Identifying Changes in the Spatial Distribution of Crime: Evidence from a Referee Experiment in The National Football League.

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Abstract

Between the 2009-10 and 2010-11 seasons, the National Football League (NFL) repositioned one of its officials in order to prevent injuries amongst officials. This creates a quasi-experiment for studying how a change in the extent of policing affects detection of offences. Using play by play data from the 2009-10 and 2010-11 NFL season, I estimate how the detection of offensive holding changes when the positioning of an official changes. I find that there is approximately a 20 percent increase in the number of offensive holding penalties called after the NFL repositioned the official. Penalties called on defensive lineman fell as a result of the repositioning. Overall, there was no change in the total number of penalties called. Using the estimated change in the probability of a penalty, I estimate of the probability of an official calling a penalty. I infer that NFL officials detect approximately 60 percent of crimes committed on the field.

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1 Introduction

Becker's (1968) model of the rational criminal makes a strong prediction that when the probability of detection increases, crime should fall. However, there are multiple components to this change, the first is that criminals alter their behavior, while simultaneously, the number of wrongful arrests decreases, and the number of crimes per capita detected increases. Furthermore, numerous authors have suggested that it is difficult to determine if crime rates are reduced because of increased incarceration of the at risk individuals, or because of increases in police patrols. These multiple effects make the theory difficult to test empirically. This has led several authors to the quasi experimental nature of sports.

Frequent rule changes in athletic competition provide a source of exogenous variation to identify the effects of a changing police force, ie, officiating crew. This paper will most closely follow the methodology of McCormick and Tollison (1984), henceforth MT, Levitt (2002), and Heckelman and Yates (2003) using changes in officiating of high stakes athletic competitions to determine the effects of policing effort on crime. These papers focus on changes in the number of penalties per game when an additional referee is added to a game. The results from these papers are mixed. MT (1984) find that when an additional referee was added to Atlantic Coast Conference basketball games that the number of fouls called per game fell. Levitt (2002) and Heckelman and Yates (2003) both examine a referee experiment in the NHL and find that there is a slight increase in the number of penalties called per game.

These mixed results likely stem from the fact that the sports examined are different, ie, the incentives of committing a penalty in basketball are different than in hockey, thus the effect of an additional referee is different. These papers have also been limited by the nature of the sports they examine, which are fluid and do not allow the authors to control for the value of committing a penalty/foul at

a specific point during a game. Furthermore, these previous papers have not been able to determine if the observed change in penalties is due to increased ability to detect penalties by officials or if players alter their behavior in response to increased policing. This paper contributes to the literature by offering a situation where the number of referees is fixed, situational factors can be taken into account, and I can test to see if player behavior changes in response to the change in referee position. Combined these factors allow me to plausibly identify the detection effect.

In this paper I examine the effects of a National Football League (NFL) referee experiment that occurred between the 2009-10 and 2010-11 seasons. Between these two seasons, the NFL repositioned one official from the middle of the defense to behind the offense to protect the official from injury. Previously, the official was positioned in the portion of the field with the most activity, making him susceptible to injury. By repositioning the official, some players experience a decrease in their localized police force, while others experienced an increase. Offensive lineman and defensive lineman were particularly impacted by the repositioning.

Using a rich play by play data set from the 2009-10 and 2010-11 NFL seasons I examine changes in the distribution of penalty rates resulting from the repositioned official. My baseline empirical results show that when repositioning the official, offensive holding penalties increased while defense holding on run plays decreased, and the total number of penalties remained unchanged. In practice, this observed change in offensive holding rates could be due to several factors: (i) players could change their behavior in response to the repositioning of the official, (ii) referees could be detecting different penalties than they did previously, and (iii), the likelihood of a referee calling a penalty could change. I believe that the observed increase is due to the second factor, the referees observe a different set of penalties being committed. As I will describe below, there is empirical evidence that penalty rates did not change throughout the season, which might have been expected to occur if

players sought to adjust their behavior to the repositioning, and were learning how to do this throughout the season. Given this evidence, it is unlikely that offensive players changed their behavior in response to the repositioning. Additionally, there is empirical evidence that referee crews did not have significantly different overall penalty rates following repositioning. This leaves the change in detection as the primary channel of causality for the observed increase in offensive holding and decline in defensive holding.

In the empirical specifications, I am able to control for a variety of play specific characteristics. At the beginning of every play I am able to account for the positioning of the referee crew and several features of the play such as the play selection (run or pass), the down, the distance to first down, quarter of the game, field position, the score differential, team fixed effects, rivalry fixed effects, week of the season fixed effects, and referee crew fixed effects.

The results from reduced form regressions, controlling for a variety of play specific features, suggest that there was a large distributional change in the types of penalties called following the repositioning. Offensive holding increased by 20 percent, while defensive holding decreased by an almost equal and offsetting magnitude. Robustness checks show that this effect was persistent throughout the entire season which suggests that players did not alter their behavior after potentially becoming aware of the effects of official repositioning. Using the point estimates, it is possible to back out the underlying probability that officials detect crime on the field. I infer that officials detect approximately 60 percent of all penalties committed during game play.

2 Model of Crime

For any given individual, the decision to commit a crime is assumed to be rational. In football, committing a crime has an expected value of improving the outcome of a play, either in terms of the change in the expected yards per play, or the change in the expected win probability, defined as $E(Y_c)$. The expected marginal cost of crime, c, is most simply defined in terms of penalty yardage, or alternatively as a function of penalty yardage and other pre play observable characteristics, which yields a known value for any penalty prior to the snap.[1] A rational criminal will only commit the crime if the expected marginal benefits outweigh the expected marginal cost.

I assume that each official on the field has has a homogeneous probability of detection p_c. Under this assumption, with n officials, the probability of detection is one minus the probability that all the officials do not observe the penalty, $[1-(1-p_c)^n]$.[2] Thus, the expected marginal benefit would be defined as the change in the expected win probability, multiplied by the probability that detection does not occur, $E(Y_c)(1-p_c)^n$. The marginal cost is similarly defined as the cost multiplied by the probability of detection, $c[1-(1-p_c)^n]$. The rational criminal equates the expected marginal benefit and the expected marginal cost and will commit a crime if and only if the expected marginal benefit is greater than or equal to the expected marginal cost.

When officials are repositioned, it leads to an increase in the local police force. If one official is moved into a player's area, the marginal increase in detection for that player is $p_c(1-p_c)^{n-1}$. Implicitly this assumes that referee behavior is not changed due to repositioning, which will be tested below. Recent research has shown that referees in athletic contests may have behavioral biases towards players which would

[1] Some penalties in the NFL, such as Pass Interference, are spot fouls, however, if a player is able to determine their positioning on the field in relation to the line of scrimmage, they can determine the magnitude of the penalty.

[2] Note that because each official has a unique probability of detection, east officiating crew will have its own probability of detection, but this is fixed for all plays within a game.

impact the decision of whether or not to call a penalty.[3] While these biases are not directly incorporated into the model, as long as these biases do not depend on the referee's placement on the field or vary from play to play within a game, the estimates presented in the empirical section will not be affected.

Given the increase in detection outlined above, economic theory would suggest that criminals would respond by investing effort in detection avoidance. In previous work, it has been difficult to disentangle the detection and avoidance effects, making it difficult to determine if increasing the police presence has a positive or negative effect. In this setting it is possible to rule out changes in player behavior as follows. Suppose players could invest in new approaches to deterrence following the rule change, ie practicing how to not get caught holding during the season. If they make these investments, then one might expect to see lower offensive holding rates in the later portion of the season as those investments begin to payoff. Therefore, I can test to see if weekly offensive holding calls are decreasing throughout the season.[4] The empirical results show that the offensive holding rates do not fall over time. This suggests that any change in offensive holding must then be attributable to the detection effect rather than player avoidance.

3 The NFL's and its Referee Adjustment

American football is a very complex game, but the basics are as follows, each team has eleven players on the field for each play. Each team has a designated scoring zone, which if reached by the opponent, is valued at six points. Teams can also score by kicking the ball through their opponents set of vertical posts, which is valued at three points, drop kicking the ball through the uprights, which is worth two points,

[3]For example, see Price and Wolfers "Racial Discrimination Among NBA Referees" Quarterly Journal of Economics 2010.

[4]If players can instantaneously change their behavior at the beginning of the season then my estimates represent a lower bound of the true detection effect.

or by forcing their opponent to be downed or penalized in their own scoring zone, which is also worth two points. The game is divided into four fifteen minute quarters. Whoever has more points at the end of regulation play is the winner. If the score is tied, the game proceeds to a sudden death overtime period, lasting up to but not exceeding fifteen minutes. If the game is tied at the end of the overtime period the game ends in a draw.[5]

The rules dictating the basic structure described above are incredibly complex. As such there are seven primary officiating jobs, each with a specific position and responsibilities during game play. These officials can briefly be described as the Referee, Umpire, Head Linesman, Line, Side, Back, and Field Judges.[6] Up until the 2010-11 season, the Umpire was located in the middle of play, just behind the linebackers, over the offensive center. Due to safety concerns, this official was moved, positioned 10-12 yards behind the line of scrimmage, deeper than the deepest offensive back. There are some instances where the referee is in the old position, these are when there are less than two minutes in the first half, less than five minutes in the second half, and when a team is positioned inside their opponents five yard line. This adjustment was made following a preseason game when Peyton Manning of the Indianapolis Colts complained about the positioning in some "hurry-up" scenarios. There was no change in the responsibilities assigned to this official. This creates a quasi experimental setting to study the effects of increased policing and the effects of repositioning a fixed policing asset.

As a result of this rule change, some players on the field experienced an increase in policing. Offensive lineman in particular are likely to be impacted by this rule because they have another official behind them. To explore this relationship, penalties that are frequently committed by offensive lineman are of interest. These penalties are

[5]In the 2010-11 Playoffs, overtime rules were changed so that the game could not be ended on a first field goal.

[6]For a complete description of official responsibilities consult the NFL rule book.

likely to include false starts (moving before the snap) and offensive holding. It is unlikely that moving the referee changes the detection of a false start, when a 6' 6" 300 pound person moves, it is visible on the field and in the bleachers. This narrows the focus of this study to offensive holding. In its most basic form offensive holding occurs when there is "interlocking interference" (NFL Rule Book) between on offensive player and a defensive player. As the rule is written, it could be called on any play that occurs in the NFL. In practice, this penalty is called on offensive lineman when their hand is placed on the outside of a defenders shoulder pads, or when the offensive player pulls an opponent to the ground.

4 Data

Play by play data for every regular season game in the 2009-10 and 2010-11 NFL seasons has been collected from NFL Internet "Game Cast" by advancednflstats.com,[7] which is a fan based website that produces win probability graphs of each weakly matchup using the play by play data. This data is freely downloadable from the website. The data set is comprised of over 85,000 individual plays, with over 77,000 regular downs. After restricting the sample to only run and pass plays, ie, the plays which were effected by the repositioning, there are approximately 75,000 observations. For each play, information detailing the quarter, down, distance to first down, field position, team on offense, team on defense, the score or each team. In addition to this information, there is a textual description of what happened during each play. This textual description is useful in determining whether or not any penalty occurred, and more specifically if offensive holding or defensive holding occurred. The description can also be used to examine if the play is a pass, kick, or punt. If a play is none of these, then it is assumed to be a run. This data was then merged with referee crew assignments from www.football-refs.com, another fan website.

[7] http://www.advancednflstats.com/2010/04/play-by-play-data.html

Prior to a snap, there is a 7.1% chance that the play will draw a penalty. Offensive holding occurs on 1.2% of plays, meaning that holding accounts for roughly 16.9% of all penalties called in the NFL. During the 2009-10 season, holding occurred on 1.2% of all plays, and during 2010-11, holding occurred on 1.3% of all plays. On the surface, this difference provides some support for the claim that repositioning led to an increase in holding calls. It should also be noted that the new official positioning has occurred on 77% of plays during the 2010-11 season. The fraction is less than one because of the special circumstances when the rule is in effect and due to special teams plays, such as kickoff, where the officials have slightly different positioning.

5 Empirical Specification and Results

5.1 Identifying Changes in the Distribution of Crime

To estimate the effect of the new rule, I will exploit the quasi experimental nature of the data. Similar to Levitt (2002), a simple difference in means test will consistently identify the causal effect of the repositioning the official. Table 1 presents the difference in means test. Row 1 of Table 1 shows that on all regular down plays, there is a .0024 increase in the number of offensive holding penalties resulting from repositioning. This represents a relative increase of 20 percent when the new official positioning is in play, which accounts for all special end of half and goal line situations. Over the entire season, this increase leads to over 100 additional offensive holding calls. In row 2, it is shown that defensive holding does not increase on all regular down plays, however, this lumps together defensive holding calls on defensive backs as well as defensive lineman. To get a better sense of the change for defensive lineman, who are impacted by repositioning, row 4 shows the difference in means for defensive holding on run plays only. The difference in means with the new rule in effect is -.00066. While small in magnitude, it represents a 37.4 percent decrease in

defensive holding on run plays. Because run plays account for only 45 percent of all downed plays, the total percentage change is equal to the a 16.8 percent reduction in defensive holding. This almost exactly offsets the change in offensive holding calls. Because the total number of officials did not change, the total number of penalties called should remain constant with the implementation of the new rule. Row 3 of Table 1 shows that the difference in means for all penalties is not statistically different when the new referee positioning is in effect.

While a T-test provides consistent estimates of the causal effect, there may be several factors influencing whether or not penalties are committed. The model outlined above assumed that each potential criminal could calculate the marginal cost and benefits of committing a crime on a given play by incorporating play specific details, such as field position, down and distance, score, time remaining in the game, opponent, and propensity of the officiating crew to call penalties. To further test for the effect of repositioning, I estimate linear probability models controlling for a variety of play specific features. To identify the detection effect in isolation, I estimate the following empirical specification

$$Y_{ig} = \beta_o + \beta_1 Rule_{ig} + \theta X_{ig} + \varepsilon_{ig}$$

In each specification, the dependent variable will be a binary outcome, defined as either, offensive holding, defensive holding, or any penalty. $Rule_{ig}$ is a binary variable indicating whether or not the official is positioned behind the offense or defense on a given play within a game, it accounts for the special hurry up and goal line scenarios outlined above in Section 3. X_{ig} is a vector of play specific features, including the yards to first down, the score differential, the score differential squared, play selection (run or pass), field position, as well as a collection of down fixed effects, quarter fixed effects, week of season fixed effects, team fixed effects, officiating crew

fixed effects, and interactions between team fixed effects to control for rivalry games. These fixed effects control for a variety time invariant, play specific features, that would impact the likelihood of a penalty.

Because the repositioning of the official was for the safety of the official, it can be argued that repositioning is plausibly exogenous to penalties. However, this does not indicate that the detection effect is what is identified on its own. In this setup, β_1 identifies the change in the probability of a given penalty being called. In general, β_1 is a composite effect, as many features could impact observed changes in penalty rates. Players could change their behavior in response to the repositioning, teams could change their play calling, officials could react differently when they observe a penalty, and so on. Thus, in order to identify the detection effect, the identifying assumptions are that players can not alter their behavior due to the physical constrains of the game, any biases that officials have are consistent regardless of their location on the field, and play calling does not change as a result of the new official positioning.

While these assumptions are not directly testable, some evidence may be provided to indicate that the assumptions are plausible. The first assumption regarding players not altering their behavior will be examined in Section 5.3 to test if the identified detection effect is persistent throughout the season. I will also examine whether or not officials call penalties at differential rates based on field position. Secondly, there is at least some evidence that teams did not alter their play calling strategy in response to the repositioning of the official. In both the 2009-10 and 2010-11 seasons, 45 percent of plays were classified as runs, and 42 percent were classified as passes. Within passing plays, 75 percent of passes were considered short passes and did not statistically differ with the new referee positioning. Similarly, 17 and 18 percent of passes were considered "Deep Passes" and were not statistically different with the implementation of the new referee position. While it is possible that within these

categories the design of a pass or run may have changed, the data is not rich enough to further explore play design or personnel packages.

A simple difference in means test reveals that officiating crews have different penalty rates, which would violate the assumption in the theoretical model of officials having a homogeneous probability of detection. However, the inclusion of officiating crew fixed effects removes these differences and leads to a comparison of plays with the same officiating crew located at both the new and old positions on the field. Thus, while it has been shown by Price and Wolfers (2010) that officials in other professional sports leagues, such as the NBA, have behavioral biases which influence the number of penalties called, this identification strategy relied on differences in referee and team racial composition between games. Because my identification strategy relies on differences in referee position between plays, these types of biases, if they do exist, should be consistent throughout the course of a game and within a referee crew, and do not bias the parameter of interest.

5.2 Empirical Results

Regression results using offensive holding as the outcome of interest are presented in Table 2. In the absence of any controls, the causal effect of official repositioning is estimated to be .0024, a 20 percent increase in offensive holding. When the full set of controls are included, the estimated increase in holding falls to .0017, which is a 14 percent increase in offensive holding. Other co variates have the expected signs, being further away from a first down makes it more likely for an offensive holding call to occur, while playing with the lead makes it less likely. Play selection also heavily influences the probability of offensive holding: pass plays have a much lower penalty rate than run plays. Field position tends not to impact penalty rates. While theory suggests that having really good field position would increase the cost of a penalty, there is little to no empirical evidence to suggest that field position has

an economically or statistically significant impact on penalty rates. This is likely because other factors of the game: score differential, down and distance, and time remaining have more importance in the decision to commit a penalty.

Estimates of defensive holding on run plays are presented in Table 3. As a result of the repositioning, defensive holding calls fell by .00065 in the absence of controls. With the inclusion of the full set of fixed effects, the estimate changes slightly, the probability of a defensive holding call fell by .00067, which a relative decrease of 17.2 percent.

In the theoretical model, I assumed that each official had an exogenous probability of observing and calling a penalty. This would suggest that for a fixed number of officials, the overall probability of detecting any penalty should remain unchanged after an official is repositioned to a location equidistant to the players from the previous position. While this is assumed for expositional ease in the model, whether or not it holds in practice is an empirical question. Table 4 presents the results of the baseline regression using any penalty called during the play as the outcome of interest. In the absence of all controls, the change in penalties is statistically zero. Upon the inclusion of all controls, there is no statistical evidence that the total number of penalties changes. Combined, the results from Tables 2,3, and 4 suggest that the burden of penalties shifted from players on the defensive line to players on the offensive line.

5.3 Robustness Checks

If offensive lineman alter their behavior in response to repositioning of the referee, then the coefficient, β_1, would not identify the detection effect, but would instead estimate the net effect of changed player behavior and detection by officials. One way to test if players are altering their behavior is to examine the weekly impact of the repositioned official. If players invest in deterring detection, then those investments

are likely to payoff over time rather than instantaneously. Therefore, if there is a downward trend over time in the estimated effect of the repositioned official, then there is some evidence of players altering their behavior.

To test for this type of investment in deterrence, I re-estimate the empirical model by interacting the week of the season effects with the rule change using the full specification of the empirical model. The estimates of the week by week interaction terms are displayed in Figure 1. For each week the estimated interaction effect does not differ from zero, which indicates that players did not alter their behavior throughout the season.

An additional concern with the baseline estimate is that officials may call penalties differently after the rule is in place depending on field position. To address this concern, I construct an aggregated measure of field position equal to zero if you a team is in their own scoring zone (0-30 yard line), equal to 1 if in the middle of the field (opponents 30 yard line to own 30 yard line), and equal to 2 when inside the opponents scoring zone. I then interact this field position variable with the $Rule_{ig}$variable to test for differential effects. These results show that regardless of where game play is occurring, the officials do not differentially enforce the rules after repositioning.[8]

The empirical model outlined above also assumes that the effect of relocating officials is constant across different play types, however, there may be heterogeneous effects. For instance, now that there are multiple officials behind the offensive line, heavy pass rushes may result in more penalties, or alternatively, it may be easier for officials to see hand placement on runs. To empirically test for heterogeneous effects, I re-estimate the model with the inclusion of an interaction term between the play type and the new positioning of the official. The results, presented in Table 5, show that there is a strong negative interaction effect between pass plays and the

[8]These results are available from the author upon request.

new positioning of the umpire. On passing plays in which the official is in the new position, there is only a .0005 increase in the probability of an offensive holding call, or a 4 percent relative increase. Given the large overall increase in offensive holding, these results show that the majority of the new offensive holding calls are coming from run plays.

6 Interpreting the Results

The results suggest that the detection effect is large. Simply by repositioning the officials in the NFL, the players with an extra set of eyes behind them experienced a 20 percent in increase in the number of called penalties, while the set of players who had the set of eyes removed had a large decrease in the number of penalties detected. This suggest, that in the NFL, being in proximity to an official greatly increases the chance of being caught committing a crime. This may have some relevance to the previous literature. MT (1984) found that in ACC basketball games, an extra official led to decreases in the number of fouls called in a game. Given that detection effects are large and officials have relatively set positions in basketball, it makes sense for players in college basketball to alter their behavior to avoid fouling given that each player has a limited number of fouls per game. In previous papers examining professional hockey the estimated change in penalties was small. In both Levitt (2002) and Heckelman and Yates (2007), an additional referee did not lead to large increases in the detection of penalties. This result may due to the speed of play which would lead to the officials being out of position frequently. Because the additional official may not be in position, players do not alter their behavior in response to the additional referee, leading to little change in the number of penalties called.

Using the results from the regressions specified above, the probability that an official observes and penalizes a committed penalty on the field may be determined.

The coefficient of interest, β_1 is equal to the change in the probability that a crime is committed. Previously, this change in the probability of detection was defined as $\beta_1 = p_c(1-p_c)^{n-1}$. Provided that there are seven officials on the field, and that the estimate of β_1 ranges from .0016 to .0025, the implied probability of detection for any given NFL official ranges from .6 to .63. While the NFL collects statistics on referee performance, these statistics are not publicly available. What these results suggest is that there is plenty of reason for coaches to be screaming up and down the sidelines at officials for missed calls that potentially affect the outcome of games.

7 Conclusions

When the NFL repositioned one of its officials for safety purposes, it created a natural experiment to study distributional changes in crime detection. Using play by play data from the 2009-10 and 2010-11 NFL regular season, I estimated the change in penalty rates for offensive holding, defensive holding, and the overall penalty rate. Players experiencing an additional official in their area had a 20 percent increase in detected penalties, which is robust to a variety of controls. Players that experienced the removal of a referee had penalties detected less often. Because there was no increase in the number of referees, observed changes in penalties represented transfers from defensive players to offensive players. These results highlight the distributional impacts of changes in the spatial distribution of policing forces in a highly stylized context which may inform policy makers in other contexts.

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Tables and Figures

Figure 1

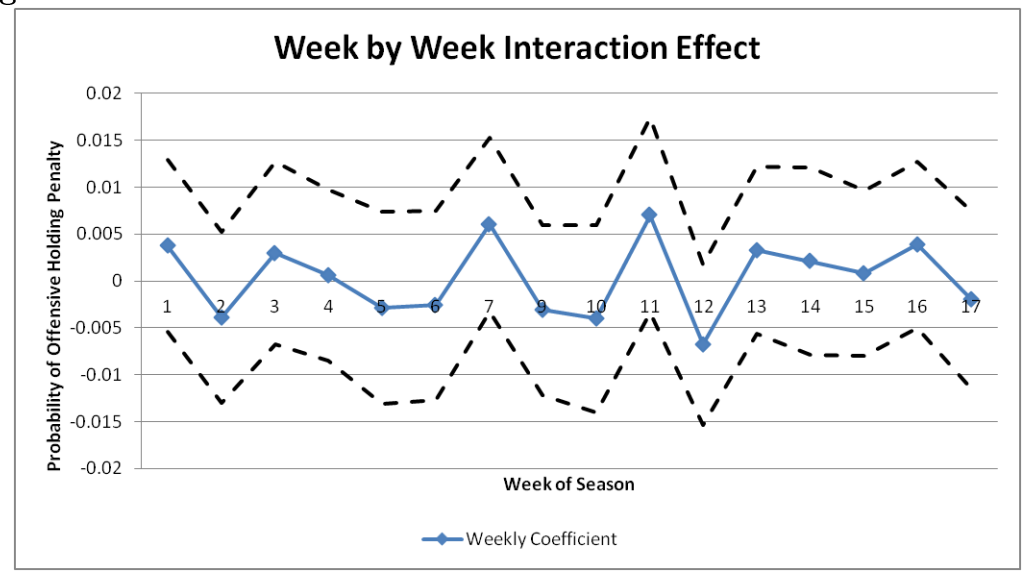

Table 1

T-Test of Mean Penalty Rate by Official Positon

Penalty	Old Position	New Position	Difference	T-stat
Offensive Holding	0.0117	0.0141	0.0024	2.83
Defensive Holding	0.0035	0.0035	0.00025	0.588
All Penalties	0.0702	0.0731	0.0029	1.49
Defensive Holding on Runs	0.0016	0.0008	0.0008	2.41

Table 2

Linear Probability Model Offensive Holding

	1	2	3	4	5	6	7
New Rule	0.00244 ***	0.00203 **	0.00195 **	0.00197 **	0.00188 **	0.00158 *	0.00173 *
	(0.00084)	(0.00087)	(0.00087)	(0.00088)	(0.00085)	(0.00086)	(0.00096)
Yards to 1st down		0.00028 ***	0.00025 **	0.00025 **	0.00021 *	0.0002 *	0.00009
		(0.00010)	(0.00011)	(0.00011)	(0.00011)	(0.00011)	(0.00012)
Score Differential		-0.00002	-0.00003	-0.00003	-0.00003	-0.00002	0.00002
		(0.00004)	(0.00004)	(0.00004)	(0.00004)	(0.00004)	(0.00005)
Score Differential Squared		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Field Position		0.00001	0.00000	0.00000	0.00000	0.00000	0.00000
		(0.00002)	(0.00002)	(0.00002)	(0.00002)	(0.00002)	(0.00002)
Play Type (Pass=1, Run=0)		-0.00724 ***	-0.00765 ***	-0.00779 ***	-0.00779 ***	-0.00776 ***	-0.00768 ***
		(0.00088)	(0.00092)	(0.00092)	(0.00091)	(0.00092)	(0.00092)
Down	N	N	Y	Y	Y	Y	Y
Quarter	N	N	Y	Y	Y	Y	Y
Week	N	N	N	Y	Y	Y	Y
Offense	N	N	N	Y	Y	Y	Y
Defense	N	N	N	Y	Y	Y	Y
Referee Crew	N	N	N	N	N	Y	Y
Rivalry	N	N	N	N	N	N	Y
N	74881	72028	72028	72028	72004	70629	70629

* p<.1, ** p<.05, *** p<.01

Table 3

Linear Probability Model Defensive Holding on Run Plays

	1	2	3	4	5	6	7
New Rule	-0.00066 *	-0.00079 *	-0.00078 *	-0.00069 *	-0.00071 *	-0.00061	-0.00058
	(0.000370)	(0.000410)	(0.000410)	(0.000400)	(0.000380)	(0.000390)	(0.000490)
Yards to 1st down		-0.00007 *	-0.00006	-0.00006	-0.00006	-0.00007	-0.00007
		(0.000040)	(0.000050)	(0.000050)	(0.000050)	(0.000050)	(0.000050)
Score Differential		0	0	-0.00001	0	0	0
		(0.000020)	(0.000020)	(0.000020)	(0.000020)	(0.000020)	(0.000020)
Score Differential Squared		0	0	0	0	0	0
		(0.000000)	(0.000000)	(0.000000)	(0.000000)	(0.000000)	(0.000000)
Field Position		0.00002 *	0.00001	0.00002 *	0.00002 *	0.00002	0.00002 *
		(0.000010)	(0.000010)	(0.000010)	(0.000010)	(0.000010)	(0.000010)
Down	N	N	Y	Y	Y	Y	Y
Quarter	N	N	Y	Y	Y	Y	Y
Week	N	N	N	Y	Y	Y	Y
Offense	N	N	N	Y	Y	Y	Y
Defense	N	N	N	Y	Y	Y	Y
Referee Crew	N	N	N	N	N	Y	Y
Rivalry	N	N	N	N	N	N	Y
N	38392	35623	35623	35623	35607	34931	34931

* p<.1, ** p<.05, *** p<.01

Table 4

Linear Probability Model All Penalties

	1	2	3	4	5	6	7
New Rule	0.0029	0.00176	0.00165	0.00167	0.00144	0.00159	0.00261
	(0.00204)	(0.00213)	(0.00212)	(0.00220)	(0.00205)	(0.00203)	(0.00223)
Yards to 1st down		-0.00018	0.00085 ***	0.00084 ***	0.00072 ***	0.00066 **	0.00037
		(0.00025)	(0.00028)	(0.00028)	(0.00027)	(0.00028)	(0.00028)
Score Differential		-0.00032 ***	-0.00036 ***	-0.00037 ***	-0.00044 ***	-0.00041 ***	-0.00049 ***
		(0.00009)	(0.00009)	(0.00009)	(0.00009)	(0.00009)	(0.00011)
Score Differential Squared		-0.00001	-0.00001 *	-0.00001	-0.00001 **	-0.00001 *	-0.00001 *
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Field Position		-0.00001	0.00001	0.00001	0.00002	0.00002	0.00003
		(0.00004)	(0.00004)	(0.00004)	(0.00004)	(0.00004)	(0.00004)
Play Type (Pass=1, Run=0)		-0.03057 ***	-0.03528 ***	-0.03562 ***	-0.03611 ***	-0.03594 ***	-0.03638 ***
		(0.00204)	(0.00213)	(0.00212)	(0.00215)	(0.00219)	(0.00221)
Down	N	N	Y	Y	Y	Y	Y
Quarter	N	N	Y	Y	Y	Y	Y
Week	N	N	N	Y	Y	Y	Y
Offense	N	N	N	Y	Y	Y	Y
Defense	N	N	N	Y	Y	Y	Y
Referee Crew	N	N	N	N	N	Y	Y
Rivalry	N	N	N	N	N	N	Y
N	74881	72028	72028	72028	72004	70629	70629

* p<.1, ** p<.05, *** p<.01

Table 5

Linear Probability Model Offensive Holding Heterogeneous Effects by Play Type

	1	2	3	4	5	6
New Rule	0.00426 ***	0.00352 **	0.00353 **	0.00347 **	0.00321 **	0.00338 **
	(0.00130)	(0.00138)	(0.00139)	(0.00136)	(0.00136)	(0.00136)
Play Type x New Rule	-0.00368 **	-0.00312 *	-0.0031 *	-0.00315 *	-0.00323 *	-0.00328 *
	(0.00166)	(0.00173)	(0.00173)	(0.00173)	(0.00173)	(0.00173)
Yards to 1st down		0.00025 **	0.00025 **	0.00021 *	0.0002 *	0.00009
		(0.00011)	(0.00011)	(0.00011)	(0.00011)	(0.00012)
Score Differential		-0.00002	-0.00003	-0.00002	-0.00002	0.00002
		(0.00004)	(0.00004)	(0.00004)	(0.00004)	(0.00005)
Score Differential Squared		0	0	0	0	0
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Field Position		0	0	0	0	0
		(0.00002)	(0.00002)	(0.00002)	(0.00002)	(0.00002)
Play Type (Pass=1, Run=0)	-0.00438 ***	-0.00645 ***	-0.0066 ***	-0.00657 ***	-0.00649 ***	-0.00637 ***
	(0.00101)	(0.00112)	(0.00112)	(0.00111)	(0.00112)	(0.00111)
Down	N	Y	Y	Y	Y	Y
Quarter	N	N	Y	Y	Y	Y
Week	N	N	N	Y	Y	Y
Offense	N	N	N	Y	Y	Y
Defense	N	N	N	Y	Y	Y
Referee Crew	N	N	N	N	Y	Y
Rivalry	N	N	N	N	N	Y
N	74881	72028	72028	72004	70629	70629

* p<.1, ** p<.05, *** p<.01