in terms of both scoring on the power play and killing penalties. By imposing a stricter enforcement of specific penalties, the post-lockout NHL has made power play performance a significant factor for winning games.

Similar to special teams situations, the penalty shot has become more prevalent after the lockout. In 2003-2004 there were only 57 penalty shots, compared to 103 in 2005-2006. Since the penalty shot gives the offensive player a chance to skate one-on-one against the goalie, it comes as no surprise that in both seasons the penalty shot positively affects the probability of winning the game. Using the estimated marginal effects we find that in the post-lockout season a penalty shot increased a team's chances of winning by an estimated 7.1% compared to only 3.3% before the lockout. In addition, penalty shots are not a significant predictor of game outcome in the pre-lockout model, but they are in the post-lockout model with a higher estimated coefficient and a higher t-statistic. Since the pre-lockout season is characterized by fewer goals and fewer quality scoring chances, we would expect the penalty shot to be more of a game changing feature in that season, which would suggest a higher marginal effect on the probability of winning. A great chance of scoring is certainly more valuable to winning when there are fewer goals because that opportunity is more likely to be the difference in the game. This logic clearly contradicts the results obtained in the logit models. Because there were so few penalty shots in the 2003-2004 season (less than 1 every 20 games), there is likely too much variation in game outcomes which include penalty shots to measure the true importance of the penalty shot. When there are twice as many penalty shots in 2005-2006, the penalty shot becomes much more important to the probability of winning on the margin. In some sense, by calling more penalty shots, the penalty shot has become a significant part of the game in the "New NHL," whereas prior to the lockout the penalty shot was rare enough to not be an important factor in predicting the outcome of an individual game despite the fact that the penalty shot was likely more valuable prior to the lockout.

With respect to face-offs, the results of the logit estimation confirm our expectations. In both seasons face-off percentage is statistically significant and has a positive effect on the probability of winning. Although this initial finding is not surprising, there is a remarkable difference in the impact of face-off percentage on winning between the seasons. In the 2005-2006 model, face-off percentage is borderline significant. Using the estimated partial effects, a 0.10 increase in face-off percentage would only lead to a 0.027 increase in the probability of winning. The pre-lockout model predicts that the same 0.10 increase would lead to a 0.048 increase in the likelihood of victory, nearly double the effect in the post-lockout season. The coefficient estimate for face-off percentage in 2003-2004 is highly significant with a t-statistic more than double the same value in 2005-2006. Clearly, face-off percentage is much more important in both winning hockey games and predicting the probability of victory in the pre-lockout NHL. The rule changes in the post-lockout NHL were partially intended to increase the pace of play and reduce the number of stoppages. With faster play and fewer stoppages there are more changes of possession and fewer face-offs than there were in the pre-lockout era. With fewer face-offs, a higher face-off percentage is immediately less valuable. In addition, in the "New NHL" the puck changes hands much more often, meaning possession of the puck after the face-off is less valuable. With the more open style of play it is easier to regain possession. Further, in the pre-lockout NHL scoring chances were much harder to create. Winning a face-off in the offensive zone would then be crucial to retaining the puck in a dangerous territory and generating opportunities on goal; whereas under the new rules, scoring chances are abundant making the ability to win offensive zone face-offs less important. Overall, in the "New NHL" the value of winning face-offs has fallen dramatically but remains a significant predictor on the probability of winning games.

In all sports there is almost certainly a home arena advantage. Teams playing at home are more familiar with their surroundings and the playing surface, not to mention the emotional boost from the support of the fans, not having to travel, and the desire to protect the reputation of their arena. As expected, hockey is no different. For both the 2003-2004 and 2005-2006 seasons, playing at home significantly increases the probability of winning. It is not clear, however, that the value of home-ice advantage has changed after the lockout. Playing at home increased a team's probability of winning by approximately 0.042 prior to the lockout and 0.034 after the lockout, a difference between the seasons that is not significant. Factors that contribute to home-ice advantage such as travel fatigue, fan support[4], and knowledge of the ice surface do not change even though the rules change. So, while the other team performance factors tend to have either more or less importance on the game outcome after the lockout, the value of playing at home stays relatively constant.

Finally, major penalties were included in the model primarily as a chance to reconsider the conclusions of the Heyne et al. paper that found that major penalties had a significantly positive impact on season long performance. Specifically, the Heyne et al. study determined that there was a significant and positive relationship between season long point accumulation[5] and major penalties, suggesting that major penalties contribute positively to season long

[4]Unlike in Major League Baseball, attendance actually rose after the labor dispute, suggesting that fan support did not decline after the lockout and may have actually increased.

[5]In the NHL team standing is determined by points. A team earns two points for a victory and one point for a tie or overtime/shootout loss. In the New NHL, we note that there are no longer ties.

success. As expected, in both models considered here, major penalties are highly insignificant, with coefficients of essentially zero. This result would suggest that on a game-by-game basis, majors do not impact the probability of winning. Because majors are usually appropriated for fighting, and fighting penalties are typically assessed one-for-one to both teams, a major penalty provides very little differential information about team performance in a game. Over the course of the season however, especially in the pre-lockout era examined in the Heyne et al. study, a team that accumulates more majors would likely possess more physical players that would be well suited to the style of play in the NHL at that time, translating to team success. Unfortunately, in a single game an additional major penalty provides no information about the probability of winning.

3.4 Conclusions from the Logit Model

As the results of the logit models show, there are clearly significant differences in how team performance factors affect game outcome in the "New NHL" as compared to the pre-lockout NHL. In a typical post-lockout NHL hockey game, the quality of scoring chances is less important, power play numbers and efficiency are far more crucial, face-off percentage is less critical, and the penalty shot has become significant toward increasing the probability of victory. An NHL hockey game in the "New NHL" likely has fewer stoppages (unfortunately we do not have the data to confirm this hypothesis), and it certainly has more shots, goals, power play opportunities, and penalty shots. From a casual fan's perspective, the game is probably more attractive due to the faster pace and higher scoring games. However, the post-lockout NHL places a much greater emphasis on a team's special teams performance, at the expense of the importance of even strength play. A game riddled with penalties and power play goals may seem cheap and gimmicky to long time fans of the NHL. While it is unclear whether or not the game is more appealing from a fan's perspective after the lockout, there is no doubt that the league achieved its goal of revamping the play of hockey in the NHL, especially with regard to increasing the number and quality of scoring opportunities in a game; although, much of this increase is directly attributable to the substantial rise in power play chances.

Chapter 4

Stochastic Frontier Model

4.1 Empirical Model

While the previous discussion was concerned with detecting differences in play between the two NHL seasons, we would now like to determine if teams produce goals more efficiently in the "New NHL." If the league has created rules in an effort to "allow skill players to use their skill" in order to create more and better goal scoring opportunities, we would expect the post-lockout NHL teams to produce goals more efficiently than in 2003-2004. A stochastic frontier model for the goal scoring production estimates the maximum possible goal scoring output using the frontier estimate and calculates an efficiency score based on each teams' shortfall in actual goal output from its frontier output. A high efficiency score suggests that a team operates near its production frontier for goals given the inputs in the model.

In the construction of this stochastic frontier model for goal scoring output, we have aggregated the game-by-game data for each team to find season long totals for the 2003-2004 and 2005-2006 seasons. For each season, the data set we will consider in this model consist of 30 observations (or teams) with season totals for all of the data originally collected on a game-by-game basis, including goals, power play goals, power play opportunities, penalty minutes, majors, face-off percentage, and penalty shots for each team.

To estimate technical efficiency we use the stochastic frontier production function formulated by Aigner, Lovell, and Schmidt (1977) with the efficiency estimates for each observation calculated according to the results of Jondrow et al. (1982). The model is constructed as follows.

$$(1) \quad y_i = x_i\beta + e_i$$

$$(2) \quad e_i = v_i - u_i$$

$$(3) \quad v_i \sim N(0, \sigma_v^2), u_i \sim |N(0, \sigma_u^2)|$$

$$(4a) \quad \sigma^2 = \sigma_u^2 + \sigma_v^2, \lambda = \sigma_u / \sigma_v$$

$$(4b) \quad E(u|\ e) = \frac{\sigma\lambda}{1+\lambda^2}\left[\frac{\phi(e\lambda/\sigma)}{1-\Phi(e\lambda/\sigma)} - \frac{e\lambda}{\sigma}\right]$$

Equation (1) is the production function, with all variables in the model transformed to their natural logs. y is the season total for goals, which is what the teams are producing in this model. β is the vector of parameters to be estimated, and e is a composite error term. In addition, x is a vector of inputs in the production function. In this model, x includes shooting percentage, power play percentage, face-off percentage, and power play opportunities. These factors provide an excellent, though not exhaustive, picture of how teams in the NHL generate goals. They give an idea of the quality of the team's scoring chances, power play efficiency, possession of the puck, and the number of power plays. All of these factors should positively contribute to the production of goals in the NHL.

The crucial assumption of the stochastic frontier model is the decomposition of the error term in the production function into two independent components, as shown in equation (2). v_i is a two-sided error that represents the typical statistical randomness present in any relationship, and u_i is a one sided error term that represents the technical inefficiency on the part of the teams in producing goals[1]. The distributions of u and v are shown in equation (3). The production efficiency of a team is then determined by $y_i/(x_i\beta + v_i)$, which is the percentage of potential output that the team actually generates in the season. u_i then is a measure of the shortfall of output from its frontier. In Equation (4), ϕ and Φ are the standard normal density and cumulative distribution function respectively. Equation (4) allows for the decomposition of e_i into u_i and v_i for each observation, in particular the estimate of u_i provides an estimate of inefficiency in goal production for each individual team. The model also gives information about the average efficiency across all teams, and statistical tests can

[1]Other distributional assumptions can be made about u_i, here we have chosen the half-normal distribution for convenience.

be conducted for the presence of league-wide inefficiencies for each season. Ultimately, we would like to determine whether teams are more efficient in producing goals in the "New NHL" than in the pre-lockout NHL.

4.2 Results

The results of the stochastic frontier estimation, using maximum likelihood, for both seasons are shown in Table 4.1. The first and most interesting result is the test for the presence of inefficiency in the models. According to Coelli (1996), the likelihood ratio test for the presence of the one-sided error term, u_i, in this model takes on a mixed chi-square distribution with one degree of freedom. From Kodde and Palm (1986), the critical value for a significance level of 0.05 for the mixed chi-square statistic with one degree of freedom is 2.706. If the one-sided error term is insignificant, the model reduces to the standard OLS model with no deviation from the frontier level of output. Simply, if the null hypothesis of the test is not rejected, then there is not significant statistical evidence to suggest that goals are produced inefficiently in the NHL for the season under consideration. As shown in the table, for the 2005-2006 model the likelihood ratio test statistic is 0.041. In the 2003-2004 model the test statistic is 9.815. Thus, in 2005-2006 we fail to reject the null hypothesis and conclude that there is no significant evidence of league-wide inefficiencies in goal scoring. For the 2003-2004 season, on the other hand, the test statistic exceeds the critical value and we do reject the null hypothesis and conclude that the stochastic frontier model specified is appropriate and that there is a league-wide failure to achieve maximal goal output. Thus, goals were produced inefficiently prior to the lockout, but, due to the rule changes, teams in the "New NHL" produce goals efficiently. Of course, this result is not surprising since the new rules were implemented by the league with the specific intent of making goal scoring more efficient by giving skilled players more and better chances to score. This finding does, however, show that the league achieved its main objective in modifying the rules of the game.

Table 4.1: Stochastic Frontier Model for Production of Goals

	2003-2004 Season		2005-2006 Season	
	Coefficient	t-Statistic	Coefficient	t-Statistic
Constant	8.84630	14.97410	10.27089	6.54179
Shooting Percentage	0.98897	30.01165	1.01205	4.93513
Power Play Percentage	0.12831	8.78500	0.13597	1.12677
Face-off Percentage	0.57033	3.22650	0.61392	1.40184
Power Play Opportunities	-0.07541	-1.12836	-0.28117	-1.66286
σ^2	0.00642		0.00413	
λ	0.99101		0.60300	
LR Test (one-sided error)	9.81558		0.04149	

While the likelihood ratio test suggests that the OLS model is superior for the 2005-2006 season, for the sake of comparison we proceed with our consideration of the stochastic frontier models for both seasons. Interestingly, the parameters estimated for the pre-lockout season are extremely close to those for the post-lockout season. In fact there are no significant differences between any of the parameters in the separate models. However, this statistical test is certainly limited by the small sample size of only 30 teams in the models. The similarities of the estimates provide some evidence that the production of goals on a season long basis may not have changed much. Teams that over the course of the season have high quality scoring opportunities, strong power play production, and good puck possession will score goals, regardless of the rules of the league. However, on a game-by-game basis, as our logit model showed for predicting game outcomes, there are significant differences in how team performance affects the final score of the game. We know that the "New NHL" is more efficient in producing goals. Thus, a team that performs equally as well in 2005-2006 as in 2003-2004, will score more goals ceteris paribus, even though the production functions for both seasons are quite similar.

From the stochastic frontier models, efficiency scores are estimated for each team in both seasons, with an efficiency score closer to one indicating a higher level efficiency as a team comes closer to achieving its maximum goal scoring output. These efficiency scores and rankings are shown in Table 4.2, along with actual and potential output rankings. While the average efficiency in each league is similar, 0.939 in 2003-2004 and 0.961 in 2005-2006, we have already shown that the pre-lockout season was less efficient in producing goals than the post-lockout season. Consider the maximum and minimum efficiency scores for each season. For the 2003-2004 season, Tampa Bay (who won the Stanley Cup) had the highest efficiency score of 0.995 and Washington had the lowest at 0.787. For the 2005-2006 season the maximum efficiency belonged to Ottawa at 0.986, and the lowest was Minnesota with a score of 0.917. In the 2003-2004 season there were five teams with higher efficiency scores than Ottawa's the following season, but there were eight teams in 2003-2004 with scores lower than Minnesota's in the post-lockout season. Clearly, in the pre-lockout season there is a much wider gap in efficiency scores. For the 2003-2004 season, there are several teams which were remarkably efficient (Tampa Bay, Ottawa, New Jersey) but many more that were surprisingly inefficient (Washington, Pittsburgh, Minnesota, Toronto, Dallas, St. Louis, Montreal). In the "New NHL," the rule changes have allowed all teams to produce goals more efficiently. In fact, there were no teams with an efficiency score less than 0.900 in the 2005-2006 season, while there were eight such teams the previous season. Even though the rule changes have brought efficiency scores closer together, output and potential output gaps between the best and worst teams were both much wider in the "New NHL" than they were the previous season.

The ultimate goal for the teams in the NHL is to win the Stanley Cup playoffs. 16 of 30 teams qualify for the playoffs, with eight teams representing each conference. Strangely, there is little relationship between efficiency score and playoff participation. In 2003-2004, only five teams that made the playoffs were in the top third of the league in efficiency; six were in the middle third, and the remaining five were in the lower third. The breakdown was

Table 4.2: Team Efficiency and Output Ranks

	2003-2004 NHL Season Goals (Rank)			2005-2006 NHL Season Goals (Rank)		
Team	*Efficiency*	*Output*	*Potential*	*Efficiency*	*Output*	*Potential*
ANA	0.91954 (22)	184 (28)	200.26 (26)	0.97503 (8)	254 (15)	251.45 (20)
ATL	0.93308 (19)	214 (13)	229.50 (14)	0.9755 (6)	281 (5)	275.83 (8)
BOS	0.98710 (5)	209 (15)	211.57 (23)	0.96036 (20)	230 (25)	240.39 (23)
BUF	0.94621 (18)	220 (10)	232.63 (10)	0.96431 (16)	281 (5)	287.69 (4)
CAR	0.98547 (6)	172 (30)	174.47 (30)	0.97587 (5)	294 (3)	285.37 (6)
CBJ	0.97842 (8)	177 (29)	180.94 (29)	0.93662 (27)	223 (27)	239.21 (25)
CGY	0.92257 (21)	200 (19)	216.95 (19)	0.93136 (28)	218 (28)	242.81 (22)
CHI	0.98926 (4)	188 (23)	189.75 (28)	0.97440 (10)	211 (29)	209.98 (29)
COL	0.96410 (12)	236 (6)	244.88 (5)	0.9690 (14)	283 (4)	287.38 (5)
DAL	0.88266 (26)	194 (20)	220.05 (17)	0.94739 (23)	265 (9)	275.27 (9)
DET	0.95399 (15)	255 (2)	267.42 (2)	0.97804 (4)	305 (2)	296.99 (1)
EDM	0.96779 (10)	221 (9)	228.43 (15)	0.94703 (24)	256 (13)	271.13 (10)
FLA	0.96021 (13)	188 (23)	195.87 (27)	0.98102 (2)	240 (22)	228.67 (27)
LAK	0.96658 (11)	205 (18)	212.16 (22)	0.97520 (7)	249 (17)	243.24 (21)
MIN	0.85844 (28)	188 (23)	219.31 (18)	0.91727 (30)	231 (24)	260.89 (15)
MTL	0.89781 (24)	208 (16)	231.91 (11)	0.96215 (18)	243 (20)	252.82 (19)
NJD	0.99022 (3)	213 (14)	214.67 (20)	0.94673 (25)	242 (21)	253.87 (18)
NSH	0.93224 (20)	216 (12)	231.85 (12)	0.93734 (26)	259 (10)	281.09 (7)
NYI	0.95374 (16)	237 (5)	248.61 (4)	0.96954 (13)	230 (25)	226.41 (28)
NYR	0.98118 (7)	206 (17)	209.96 (24)	0.96324 (17)	257 (11)	261.43 (13)
OTT	0.99152 (2)	262 (1)	263.46 (3)	0.98614 (1)	314 (1)	289.30 (2)
PHI	0.94656 (17)	229 (8)	242.06 (7)	0.97097 (12)	267 (7)	268.00 (11)
PHX	0.91623 (23)	188 (23)	205.36 (25)	0.95937 (21)	246 (18)	255.83 (17)
PIT	0.84725 (29)	190 (22)	224.60 (16)	0.95840 (22)	244 (19)	257.55 (16)
SJS	0.95454 (14)	219 (11)	229.53 (13)	0.97466 (9)	266 (8)	265.92 (12)
STL	0.89599 (25)	191 (21)	213.39 (21)	0.96081 (19)	197 (30)	203.23 (30)
TBL	0.99534 (1)	245 (3)	243.91 (6)	0.97971 (3)	252 (16)	240.38 (24)
TOR	0.88161 (27)	242 (4)	274.82 (1)	0.92498 (29)	257 (11)	289.01 (3)
VAN	0.97644 (9)	235 (7)	240.73 (8)	0.96596 (15)	256 (13)	261.32 (14)
WSH	0.78698 (30)	186 (27)	236.87 (9)	0.97122 (11)	237 (23)	234.15 (26)
Avg.	0.93877	210.6	224.53	0.96132	252.9	257.89

essentially the same in 2005-2006. Further, regular season efficiency scores do not seem to be a good indicator of playoff success. The efficiency rankings for the Stanley Cup semi-finalists were 1, 14, 17, and 21 in the pre-lockout season, and 5, 8, 16, and 24 in the post-lockout season. We should note that the most efficient goal scoring team ultimately won the Stanley Cup in 2003-2004.

Efficiency is certainly important for a team's success; every team would like to get the most out of its goal scoring potential. Perhaps a more telling measure of the overall quality of the team, however, is the potential goal scoring output. The potential output is determined using the estimated frontier production function along with a team's actual input data from the season. Potential output is then a measure of the inherent goal scoring ability of a team and a prediction of the number of goals a team would produce in the absence of inefficiency and randomness[2]. Not surprisingly, there is a strong relationship between goal scoring potential and playoff participation. In both seasons, 11 of the top 13 teams in terms of potential qualified for the playoffs. Unfortunately, there does not seem to be a correlation between regular season potential and playoff performance. This result is likely due to the fact that the style of play seems to change dramatically in the playoffs. Playoff games tend to be more physical and grinding affairs, meaning goal scoring is probably less valuable. A team that just scores goals will have trouble succeeding in a grueling playoff atmosphere that requires victory in four best of seven series. Obviously, these comments are merely speculation, and it would be another interesting study to statistically consider the goal scoring efficiency of teams in the playoffs, rather than in the regular season, and its relationship to success.

In general, individual teams tend to have similar efficiency scores in both seasons, though most teams show some minor improvement in efficiency in 2005-2006. Several teams exhibit remarkable efficiency across both seasons. Notably, Ottawa, Tampa Bay, and Carolina were

[2]Since potential output is a measure of a team's inherent goal scoring ability there are several cases in which teams' actual output exceeds potential output due to random effects accounted for in the v term. It is more common, however, for a teams' output to fall short of potential output due to inefficiency accounted for in the u term.

in the top six of efficiency in both seasons. The teams that had the largest gains in efficiency scores were Pittsburgh and Washington. Washington's efficiency score improved incredibly from 0.787 to 0.971. Pittsburgh's efficiency also jumped more than 0.1 from 0.847 in 2003-2004. As any fan of the NHL knows, both of these teams made huge additions to personnel following the 2003-2004 season. The 2005-2006 season was the rookie campaign for Alexander Ovechkin and Sidney Crosby, who are widely regarded as the best two players in the league. Ovechkin, a true goal scorer, joined Washington and scored 52 goals along with 54 assists (third in the league for both goals and points) in his rookie year. Crosby chipped in 39 goals and 63 assists (sixth in points) for Pittsburgh. Without a doubt, these players made immediate impact for their teams, contributing to the substantial increases in goal scoring efficiency and helping the teams reach their goal scoring potential.

It is also worth noting that there are instances in both seasons when teams with high efficiency scores have low output, and teams with low efficiency scores have high output. As a general rule, though, teams with good efficiency scores tend to have high levels of output. In 2003-2004 Chicago, Carolina, New York (Rangers), and Columbus were all in the top ten in terms of efficiency and the bottom half of the league in terms of output. Carolina, in particular had an efficiency score of 0.985 (sixth highest), but the lowest output of all 30 teams, suggesting that Carolina was especially poor in terms of scoring. Amazingly, in the next season of play, Carolina increased its goal scoring output by 122 goals, again placing near the top of the league in efficiency, and went on to win the Stanley Cup. Likewise, Florida, Tampa Bay, Los Angeles, and Anaheim were near the top in efficiency but finished in the bottom half of output in the 2005-2006 season. Philadelphia, New York (Islanders), and Dallas on the other hand were in the top ten for output in 2003-2004, but the bottom half of efficiency. The same was true for Buffalo, Dallas, and Nashville in 2005-2006.

Overall, teams in the NHL produce goals very efficiently. Despite statistically significant inefficiencies in the pre-lockout season, the average efficiency score among the teams was still 0.939. The following season, there was no significant evidence of league-wide inefficiencies, and the average score rose to 0.961. It should not be surprising that NHL teams score goals in an efficient manner. The Stanley Cup has been awarded since 1920 and no team has been in the league for fewer than seven seasons. Hockey is much the same sport today as it was decades ago, and if teams were producing goals inefficiently, strategies and personnel decisions would likely evolve and mature over time to reach efficiency. The new rule changes imposed after the lockout succeeded in making NHL goal scoring more efficient, but the increases are only moderate for the NHL as a whole. However, several teams that were especially inefficient in 2003-2004 made large efficiency gains in the "New NHL," bringing all of the teams closer together in terms of efficiency. Because teams produced goals significantly more efficiently in 2005-2006 than in 2003-2004, we can say that the NHL achieved its objective of increasing the number and quality of goal scoring opportunities after the lockout leading to the increase in efficiency.

Chapter 5

Conclusions

This paper is the first study of the "New NHL." The main conclusion we can draw from our results is that the "New NHL," the result of a new collective bargaining agreement and a revamped rule book, really is new. The descriptive statistics and the results of our logit model confirm that there is a statistically significant difference in NHL game play after the lockout. Simple t-Tests confirm that in the first post-lockout season there were substantial increases in goal scoring (both even strength and power play) and shots. With respect to penalties, there were also increases in power plays, penalty minutes, and penalty shots.

In the logit model, the parameter estimates were as expected. Shooting and save percentage were the most important factors in determining the winner of a game in both leagues. However, in the "New NHL," performance in special teams situations had significant impact on game outcome, which was not the case for the 2003-2004 season. In both seasons face-offs, penalty shots, power play opportunities, and home ice advantage contributed positively to the probability of winning, but with different magnitudes, further exhibiting the differences in play before and after the lockout. The ability to win face-offs in particular has become far less valuable in the "New NHL." Not surprisingly, major penalties exhibited no significant effect on outcome in either season.

Clearly, the "New NHL" is a very different game. The pace of play is faster and more goals are scored. While the NHL achieved its goal of increasing "the number and quality of scoring opportunities," most of the increase can be attributed to the power play. There are many more penalties and much of the game is now played in odd-man situations. The primary difference between pre- and post-lockout NHL play is the importance of special teams performance in the post-lockout season. By placing an emphasis on producing power play goals and killing penalties, even strength play has necessarily become less important. Even though many fans enjoy high scoring games, the power play is a one-sided onslaught on goal that hockey purists would probably find boring and lacking in strategic play. If the beauty of hockey comes from teams skating 5-on-5 up and down the ice, then the “New NHL” is not necessarily an improvement. While we leave these value judgments to the fans, the players, and the league, there is no denying that the power play has become a significant part of the game of hockey in the post-lockout NHL.

The stochastic frontier model for the production of goals in the NHL revealed further differences in play between the two seasons under consideration. Because teams in the NHL produced goals more efficiently in 2005-2006 than in 2003-2004 we can say that the NHL achieved its goal of increasing the quality of scoring chances. Given the same inputs, a team in the “New NHL” would produce more goals than its pre-lockout counterpart. We also know that the rule changes increased the number of scoring chances as evidenced by the significant increase in shots on goal per game. Interestingly, the teams that made the largest efficiency gains were the teams that made the most significant personnel additions after the lockout. Washington and Pittsburgh each acquired a future NHL legend in Ovechkin and Crosby respectively and went on to post large increases in efficiency. While the efficiency scores gave little indication of playoff success, potential output provides us with a good measure of the inherent goal scoring ability of the teams, which was highly correlated with playoff qualification and playoff wins.

This study is admittedly somewhat limited by the fact that there has only been one full season of play after the lockout. Though certainly not premature, this article would benefit from additional data. It would be interesting to examine the trends in goal scoring and penalties over time in the “New NHL.” As players adjust to the new style of play and new rules it is possible that the number of power plays in a season will return to their original levels and goal scoring will decrease along with it. Future studies considering the auxiliary statistics created after the lockout (hits, blocked shots, missed shots, takeaways, giveaways) would also be a worthwhile endeavor. Of course the business aspect of the lockout raises a number of research questions that should be considered in the future. Intriguing topics that merit study include post-lockout attendance, violence, discrimination, personnel decisions, and the impact of the shootout on game results.

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