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Paying for Protection

The Effects of Having an Elite Left Tackle

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Abstract

We exploit relatively new data collected by the NFL, since 2009, on the number of hits taken by a team's quarterback to estimate the benefits and costs of employing an elite left tackle. We model the effect of an elite left tackle using a system of equations, which is estimated with seemingly unrelated regressions. Our system of equations considers quarterback hits, yards gained, and the probability of a quarterback injury. Overall, an All-Pro left tackle increases offensive production by 106 yards, or 8.5 points, and reduces the probability a team's quarterback misses a game due to injury by 10.3 percentage points. However, the estimated compensation premium for elite left tackles is $1,151,000 to $1,528,000. Furthermore, the cost of an elite left tackle is far greater than the cost associated with an equal increase in points scored acquired through the running back market. Taken together; our results suggest elite left tackles are valued far above their expected contribution to offensive production due to the very large reduction in quarterback injury risk.

Keywords: *Left tackle, quarterback protection, points scored, compensation premium*

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Introduction

Player compensation in the National Football League (NFL) is different than other professional sport leagues. The distinguishing factor is the presence of a hard salary cap. Any dollar spent on a player's compensation is directly debited from a team's total season allotment, which is calculated as a percentage of league revenues (National Football League, 2006). As a result, the presence of a positional premium is very consequential. There are several positions in the NFL that command a premium, two of which are quarterback and left tackle. For example, in 2009, the average starting left tackle accounted for 3.6% of the total salary cap. Table 1 presents a complete list of the percentage of the salary cap teams spent on starting left tackles, starting quarterbacks, and starting tight ends in 2009. Twelve of the 32 starting left tackles accounted for at least 4.5% of the salary cap. There were also five players who represented greater than 6% of their team's salary cap allotment. Considering there are 53 players on an active NFL roster and 22 starters (11 on offense and 11 on defense), there seems to be a premium paid to left tackles in the NFL. A more rigorous econometric analysis by Berri, Humphreys, and Simmons (2013) finds a large premium, approximately $230,000 to $400,000, for starting left tackles, compared to other lineman.[1] However, whether or not the compensation premium is justified has been strongly debated (Joyner, 2008).

Whether one agrees with the premium or not, the premium paid to left tackles is the result of their role in protecting the quarterback. Left tackles are responsible for pass blocking on a quarterback's blind side, a characteristic that has garnered increased attention since Michael Lewis's (2006) book, *The Blind Side: Evolution of a Game*. It is believed that an elite left tackle will significantly reduce the number of hits on a team's quarterback, including sacks. In turn, fewer hits taken by a quarterback increases offensive production and reduces the chance of a quarterback injury. The empirical question is "What are the magnitudes of these effects?"

We take advantage of relatively recent data on hits taken by quarterbacks to determine the benefits and costs of an elite left tackle. Specifically, we attempt to answer, by how much does an elite left tackle affect offensive productivity and reduce the probability of a quarterback injury? Also, what is the compensation premium paid to an elite, not simply starting, left tackle? Berri et al. (2013) examine the compensation premium for starting left tackles; however, it is not possible to estimate the effect of starting left tackles on offensive production and quarterback injury risk because every team has a starting left tackle. Therefore, we must distinguish between starting left tackles of different ability. For other positions in the NFL, performance statistics can be used to differentiate players based on quality. However, for offensive lineman, there is a void of reliable individual performance measures. As a result, we use a binary distinction between elite left tackles other

[1]Berri et al. (2013) state their results are for elite left tackles; however, the effects reported are for being a starting left tackle, not an elite starting left tackle.

Table 1

2009 Percentage of Overall Salary Cap

Team	LT	QB	TE
San Francisco 49ers	11.67%	4.43%	1.91%
Philadelphia Eagles	10.83%	13.10%	0.36%
Miami Dolphins	8.00%	0.47%	0.42%
Green Bay Packers	6.67%	7.54%	0.30%
Detroit Lions	6.08%	2.42%	0.24%
Carolina Panthers	5.00%	6.71%	1.21%
New York Jets	5.00%	1.99%	0.52%
Minnesota Vikings	4.92%	9.38%	1.64%
Arizona Cardinals	4.83%	8.99%	0.36%
Cincinnati Bengals	4.75%	11.17%	0.36%
New England Patriots	4.75%	11.43%	0.71%
Pittsburgh Steelers	4.50%	10.33%	1.14%
Chicago Bears	4.42%	9.01%	0.36%
Tennessee Titans	3.75%	3.62%	3.49%
New York Giants	3.58%	10.21%	0.36%
Cleveland Browns	3.25%	1.35%	1.95%
St. Louis Rams	3.08%	6.65%	2.81%
Denver Broncos	2.92%	0.86%	2.50%
Seattle Seahawks	2.92%	7.39%	0.33%
Dallas Cowboys	2.58%	3.58%	1.95%
Tampa Bay Buccaneers	2.33%	1.08%	4.04%
Kansas City Chiefs	1.83%	11.88%	0.42%
Jacksonville Jaguars	1.75%	7.03%	0.42%
Atlanta Falcons	1.33%	7.74%	3.13%
Houston Texans	1.17%	8.01%	2.18%
San Diego Chargers	0.71%	9.02%	2.54%
Oakland Raiders	0.52%	10.64%	0.36%
New Orleans Saints	0.47%	8.33%	2.13%
Indianapolis Colts	0.47%	16.57%	2.58%
Baltimore Ravens	0.42%	3.81%	2.81%
Buffalo Bills	0.39%	1.73%	0.24%
Washington Redskins	0.25%	3.04%	0.30%
Mean	3.60%	6.86%	1.38%
Median	3.17%	7.47%	0.93%

starting left tackles. Our definition of elite simply means the highest quality, or ability; we expand on our empirical definition of elite players in the Data section.

Method

Offensive Production

In order to determine the benefits of having an elite starting left tackle, we specify a system of equations that relates an elite left tackle to two outcomes of interest for NFL teams, offensive production and quarterback injury risk. We begin with an elite left tackle's effect on protecting the quarterback. Typically, quarterback protection is measured using sacks, S, when a quarterback is tackled behind the line of scrimmage while attempting a pass. However, sacks are only one measure of quarterback protection. Quarterbacks may be hit while attempting a pass that does not result in a sack, which we call knockdowns, K. A quarterback may be hit by a defensive player while throwing the ball or directly after the ball is released from his hand. Thus, an elite left tackle may affect quarterback protection beyond sacks. We define the number of quarterback hits, H, as the total number of times a team's quarterback is hit while attempting a pass, $H = S + K$. We estimate the effect of having an elite left tackle on quarterback protection, using the following specification:

$$H_{it} = \alpha_i + \alpha_t + \beta ELT_{it} + X_{it}\lambda + \epsilon_{it} \tag{1}$$

where i indexes teams and year is indexed by t. Elite left tackles are identified by the binary variable ELT. The α parameters capture team and year fixed effects, and X is a vector of other variables determining the number of quarterback hits. The number of quarterback hits is a function of several non-left tackle-related variables. First, it is a function of the quality of a team's other offensive linemen. Thus, we include binary variables for elite players at the other offensive line positions and a measure of the cumulative experience of a team's starting five offensive linemen. Also, the quality of a team's offensive skilled players may impact quarterback protection. For instance, an elite quarterback may throw the ball quicker or better receivers may get open quicker and more often, eliminating hits on the quarterback. Therefore, we include binary variables for elite players at all other offensive positions. Finally, the number of quarterback hits depends on the number of passing attempts and the number of yards per completion. These two variables control for the number of opportunities to allow a hit on the quarterback as well as the tendency of a team to either throw short or long passes.

Next, we examine how the effect of an elite left tackle on quarterback protection translates into offensive effectiveness, measured in yards gained.

$$Y_{it} = \varphi_i + \varphi_t + \theta H_{it} + R_{it}\delta + \mu_{it} \tag{2}$$

Where Y is the number of offensive yards gained and R is a vector of control variables. The other factors determining yards gained are offensive plays, passing attempts, third down conversion rate and penalty yards. From equations (1) and (2), the effect of an elite left tackle on offensive effectiveness is $\beta\theta$.

The estimation of offensive effectiveness lends itself naturally to stochastic frontier analysis (Aigner, Lovell, & Schmidt, 1977; Meeusen & van den Broeck, 1977), which has been recently applied to baseball (Humphreys & Pyun, 2016; Lee, 2011). Stochastic frontier analysis allows for random shocks, specific to teams in a given season, to affect the production of yards. Specifically, we assume a Cobb-Douglas yards production function

$$Y = bH^{\theta}R^{\delta}c$$

where b is a deterministic parameter and c is a stochastic parameter. This formulation allows for random shocks to affect the maximum possible production of yards. However, teams, much like firms in other sectors, may not efficiently employ their resources or technology. As a result, they may not achieve the maximum possible production. Therefore, a stochastic inefficiency parameter, $g \in [0,1]$, is included.

$$Y = bH^{\theta}R^{\delta}cg$$

In log terms the production function is

$$\ln Y = \ln b + \theta \ln H + \delta \ln R + \ln c + \ln g$$

Finally, assuming $c = \exp(\mu)$ and $g = \exp(-a)$, we have

$$\ln Y_{it} = \varphi + \theta \ln H + \delta \ln R + \mu - a$$

where $\varphi = \ln b$. Compared to equation (2), the stochastic frontier analysis model is linear in logs, not levels.

$$\ln Y_{it} = \varphi_i + \varphi_t + \theta \ln H_{it} + \ln R_{it}\, \delta + \mu_{it} - a_{it} \qquad (2')$$

Equation (2') is estimated via maximum likelihood where a, the inefficiency term, is assumed to be exponentially distributed.

While yards gained are extremely important, perhaps a more critical measure of offensive production is points scored. Therefore, we translate our results into the effect on offensive points scored using the established relationship between yards and points in the literature. Each additional one hundred yards gained yields an additional eight offensive points (Berri, 2007; Simmons and Berri, 2009).[2]

Finally, we examine how an elite left tackle's impact on quarterback protection affects on our second outcome measure, quarterback injury risk.

$$INJ_{it} = \tau_t + \psi H_{it} + J_{it}\vartheta + u_{it} \qquad (3)$$

Where INJ is a binary variable for a team's starting quarterback missing at least one game due to injury in a given season. The control-variable vector J includes the number of quarterback rushing attempts, the number of offensive plays and having an elite quarterback. Team fixed effects are omitted from our injury equa-

[2] Offensive points scored are points that can be attributed to a team's offense, Total Points – 7*(Defensive Touchdowns + Special Teams Touchdowns).

tion as there are seven teams who did not have a starting quarterback miss a game and one team who every year had a quarterback miss a game during the sample period. Since our dependent variable is binary, least squares estimation of equation (3) yields a linear probability model (LPM). However, we also estimate the equation with logistic regression, which assumes the log of the odds ratio is a linear function, for comparison.[3]

$$\ln\left[\frac{\Pr(INJ_{it}=1)}{1-\Pr(INJ_{it}=1)}\right]=\tau_t+\psi H_{it}+J_{it}\vartheta+u_{it} \tag{3'}$$

From our equations, the effect of an elite left tackle on quarterback injury risk is $\beta\psi$.

Our empirical strategy yields a recursive system of three equations.

$$H_{it}=\alpha_i+\alpha_t+\beta ELT_{it}+X_{it}\lambda+\epsilon_{it}$$

$$Y_{it}=\varphi_i+\varphi_t+\theta H_{it}+R_{it}\delta+\mu_{it}$$

$$INJ_{it}=\tau_t+\psi H_{it}+J_{it}\vartheta+u_{it}$$

We estimate our system of equations using several methods. First, we estimate each equation separately, using ordinary least squares (OLS) for (1), stochastic frontier analysis for (2') and logistic regression for (3'). However, estimating the parameters of the system using three separate regressions assumes the equations are independent. Since the system is recursive, the three equations are not independent. Therefore, we also estimate the parameters simultaneously using seemingly unrelated regression (SUR) (Zellner, 1962).[4] SUR considers the relationship between equations by constructing a weighting matrix based on the covariance of the equations' residuals when estimated separately via OLS.[5] The benefit of SUR is that it does not assume independence between equations. However, SUR does not allow for stochastic frontier analysis or logistic regression to be incorporated in the model. As a result, we lose the ability to consider technical inefficiency in offensive production and we cannot use a nonlinear estimator for our binary injury risk variable. Therefore, we present both methods and compare them to analyze the robustness, in terms of both size and significance, of our results.

[3]Since our equation for quarterback hits contains regressors not included in our equation of injury risk, we could potentially estimate ψ using instrumental variables (IV) techniques, such as two-stage least squares (2SLS) and IV-probit estimations. 2SLS and IV-probit results are similar to the results presented, even when correcting 2SLS estimates for the presence of weak instruments using the conditional likelihood ratio (CLR) method (Andrews, Moreira, & Stock, 2006, 2007; Moreira, 2003).

[4]The system could potentially be estimated via three-stage least squares (3SLS). However, due to the large number of exogenous variables, 3SLS, in this case, suffers from very weak instruments. 3SLS estimates are available from the author.

[5]See Zellner (1962) for full properties of the SUR estimation method.

We also specify the effect of an elite left tackle on offensive production and quarterback injury risk using a system of five recursive equations, the two additional equations are for interceptions thrown and offensive points scored. We present the five-equation system and its results in the Appendix. The results do not differ between the two models; thus, we opt to present the parsimonious one.

Compensation

To examine the cost of an elite left tackle, we estimate the compensation premium paid to elite left tackles.

$$\ln w_{nit} = \varrho_i + \varrho_t + \phi ELT_{nit-1} + M_{nit}\xi + e_{nit} \tag{4}$$

Where w is compensation for starting left tackle n on team i in year t. Compared to Berri et al. (2013), who use all offensive linemen, we use a sample of starting left tackles. Therefore, we are analyzing the effect of being an elite left tackle compared to an average starting left tackle. As compensation is determined prior to the beginning of a season, we are analyzing the effect on compensation of being an elite left tackle the previous season. Therefore, the estimation eliminates any first year players. The vector M contains other variables affecting compensation. The control variables include experience, experience-squared, the number of previous season games played, to measure durability, and body mass index (BMI) and BMI-squared, to capture the returns to physical stature. We also use binary variables for restricted and unrestricted free agency eligibility, three and four or more years of experience respectively, which have been shown to significantly increase player compensation (Berri et al., 2013; Keefer, 2015; Krautman, von Allmen and Berri, 2009; Simmons and Berri, 2009; Vrooman, 2012).[6] We include a binary variable for players on a new team, as previous research has also shown players who switch teams receive less compensation (Berri et al., 2013; Berri & Simmons, 2009; Keefer, 2015; Simmons & Berri, 2009). Next, we control for the potential lasting effect of selection in the NFL draft on compensation by including binary variables for selections in each of the first three rounds (Berri et al., 2013; Berri & Simmons, 2009; Keefer, 2015; Simmons & Berri, 2009). Finally, we include previous season wins and points scored to control for team quality.

One potential issue with the estimation of earnings equations is many times earnings data are highly skewed; few individuals earn far greater salaries than others. Therefore, we estimate our wage equation using quantile regression, which is consistent in the presence of outliers and is common in the sports economics literature (Berri & Simmons, 2009; Hamilton, 1997; Keefer, 2013; Leeds & Kowalewski, 2001; Simmons & Berri, 2009). We estimate the effect of being an elite left tackle using median regression, or least absolute deviations (LAD) regression.

[6] Free agency eligibility is specified in the NFL collective bargaining agreement (CBA) (National Football League, 2006). For a more detailed discussion see Keefer (2015) or Vrooman (2012).

Data

Our econometric approach brings with it two unique data questions. The first is how to define a team's starting left tackle. To accomplish this, we use Pro Football Reference team depth charts. The second question is how to identify elite players at their positions in a given season. Our analysis relies on the ability to identify elite players at their positions, especially left tackles. To do so, we use All-Pro status. There are four All-Pro teams we consider. *Pro Football Weekly* identifies first and second team all-conference performers. Also, the Associated Press, Pro Football Writers and *Sporting News* each identify first and second team all-NFL players. There is much overlap between the All-Pro teams. We choose All-Pro selections instead of Pro Bowl selections, the NFL all-star game, because Pro Bowl players are selected based on player, coach and fan votes.[7] There are only four offensive line categories, left tackle, left guard, center and right guard. In the sample, all All-Pro tackles were left tackles; there were no right tackles on an All-Pro team.

We employ two data sets in our analysis. First, our data for estimating the effect of an elite left tackle on offensive production includes team-level information for 2009 through 2014. The NFL reports the number of quarterback knockdowns, but only from 2009 forward. Therefore, our data is limited to beginning in 2009. Information for this data set was collected from the NFL and Pro Football Reference.[8]

The data for our analysis of starting left tackle compensation are from 2002 to 2009. The data contain both player and team-related information. Again, the data were primarily collected from the NFL and Pro Football Reference. Compensation data were collected from *USA Today*. *USA Today* maintains a database of professional athletes salaries; however, the final year of NFL compensation data is 2009. NFL player compensation has three components, base salary, signing bonus, and incentive bonuses. The amount a player's compensation contributes to the salary cap is calculated as the sum of his base salary, easily attainable incentive bonuses and signing bonus pro-rated for the life of the contract. Salary cap value is considered the standard measure of a player's compensation in a given year, since the signing bonus is amortized (Berri & Simmons, 2009). Summary statistics are reported in Table 2 for both data sets.

Results

[7]For example, in 2010 Shaun O'Hara, a guard for the New York Giants, was selected to the Pro Bowl having only played in six games.

[8]In the five-equation model we also use average starting position, which was collected through Football Outsiders and opponent's missed field goals, which was collected from ESPN.

Table 2

Descriptive Statistics

VARIABLES	*Mean*	*SD*
Offensive Production		
QB Hits	115.0	(25.51)
QB Injured	0.391	(0.489)
Total Yards	5,498	(628.1)
All-Pro LT	0.115	(0.319)
All-Pro LG	0.0677	(0.252)
All-Pro C	0.0625	(0.243)
All-Pro RG	0.0677	(0.252)
All-Pro QB	0.0521	(0.223)
All-Pro WR	0.167	(0.374)
All-Pro TE	0.0625	(0.243)
All-Pro FB	0.0625	(0.243)
All-Pro RB	0.125	(0.332)
OL Starters Experience	313.1	(95.10)
Passing Attempts	549.6	(61.07)
Pass Yards/Completion	10.90	(0.905)
3rd Down Conversion %	38.55	(5.344)
Penalty Yards	840.7	(146.7)
QB Rushing Attempts	47.88	(24.25)
Observations	192	
Compensation		
LN(Cap Value)	14.69	(0.953)
All-Pro LT (t-1)	0.131	(0.339)
Games Played (t-1)	14.02	(3.674)
BMI	37.18	(1.675)
Starting LT (t-1)	0.733	(0.443)
Experience	5.110	(3.021)
Restricted Free Agent	0.119	(0.324)
Unrestricted Free Agent	0.636	(0.482)
Change Team	0.0763	(0.266)
Round 1	0.492	(0.501)
Round 2	0.186	(0.390)
Round 3	0.123	(0.329)
Wins (t-1)	8.000	(3.061)
Points Scored (t-1)	313.8	(65.01)
Team Payroll (% of Cap)	0.967	(0.135)
Observations	236	

Note: Offensive productivity data are from 2009 to 2014 since data on knockdowns is only available beginning in 2009. Compensation data is from 2002 to 2009 as *USA Today* compensation ends in 2009, the final year of the 1993 CBA.

Results

Offensive Production

We begin our discussion of the results by analyzing our first equation, for quarterback hits. Results are contained in Table 3. OLS estimation returns a coefficient for All-Pro left tackles of -19.13 and our SUR estimation coefficient is -17.03, both of which are highly significant. As there are 16 regular season games in the NFL, an All-Pro left tackle reduces the number of hits taken by a quarterback by slightly more than one per game. Thus, an elite left tackle has a major impact on the number of times a quarterback is hit while attempting a pass. To provide additional context, we can compare the estimated effect to that of overall offensive line quality. From our estimations, the total experience of the five starting offensive linemen has a significant effect on the number of quarterback hits, a marginal effect of -0.037 from SUR. Using the two SUR coefficients, an elite left tackle has the same impact on the number of quarterback hits as an additional 459 career games started for an offensive line, or each lineman started for an additional 5.7 seasons.[9]

Next, we examine our results for the number of yards gained, which are contained in Table 4. Quarterback hits have a significantly negative impact on yards gained, in all estimations. Our stochastic frontier analysis suggests a 10% increase in quarterback hits decreases yards by 0.84%.[10] Since the average number of quarterback hits is 115, the reduction in quarterback hits from an All-Pro left tackle is 14.8% of the average. In turn, a 14.8% decrease in quarterback hits increases yards gained by 1.25%. Since the average number of yards gained is 5,498, a 1.25% increase from the mean is only an increase of 68.5 yards. From our SUR estimation, each quarterback hit reduces the number of yards gained by 6.24. As an elite left tackle decreases the number of quarterback hits by 17.03, an elite left tackle increases yards gained by 106. Thus, our stochastic frontier analysis yields a smaller effect, but one that is still significantly positive. Using the established effect of yards on offensive points, each additional one hundred yards gained yields eight points (Berri, 2007; Simmons & Berri, 2009), an All-Pro left tackle generates 5.5 to 8.5 points, on average.[11]

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[9]One potential issue with the comparison to overall experience of the offensive line is that elite players may be more experienced. However, the simple correlations between overall offensive line experience and elite offensive linemen are very small, all less than 0.132. Furthermore, when binary variables for elite offensive linemen are omitted, the effect of overall experience is -0.0417 for OLS and -0.0399 for SUR, both of which are significant at the 5% level.

[10]The result is robust to allowing heteroskedasticity in the inefficiency term based on teams while assuming a half-normal distribution for the inefficiency term. In this case, a 10% increase in quarterback hits generates a reduction of 0.926% in yards gained, which is significant at the 1% level. Estimation allowing for heteroskedasticity based on teams while assuming an exponential distribution is not possible, due to convergence issues from the small sample size.

[11]The effect in the five-equation recursive model is 8.45 points. See the Appendix for full details.

Table 3

Estimation of QB Protection

Dependent Variable = QB Hits		
VARIABLES	OLS	SUR
All-Pro LT	-19.13***	-17.03***
	(5.750)	(6.063)
All-Pro LG	-3.629	-3.648
	(5.888)	(6.615)
All-Pro C	-5.441	-4.398
	(13.17)	(6.543)
All-Pro RG	-8.754*	-8.659
	(4.480)	(7.302)
All-Pro QB	-16.39**	-15.68**
	(7.430)	(7.324)
All-Pro WR	-5.848	-6.062
	(6.317)	(4.175)
All-Pro TE	-0.884	-1.104
	(5.282)	(6.364)
All-Pro FB	-9.009	-9.026
	(6.786)	(6.119)
All-Pro RB	-8.892**	-10.02**
	(4.008)	(4.736)
OL Starters Experience	-0.0377*	-0.0371**
	(0.0217)	(0.0175)
Passing Attempts	-0.0167	-0.0286
	(0.0509)	(0.0310)
Pass Yards/Completion	-3.978	-6.466***
	(2.412)	(1.847)
Team Fixed Effects	X	X
Year Fixed Effects	X	X
Constant	200.4***	233.4***
	(42.31)	(30.49)
Observations	192	192
R-squared	0.533	0.527

Note: Standard errors are in parentheses; standard errors clustered at the team level reported for OLS. *Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table 4

Estimation of Total Yards Gained

	Dependent Variable = Total Yards		
VARIABLES	OLS	Stochastic Frontier	SUR
QB Hits	-3.902***	-0.0841***	-6.240***
	(1.360)	(0.0252)	(1.226)
Offensive Plays	3.898***	0.772***	3.910***
	(0.875)	(0.149)	(0.773)
Passing Attempts	0.305	0.0166	0.356
	(0.759)	(0.0554)	(0.562)
3rd Down Conversion %	49.01***	0.328***	46.30***
	(9.481)	(0.0513)	(7.130)
Penalty Yards	0.473	0.0609**	0.473**
	(0.287)	(0.0300)	(0.198)
Team Fixed Effects	X	X	X
Year Fixed Effects	X	X	X
Constant	-598.6	1.958**	-233.8
	(780.3)	(0.852)	(652.8)
Observations	192	192	192
R-squared	0.771		0.767

Note: Standard errors are in parentheses; standard errors clustered at the team level reported for OLS. All variables are in natural log terms for stochastic frontier results. *Significant at 10%. **Significant at 5%. ***Significant at 1%.

Quarterback injury risk results are reported in Table 5. Each quarterback hit while attempting a pass significantly increases the probability of missing a game due to injury by 0.48 percentage points, from our LPM. Logistic regression yields a significant odds ratio of 1.023. The marginal effect at the means of all the independent variables is 0.00523, with a delta-method standard error of 0.00158. Thus, each additional quarterback hit increases the probability of injury by 0.52 percentage points. SUR estimation yields a significant coefficient of 0.0061, or each quarterback hit increases the probability of a team's quarterback missing a game due to injury by 0.61 percentage points.[12] Given a reduction of 17.03 quarterback hits,

[12]2SLS estimation yields a significant marginal effect of 0.00741. Furthermore, 2SLS returns an overidentification p-value of 0.241, providing support to the validity of the instrument set. However, 2SLS suffers from severely weak instruments. Employing the CLR method, to attempt to account for weak instrument bias, yields a significantly positive effect, with a 95% confidence interval of [0.00481, 0.0195]. The effect of quarterback hits on quarterback injury risk is also significantly positive, with a coefficient of 0.0305, in maximum likelihood IV-probit estimation. The IV-probit coefficient implies an average marginal effect of 0.00912. However, these results should be viewed skeptically, as team effects are used in the estimation of quarterback hits, but not injuries. When team fixed effects are not included as instruments, the 2SLS estimate is 0.00318, but is not significant at conventional levels. Similarly, IV-probit, excluding team effects, yields a coefficient of 0.00341, but it is also statistically insignificant.

Table 5

Estimation of Probability of Starting Quarterback Missing a Game Due to Injury

	Dependent Variable = QB Injured		
VARIABLES	LPM	Logistic	SUR
QB Hits	0.00483***	0.0227***	0.00607***
	(0.00127)	(0.00657)	(0.00139)
		[1.023]	
QB Rushing Attempts	0.000810	0.00433	0.000915
	(0.00188)	(0.00796)	(0.00140)
Offensive Plays	-0.00155*	-0.00789*	-0.00142**
	(0.000888)	(0.00460)	(0.000724)
All-Pro QB	-0.105	-1.072	-0.0683
	(0.155)	(1.339)	(0.155)
Year Fixed Effects	X	X	X
Constant	1.373	4.692	1.099
	(0.946)	(4.702)	(0.782)
Observations	192	192	192
Correctly Specified	66%	65%	

Note: Standard errors are in parentheses; standard errors clustered at the team level reported for LPM and Logistic. Logistic regression odds ratio in square brackets. Team fixed effects are not included as there are seven teams who did not have a starting quarterback miss a game and one team who every year had a quarterback miss a game during the sample. *Significant at 10%. **Significant at 5%. ***Significant at 1%.

an All-Pro left tackle reduces the probability of a quarterback injury by 8.9 to 10.3 percentage points. Examining the data, the unconditional probability of having a quarterback miss a game due to injury is 39.1%. Thus, having an elite left tackle provides a substantial reduction in the probability of a team's starting quarterback missing a game due to injury.

Compensation

We now turn to examining the effect of being an All-Pro left tackle on compensation. Estimation results from our sample of starting left tackles are contained in Table 6, which includes OLS estimates for comparison. Our baseline LAD regression indicates All-Pro left tackles earn 39.8% more than average starting left tackles, holding other factors constant.[13,14] As expected, there is a very large premium for elite left tackles, when compared to average starting left tackles.

[13]The percentage change in compensation is calculated as $e^{\phi} - 1$, where ϕ is the estimated coefficient from our wage regression.

[14]Our estimate is consistent with the Berri et al. (2013) estimate for the effect of being selected to the Pro Bowl.

Table 6

Estimation of Starting Left Tackle Compensation

	OLS		LAD	
VARIABLES	(1)	(2)	(3)	(4)
All-Pro LT (t-1)	0.341**	0.344**	0.335**	0.356***
	(0.154)	(0.157)	(0.149)	(0.130)
Games Played (t-1)	0.0248**	0.0267**	0.0120	0.0154
	(0.0113)	(0.0114)	(0.0120)	(0.0115)
BMI	-0.808	-0.749	-1.082	-1.135
	(0.789)	(0.756)	(1.158)	(1.022)
BMI-squared	0.0107	0.00997	0.0144	0.0150
	(0.0103)	(0.00985)	(0.0150)	(0.0134)
Experience	-0.00172	-0.000930	0.113	0.0676
	(0.112)	(0.109)	(0.142)	(0.0920)
Experience-squared	0.00241	0.00235	-0.00603	-0.00277
	(0.00747)	(0.00721)	(0.0100)	(0.00640)
Restricted Free Agent	0.342*	0.301	0.204	0.228
	(0.198)	(0.194)	(0.219)	(0.193)
Unrestricted Free Agent	0.946***	0.927***	0.915***	0.968***
	(0.261)	(0.255)	(0.331)	(0.194)
Change Team	-0.549**	-0.573**	-0.451*	-0.377***
	(0.263)	(0.261)	(0.247)	(0.138)
Round 1	0.844***	0.791***	0.961***	0.874***
	(0.169)	(0.171)	(0.148)	(0.114)
Round 2	0.396**	0.356*	0.585**	0.561***
	(0.185)	(0.186)	(0.250)	(0.172)
Round 3	0.0461	-0.0133	0.154	0.102
	(0.176)	(0.172)	(0.214)	(0.177)
Wins (t-1)	-0.00338	-0.00627	-0.0267	-0.0134
	(0.0193)	(0.0185)	(0.0210)	(0.0167)
Points Scored (t-1)	-0.000658	-0.000905	-9.97e-05	-0.000724
	(0.000900)	(0.000898)	(0.00113)	(0.000774)
Team Payroll (% of Cap)		0.760**		0.490**
		(0.340)		(0.231)
Team Fixed Effects	X	X	X	X
Year Fixed Effects	X	X	X	X
Constant	28.53*	26.71*	33.10	33.96*
	(15.01)	(14.32)	(22.14)	(19.24)
Observations	236	236	236	236
R-squared	0.740	0.748		
Adjusted R-squared	0.666	0.675		

Note: Robust standard errors are in parentheses. t indexes years. *Significant at 10%. **Significant at 5%. ***Significant at 1%.

One potential issue may be overall team payrolls. Even though the NFL has a salary cap, there is still variation in the amount of money spent on players' salaries. The spending habits of teams are, at least partially, captured with the included team fixed effects. However, year-to-year within-team variation in payrolls is not captured with fixed effects. Therefore, we examine the robustness of our estimate by including teams' total payrolls as a percentage of the salary cap. Our results are extremely robust; including team payrolls, the All-Pro left tackle premium is 42.8% and is significant to the 1% level.

From our baseline LAD estimation, the effect of being an All-Pro left tackle is an increase of $1,151,000 to $1,528,000.[15] The compensation premium is the result of multiple factors. Elite left tackles earn greater compensation than average left tackles, because they are more productive. However, the compensation premium is also the result of the monopoly power possessed by elite left tackles. There are very few players with the ability to reduce the number of hits on a quarterback by a substantial amount. Thus, All-Pro caliber players may use their market power in negotiations, to earn a larger compensation premium.

Cost Effectiveness

Since we have the effect of an elite left tackle on offensive production and the associated cost, the question is whether or not a team can obtain an equal level of offensive productivity at a lower cost. Simmons and Berri (2009) estimate the maximum return to an additional 100 rushing yards for a running back is 8.4%, from the 0.90 quantile. Thus, an increase of 106 yards generates a return of 8.93% for a running back. In their sample, the average number of rushing yards is 363 and the standard deviation is 445. Thus, the increase of 106 yards is an increase of 0.24 standard deviations. Furthermore, the mean running back salary is $1,044,211, and the median is $590,000. For an average running back, the increase in compensation from an additional 106 yards is $93,248. Thus, the increase in offensive productivity would be substantially cheaper for teams to acquire via the running back market. However, a substantial part of the impact of an elite left tackle is the reduction in the probability of a quarterback injury. As quarterbacks represent substantial investments for NFL teams, it seems logical that teams may be risk averse with respect to quarterbacks. Our results are consistent with risk aversion in this domain. Teams with All-Pro left tackles are revealing a substantial willingness to pay for an 8.9 to 10.3 percentage point reduction in quarterback injury risk. The NFL values elite left tackles far above their expected contribution to offensive production because they have such a large impact on quarterback safety.

[15]We find the predicted salary cap for all players who were not All-Pros and calculate the change in compensation if they had been, which yields an average increase of $1,151,275. We also find the predicted salary cap for all players who were All-Pros and calculate the decrease in salary cap value if the had not been, which yields an average decrease of -1,528,182.

Conclusion

Exploiting relatively new NFL data on quarterback hits, we show an All-Pro left tackle increases offensive production by 8.5 points, on average. Our estimation strategy considers various ways elite left tackles affect offensive production. Specifically, we consider a system of equations for quarterback hits, yards gained and the probability of a quarterback injury. We estimate the equations separately and also using SUR, as they are simultaneously determined. From SUR estimation, we find an All-Pro left tackle decreases the number of hits taken by a team's quarterback by 17.03. As a result, an All-Pro left tackle increases yards gained by 106. Thus, an elite left tackle increases the number of points scored by 8.5, on average. Due to the reduction in quarterback hits, an elite left tackle also reduces the probability a team's quarterback misses at least one game due to injury by 10.3 percentage points, a substantial reduction in quarterback injury risk.

Next we estimate the cost of an elite left tackle by determining the compensation premium paid to an All-Pro left tackle compared to an average starting left tackle. We use LAD regression on a sample of starting left tackles. Our results suggest an All-Pro left tackle earns 39.8% more than an average starting left tackle, holding other factors constant. In dollar terms, the compensation premium for an elite left tackle is $1,151,000 to $1,528,000.

Finally, we examine the cost effectiveness of an elite left tackle, by comparing our results to the market for running backs. In the running back market, NFL teams can obtain the additional 106 yards at a substantially lower cost. Our results indicate the NFL values elite left tackles far above their expected contribution to offensive productivity. The premium for All-Pro left tackles is a result of their significant effect on quarterback protection.

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Appendix

To present our five-equation system, we begin with our simplified three-equation recursive system.

$$H_{it} = \alpha_i + \alpha_t + \beta ELT_{it} + X_{it}\lambda + \epsilon_{it}$$

$$Y_{it} = \varphi_i + \varphi_t + \theta H_{it} + R_{it}\delta + \mu_{it}$$

$$INJ_{it} = \tau_t + \psi H_{it} + J_{it}\vartheta + u_{it}$$

Another avenue by which an elite left tackle may have an effect is interceptions thrown. The number of interceptions, *INT*, is a function of quarterback injuries as well as other factors, *V*.

$$INT_{it} = \pi_i + \pi_t + \gamma INJ_{it} + V_{it}\delta + \varepsilon_{it}$$

The other factors we include in our equation of interceptions thrown are pass attempts, yards per completion and binary variables for elite skilled position players.

Also, rather than relying on previous estimates of the relationship between yards and offensive points we include a structural equation for offensive points. We follow previous literature and specify offensive points as a function of the various ways teams can gain possession, move the ball, score and relinquish possession, *Z* (Berri, 2007; Berri, Schmidt and Brock, 2006; Simmons and Berri, 2009).

$$P_{it} = \sigma_i + \sigma_t + \eta_1 Y_{it} + \eta_2 INT_{it} + Z_{it}\kappa + \nu_{it}$$

The specification includes the number of kick off returns, punt returns, interceptions by the team's defense, recovered fumbles by the team's defense, opponent's missed field goals, average starting field position, yards gained, offensive plays, penalty yards, third down conversion rate, interceptions thrown, fumbles lost, field goals missed, extra point conversion rate, touchdown rate and year and team fixed effects.

As a result, we have a recursive system of five equations.

$$H_{it} = \alpha_i + \alpha_t + \beta ELT_{it} + X_{it}\lambda + \epsilon_{it}$$

$$INJ_{it} = \tau_t + \psi H_{it} + J_{it}\vartheta + u_{it}$$

$$INT_{it} = \pi_i + \pi_t + \gamma INJ_{it} + V_{it}\delta + \varepsilon_{it}$$

$$Y_{it} = \varphi_i + \varphi_t + \theta H_{it} + R_{it}\delta + \mu_{it}$$

$$P_{it} = \sigma_i + \sigma_t + \eta_1 Y_{it} + \eta_2 INT_{it} + Z_{it}\kappa + \nu_{it}$$

Solving the system of equations for the effect of an elite left tackle on offensive points yields $\beta(\eta_1\theta + \eta^2 \gamma\psi)$.

Table A1 contains the relevant coefficient estimates from SUR estimation of our five-equation recursive system. An All-Pro left tackle reduces the number of quarterback hits by 16.89, compared to 17.03 in the three-equation model. Each quarterback hit increases the probability of a team's quarterback missing a game due to injury by 0.61 percentage points, which is equivalent to three-equation model. As a result, an elite left tackle reduces the probability of a quarterback injury by 10.3 percentage points, the same estimate as the three-equation model. Furthermore, each quarterback hit decreases yards by 6.3, compared to 6.24 in the simplified model.

Our results indicate if a team's starting quarterback misses a game due to injury, the number of interceptions increases by 2.27. This is an intuitive result; if a team's quarterback misses at least one game due to injury, the more their backup quarterback plays; thus, an increase in interceptions. Finally, each additional one hundred yards gained increases offensive points by 7.70. Our estimate is very consistent with previous studies (Berri, 2007; Simmons & Berri, 2009). Also, each interception thrown decreases points by 1.98. In total, an All-Pro left tackle reduces the number of quarterback hits by 16.89, which reduces the probability a quarterback misses a game due to injury by 10.3 percentage points. In turn, an elite left tackle increases the number of yards by 106 and only decreases the number of interceptions thrown by 0.232. Thus, a team with an All-Pro left tackle scores, on average, 8.45 more offensive points, other factors equal. Since the final results from the two models are virtually equal, we opt to present the simplified model.

A1

Five-Equation System SUR Results

VARIABLES	QB Hits	QB Injured	Yards	Interceptions	Points
All-Pro LT	-16.89***				
	(6.060)				
OL Starters Experience	-0.0374**				
	(0.0175)				
QB Hits		0.00607***	-6.300***		
		(0.00139)	(1.225)		
QB Injured				2.266***	
				(0.659)	
Yards					0.0770***
					(0.00419)
Interceptions Thrown					-1.981***
					(0.309)
Relevant Controls	X	X	X	X	X
Team Fixed Effects	X		X	X	X
Year Fixed Effects	X	X	X	X	X
Observations	192	192	192	192	192

Note: Standard errors are in parentheses. *Significant at 10%. **Significant at 5%. ***Significant at 1%. Full results are available from the author.