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WAGES AND LABOR PRODUCTIVITY: EVIDENCE FROM INJURIES IN THE NATIONAL FOOTBALL LEAGUE

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Empirical studies face severe difficulties when identifying the relationship between wages and labor productivity. This paper presents a novel identification strategy and demonstrates that the connection between wages and labor productivity is remarkably robust even when institutional constraints serve to distort the relationship. Identification is achieved by considering injuries to professional football players as an exogenous shock to labor productivity. This is an ideal empirical setting because injured players in the National Football League cannot be replaced easily because franchises are constrained by the salary cap. Injuries are shown to play a major role in franchise success and a tight connection between wages and marginal productivity emerges. This is in spite of regulatory frictions that serve to hold down wages for some workers. (*JEL* J24, J31, Z22)

I. INTRODUCTION

A tight connection between wages and the marginal revenue product of labor is a fundamental result in economic theory (Binmore 2007; Romer 2011). Yet modern empirical studies tend to avoid testing the relationship. This is because observing and measuring the marginal productivity of labor is usually not possible. Instead, the literature typically uses secondary datasets of matched workers and firms to examine differences in earnings and panel data methods to control for unobserved heterogeneity in labor productivity (Arai 2003). These studies have provided indirect evidence that wages may depart from marginal productivity for particular groups such as women (Goldin et al. 2017; Hellerstein, Neumark, and Troske 1999) and Black men and women (Charles and Guryan 2008). More generally, workers and firms have been shown to share rents and estimates of the elasticity of labor are much lower than under the competitive model (Manning 2011). This implies varying degrees of imperfect competition, including search frictions (Richard Rogerson and Wright 2005), specific human capital (Lazear 2018) or unionization (Skovsgaard Aidt and Sena 2005). Nevertheless, other studies argue that competitive forces dominate pay-setting even in the executive labor market where these imperfections are acute (Gabaix and Landier 2008; Kaplan and Rauh 2013). Crucially, none of these studies actually measure worker productivity because they do not assess the individual's marginal contribution to the firm's revenue.

A small body of work has tried to measure marginal productivity directly. The approach requires observations of the firm's output, the assignment of a production function so that the individual contribution to output can be plausibly determined as well as wages paid to the individual workers. For example, Scully (1974) estimates marginal productivity of baseball players by assessing the effect of their performance on the probability of winning and the elasticity of the franchise's revenue to winning. Frank (1984) estimates the marginal productivity of salesmen in 13 automobile dealerships based on the number of sales and the piece rate paid to each salesman. Frank (1984) finds that wages are far more compressed than the variation in marginal productivity estimates would imply. Lazear (2000) uses individual data on auto glass installers to demonstrate the productivity gains associated with moving from hourly wages to piece rates and notes that workers on average see their pay rise

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ABBREVIATIONS

NFL: National Football League
QB: Quarterback

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by less than the productivity gain. However, confirming the relationship between individual productivity and individual wages is difficult because of standard identification issues such as omitted variable bias and reverse causality. It is unlikely that all relevant variables determining marginal revenue product can be measured without error and in Lazear (2000) there is clear evidence that the structure of wages impacts worker productivity. Therefore, a source of exogenous variation in productivity, together with data at the level of the individual is necessary to identify the relationship between wages and labor productivity.

This paper uses injuries to professional American Football players in the National Football League (NFL) to establish a direct link between wages and marginal productivity. The NFL offers unique setting to identify the relationship between wages and marginal productivity. Injuries occur frequently in the NFL and team franchises are unable to replace injured players easily because the NFL operates a hard salary cap for every franchise in the league. The marginal dollar value of talent to the franchise is equal to the marginal change in win probability from employing the talent multiplied by the dollar value of a win (Szymanski 2006). Therefore, the financial impact of an injury is the expected value lost from the reduced probability of winning. If the equality between wages and marginal product holds, the financial loss should be equal to the injured player's wage; *a dollar of injured talent is a dollar of productivity lost*.

An alternative approach to identification has been undertaken by Nguyen and Nielsen (2014). Therein, stock price reactions to the unexpected deaths[1] of top executives are used to estimate the relationship between executive compensation and their contribution to the firm's market capitalization. The authors find that higher paid CEOs do indeed have higher contributions to shareholder value. Furthermore, Quigley, Crossland, and Campbell (2017) show the market reaction to an unexpected CEO death has increased between 1950 and 2009. This is a strong result but the NFL setting employed in this paper offers some advantages in terms of identification. First, the incidence of sudden deaths to the CEO is rare, only 81 CEOs died at U.S. firms unexpectedly between 1991 and 2008, whereas there were 1,599 injuries to active NFL players between 2011 and 2015. Second, the CEO's value must be estimated with reference to the expected cost and benefits of the incoming replacement. The NFL setting avoids this complication because the hard salary cap prevents highly paid injured players being replaced with like-for-like players.[2] Third, the stock market reaction must reflect only expected productivity differences between the deceased and incoming CEO. This is perhaps a strong assumption if the market negatively prices the uncertainty introduced when the CEO suddenly dies. Therefore, while shocks to productivity can occur in other employment settings it is the high frequency of injuries, together with variation in player wages and the hard salary cap in the NFL offers specific advantages in terms of identification. In addition, unlike some empirical settings, all data necessary for analysis are in the public domain including: player wages, contracts and precise statistical measures of performance, and the market's expectation of performance is captured by the betting odds prior to kickoff.

The following section outlines the relevant economic theory associated with the wages of professional sportsmen. One complication is that institutional features of the NFL, including the salary cap itself, may affect the market clearing wage rate for talent. In Section 2.1, the possibility of injury is added to the baseline model and it is shown that the prospect of injury does not impact upon the market clearing wage of talent. However, whether player wages are actually below, equal to, or above marginal product is ultimately matter for empirical examination. Section 3 introduces the data and presents descriptive statistics, before the econometric estimation of whether $W = MRP$ in Section 4. Section 5 concludes.

II. WAGES AND PRODUCTIVITY IN THE NFL

Fort and Quirk (1995) is a well-known model in the literature that captures the essential features of the NFL labor market. The problem for team i is to choose a level of talent t_i to maximize

1. The use of unexpected deaths in post as an identification strategy has been used in other empirical settings such as Jones and Olken (2005) who use unexpected deaths of country leaders to explain country growth rates.

2. Even if a franchise is able to reorganize its team in the event of an injury to, for example the starting quarterback (QB), with an equally talented QB, it can only free up the salary cap space to do this by releasing talent from elsewhere in the team, thereby suffering a loss of productivity from those players. In practice, when starting QBs get injured it is almost always the job of the substantially lower paid backup QB to take the field until the starting QB recovers.

profits[3] π_i.

$$\pi_i = R_i(w_i(t_i)) - ct_i. \tag{1}$$

The share of talent $\frac{t_i}{T}$, generates a share of wins $w_i = \frac{t_i}{T}$ in a season. The share of wins generates revenue R_i. Each unit of talent costs c in wages so team i's wage bill is ct_i. There are no fixed costs. Total talent in the league is fixed at T units of talent.[4] With each team in the league simultaneously maximizing profits, the laissez-faire equilibrium condition is:

$$\frac{\partial R}{\partial t_i} = \frac{\partial R}{\partial w_i}\frac{\partial w}{\partial t_i} = \frac{\partial R}{\partial t_j} = c^*. \tag{2}$$

Each team in the league increases their share of the talent until the marginal revenues from talent are equal and equal to the marginal cost of talent.[5] Consequently players receive their marginal product in wages. Note this does not imply equal talent shares. In Fort and Quirk (1995), team i is able to leverage its talent stock to produce more revenue than team j because it draws from a larger fan base. A strong-drawing team will continue to increase their talent stock from weak-drawing teams until marginal revenues are equalized. This is the "dominant team" problem or the problem of "unbalanced contests" (see Borland and Macdonald (2003) for a review). A desire for more balanced contests and less certain outcomes is the basis for regulations such as the salary cap.

The NFL salary cap constrains choices over talent with a view to restoring a more equal distribution of talent. Each team's annual wage bill must be below a limit[6] determined by a fraction k of total league revenues ΣR:

$$ct_i \le \overline{C} \quad \text{hence} \quad c \le \frac{\overline{C}}{t_i}, \tag{3}$$

where $\overline{C} = k\Sigma R;\ k < 1$.

With $c = \frac{\overline{C}}{t_i}$ equilibrium wages clear below the marginal revenue of talent $\frac{\partial R}{\partial t} > c = \frac{\overline{C}}{t_i}$. If the cap $\overline{C}$ binds on both franchises then talent and wins are distributed evenly with $\frac{w_i}{w_j} = \frac{t_i}{t_j} = \frac{t_j}{t_i} = 1$. The impact of the cap on franchise profits is theoretically mixed. Because wages are held lower, profits increase (especially for the smaller franchises) but, as talent is not always able to move to where it is most profitable, franchises (particularly larger ones) lose profits to misallocation (Késenne 2000a, 2014).

The other main regulations with the claimed intention of promoting competitive balance currently in operation in the NFL are the reverse order of finish college draft system and revenue sharing. Under the draft, the worst performing teams from the prior year get the first choice from the pool of graduating college students entering the league. However, the literature has emphasized the "invariance principle" (Rottenberg 1956), which, in the spirit of the Coase theorem, argues that the initial allocation of talent does not affect final distribution of talent when talent can be traded easily between teams (although it is debatable whether this is in fact the case). Additionally, franchises in the NFL share approximately 60% of their revenue. Quirk and Fort (1992) show that revenue sharing in the standard model reduces demand for talent therefore lowers the market clearing wage but does not affect competitive balance.[7] Therefore, it is the salary cap in the NFL which potentially plays the most important role in affecting competitive

3. Profit maximization is the objective typically assumed in the literature for NFL franchises (Vrooman 1995). Another possibility is that franchises maximize wins (Késenne 2000b) subject to a profit constraint (which could be negative if the owner is willing to bankroll the franchise). While win maximization is thought to be more appropriate in some European sports (Garcia-del Barrio and Szymanski 2009), profit maximization is a reasonable approximation for North American sports (Zimbalist 2003)

4. It is argued that this is the appropriate assumption for a domestic league, such as the NFL, that is effectively closed to international talent (Késenne 2014). This assumption implies that when a team hires new talent it takes it away from another team in the league. This assumption is not appropriate for leagues open to international labor such as Association Football in the English Premier League where talent can be easily hired from Europe.

5. An alternative equilibrium condition is discussed by Szymanski (2006). Therein a strong argument is made that the choice made by teams in most professional sports is one over budget for talent and that because choices over budget are made simultaneously and independently by the teams (à la Nash-Cournot), teams do not internalize the externality that increasing their budget imposes on the other team. The result is that budget choices act as strategic substitutes and marginal revenues from talent are not equalized. However, for our purposes the simpler "Walrasian" equilibrium (Késenne 2014) is appropriate as talent supply in the NFL is fixed making teams much more aware of the externalities that their hiring choices impose. Additionally, budgets are actually fixed by the Salary Cap.

6. The cap is actually a window as NFL franchises must satisfy $ct_i > \underline{C}; \underline{C} = l\Sigma R, l < k$. While theoretically, a team could desire to spend less on talent than allowed by the lower limit, more often than not, it is the upper limit that binds on NFL franchises.

7. Alternative models of franchise behavior such as win maximization as presented by Késenne (2014) show that revenue sharing increases the clearing rate for wages and could promote balance.

balance and the extent to which players' wages are tied to the players' marginal products.

A. Injuries

In Fort and Quirk (1995) the choices over talent map one-to-one with wins. I now extend their baseline model to consider the uncertainty that is introduced when injuries shock the talent stock. This section also considers the assumption underpinning the identification strategy that will be used when estimating the relation between wages and marginal productivity.

Let team i experience a talent shock due to injury $\mu_i \sim N(0, \sigma)$. Ex ante, teams cannot foresee injuries to their talent or their rival's talent so the expectation of the shock is normalized to zero. Positive realizations of $\widehat{\mu}$ can be interpreted as injuries to the opposing team ($\widehat{\mu}_i + \widehat{\mu}_j = 0$). In the NFL, talent is distributed unevenly between players within a team so an injury to a single star player could be enough to change the sign of $\widehat{\mu}$. A team is unable to replenish its talent stock after the injury shock until the next season because of the salary cap. The wages of injured players must be honored and count towards the cap in the NFL.

When i plays j, the probability p that i wins is affected by the realization of shock. Talent stock T in the league (after all injuries are realized) is fixed and normalized to 1. At the start of the season spending on talent by the teams is equal as determined by the salary cap $t_i = t_j = \frac{\overline{C}}{c}$.

$$(4) \qquad Prob(win_i = 1) = p = \frac{t_i + \widehat{\mu}_i}{T}.$$

Injury shocks reduce the probability of winning and because wins generate revenue, expected revenue falls. If talent earns its marginal product, the total injury bill (holding j's injuries constant) equals the expected loss in revenue L:

$$(5) \qquad c^* \widehat{\mu} = \frac{\partial R}{\partial t_i}.\widehat{\mu} = \frac{\partial R}{\partial w_i}.\frac{\partial w_i}{\partial t_i}\widehat{\mu} = L.$$

Equation (5) is the key equality that this paper wishes to test. With data on injuries and player wages, the dollar value sitting out due to injury $c^* \widehat{\mu}$ can be observed. While it is not possible to observe directly the franchise revenue lost to injury $\frac{\partial R}{\partial t_i}.\widehat{\mu}$ it can be calculated by estimating the reduction in win probability from injured players $\frac{\partial w_i}{\partial t_i}.\widehat{\mu}$ together with the marginal revenue from winning $\frac{\partial R}{\partial w_i}$. This task is conducted in Section 4.

Identification of the relationship between wages and productivity is possible because injuries do not fall evenly upon franchises. In fact, franchises experience significant variation in terms of the injuries they receive. Even a single injury to a star player can have a major impact on a season. Consider the 2011 Indianapolis Colts, who lost 14 out of a total of 16 games when their star QB Peyton Manning missed the season with a neck injury. In that year, Manning was paid \$26.4M or 13% of the salary cap for no on field productivity. If Manning's wages were equal to his marginal revenue product one would expect the franchise to lose an equivalent amount of revenue from having their worst season in 20 years.

The crucial identifying assumption for an unbiased estimate of $\frac{\partial R}{\partial w_i}.\frac{\partial w_i}{\partial t_i}\widehat{\mu}$ is that the expectation of the injury shock is zero and remains zero after conditioning upon the choice of talent by franchise i, that is $E(\mu_i | t_i) = 0$. In other words, injuries are assumed to be exogenous to talent choice. What are the threats to this identifying assumption? First, because the collisions that occur on the field of play are deliberate actions one may reasonably question whether injuries are not also a part of deliberate strategy by opposing teams. Moreover, it will be seen below that injuries during the game, particularly to key players such as the starting QB significantly impact the likelihood of winning that game. This provides an incentive to injure opponents and an incentive to take actions that mitigate the injury risk. Of course, targeting players for injury is illegal and heavy penalties are imposed for any team caught doing it. However, there is sufficient ambiguity in tackling that a policy of targeting players for injury could go undetected and anecdotal evidence suggests that "bounties," small bonuses for a knock-out hit on an opponent, was a historical practice.[8] Similarly, player effort, which is unobserved to the researcher, may correlate with earnings and injury risk. An issue emerges if high earning players are injured more frequently than average players.[9] This potentially introduces a correlation between talent t_i and the injury shock μ_i. The pool of injured players from which lost productivity is being estimated could then over represent highly paid and highly talented players.

8. This was brought to light in the case of the New Orleans Saints who were heavily penalized for allegedly offering bounties for players between 2009 and 2011. Coaches and players involved were given suspensions and the franchise was fined \$0.5m and, more significantly, forfeited their draft selections for 2012 and 2013.

9. Although the main identifying specification is restricted to the QB position only.

To indicate whether or not this is a likely problem affecting the estimates, two tests are provided in the Appendix (Supporting information). Table A1 (Supporting information) performs a balance test on the control variables, according to whether an injury occurred to the starting QB during the game. If such injuries occur randomly, there should be no significant differences in the means of the observable variables. All the monetary variables are calculated net of the opposition so should be zero in expectation, irrespective of whether or not an injury occurs to the starting QB. This is indeed the case, for the total amount of injured money sitting on the bench, the Gini coefficient, the ratio of starting wages to nonstarting wages and the total wage bill. Additionally, both in the injured and noninjured groups, the team plays away from home 50% of the time and there is no difference in the number of rest days prior to the match. Crucially, the market is unable to predict within game injuries as the difference in the Vegas Spread is also approximately zero for the two groups. The table also shows the importance of the injury to the QB. The backup QB's passing rating is 16 points less than the starting QB's passing rating at the mean.

The second test is reported in Table A2 and explores the relationship between injuries and player wages in more detail. Supporting the identifying assumption that injuries are exogenous to talent choices, Table A2 finds no robust relationship between injuries and player wages. There are several plausible reasons why injuries remain exogenous. With respect to player effort, it is argued that in a professional sports environment all players will be exerting close to full effort due to near perfect monitoring by their management. It is for this reason why theoretical models of sporting contests often abstract away from player effort choices and focus on varying levels of player talent. So what then of apparent incentives to injure talented players? First, many injuries simply occur off the field or are triggered during training and therefore are not the result of a single deliberate collision by an opponent. Second, to the extent that opponents may seek to injure talented players more than nontalented players there is an equal incentive for teams to protect their talented players.[10] Third, players taking "dirty shots" can expect retaliation by the more physical players on the field and sometimes a rebuke from their own teammates. Fourth, players often continue to play through knocks received during a game and are only diagnosed with a serious injury after the game. This means the beneficiaries of an injury to a star player could be the teams who have yet to play against the injured player, rather than the team responsible for the injury. Given that any player can pick up an injury at any time, both on and off the field and even after a serious collision with an opposing player it is very difficult to predict whether or not an injure will occur, what the nature of that injury would be and the likely duration of the injury. Since the market cannot predict injuries, it is argued that there always remains a substantial stochastic element to any footballer's injury.

Section 4 tests whether Equation (5) holds, although it can be noted here that are reasons to suspect departures from this equality. In particular, with the salary cap binding, the total injury bill equals $\frac{\overline{C}}{c}\widehat{\mu} < c^{*}\widehat{\mu} = L$. If wages are constrained below the market clearing equilibrium due to the salary cap the dollar value sitting out due to injury will be less than the franchise revenue lost due to injury. Players may be willing to accept with such terms if playing for an NFL franchise affords outside earnings such as lucrative deals for product endorsements. On the other hand, as entry to the league through the draft is controlled by the existing player's union, it is possible that wages are held up above their market clearing rate for some players, for example, in favor of veteran players at the expense of rookies. Therefore, whether players earn their marginal product is ultimately an empirical question.[11]

III. DATA

An advantage of the NFL setting is that most of the data necessary for analysis is located in the public domain. Detailed information on player wages and bonuses from 2011 to 2015 was collected from spotrac.com. Richard Borghesi (2008) provided the author with data on

10. The reason that the position of left tackle is the second highest paid position is because their job is to protect the QB. This is described in detail by Lewis (2007).

11. The extent to which competition is balanced in a season is also affected by the realization of the injury shock in a similar way $\frac{w_i}{w_j} = \frac{t_i+\hat{\mu}_i}{t_j+\hat{\mu}_j}$. Since the expectation of the shock is zero, competitive balance ex ante is unchanged. However, the variance of the shock will influence the realization of the distribution of wins. If teams are closely balanced ex ante, the prospect of injury is likely to reduce balance as injuries are realized unevenly between teams. If teams are unbalanced ex ante, the prospect of irreplaceable injured talent could increase balance ex post as the dominant team has more talent to lose. However, the focus in this paper is on wages and productivity rather than competitive balance.

salaries from 1995 to 2001 which had been collected from USAToday.[12] While a player's compensation can exhibit complicating features such as signing bonuses and performance incentives the bottom line is a "CAP number" which is assigned to each year of the player's contract for the purposes of monitoring the franchise's compliance with the annual salary cap. It is the CAP number which represents the opportunity cost of the player and is essentially sunk by the franchise at the start of the season. If the player is injured, and cannot play, the CAP number remains unchanged for the duration of the season.

Performance data were hand collected from sports-reference.com. The data are at a high level of disaggregation. In addition to a large number of variables which captures team performance in each game, performance statistics for each player are available on a game by game basis. For each season, each player receives an objective performance rating based on all the plays they made during each game in the season. The QB, the highest paid and most important position in the NFL, receives a rating for every game according to a formula that measures their passing accuracy. Additionally, information from betting markets can be incorporated to capture the expectation of a franchise's performance in each game.

Detailed data on injuries and their duration are obtained from mangameslost.com for the period of analysis 2011–2015. Information on games missed in each season for the period 1995–2001 used in Table 2 is obtained from sports-reference .com. Caporale and Collier (2015) calculate the number of man-games lost over the course of the season due to injuries and use the variable as a control in a regression of win percentage over an NFL season, exploring the impact of rebalancing mechanisms such as the college draft. This paper adopts a fundamentally different approach by exploiting data on injuries to individual players and matching this information to each player's wage.

A. Descriptive Statistics

A large degree of variation in player wages will assist the identification of the causal impact of a dollar lost to injury on the probability of winning. Table 1 shows mean payments by key positions between 2011 and 2015. Panel A provides a breakdown of the different elements compensation by position. In addition, to salary, players receive additional payments when signing the contract and making the playing squad. There is substantial variation between positions. The QB commands a salary that is, on average, twice that of the running back. Panel A also shows that QBs receive more supplements to their salary. The final column in panel A labeled "Dead Money" records the amount charged to the Cap in the event that the player is cut in that year. Dead money indicates that the franchise has committed to paying the player an amount which cannot be recovered if the player is cut before the end of their contract.

As well as substantial variation between positions there is substantial variation within positions. Panel B shows the breakdown by year of the CAP hit within team franchises. The standard deviation on the QBs CAP hit is \$5m, more than twice the mean salary with larger variation at the top end of the distribution. Consistent with Rosen's (1981) "superstar" theory of wages, the 90th percentile QB is paid 10 times more than the median QB, with the 99th percentile paid a further 1.5 times the 90th percentile QB. Within the same position and team, variation is even greater. The starting QB is paid, on average, 10 times more than the backup QB. If the starting QB is injured, one can expect a substantial reduction in the probability that the team wins the game.

Table 1 also shows inflation in nominal wages at the mean over a relatively short sample period. There are small increases in the Gini coefficient over the same period, implying that the increase has gone to paying the higher paid players a little more. This has occurred alongside increases in the overall team cap. The overall cap is determined each year by a formula based on approximately 48% of total league revenues. If the salary cap is increasing, it implies aggregate franchise revenues are increasing. The Cap has increased substantially since its introduction in 1994 at \$34.6m.

Panel A of Table 2 introduces the second time period for which data are available and shows the incidence of injury over the season by position for the years 1995–2001. Season long injuries occur relatively infrequently, with only 2.9% of QBs missing the entire season due to injury. However, injuries frequently cause players to miss part of the season. Only 72.8% of QBs manage the entire season without any injury at all. Injury rates at other positions are lower, with 79% of

12. Unfortunately, USAToday has withdrawn their salary data from the public domain and wage data from 2002 to 2011 is not available.

TABLE 1
Player Wages 2011–2015

Panel A: Mean Wages by Position[a]

Position	N	Salary	Signing	Roster	Dead Money
Offense					
Quarterback (QB)	467	\$2,094k	\$1,006k	\$248k	\$4,953k
Left tackle	283	\$2,044k	\$629k	\$162k	\$3,504k
Running back	697	\$1,019k	\$295k	\$96k	\$1,044k
Wide receiver	1,091	\$1,133k	\$416k	\$106k	\$1,786k
Defense					
Defensive line	748	\$1,366k	\$501k	\$145k	\$1,889k
Line backer	738	\$1,221k	\$515k	\$134k	\$2,001k
Corner back	973	\$1,217k	\$402k	\$124k	\$1,556k

Panel B: Cap Hit Inequality Measures[b]

Year	Team Cap	Mean	SD	Gini	99by90	90by50	75by25
2011	\$120.0m	\$1,806k	\$2,410k	0.5679	2.566	6.744	4.659
2012	\$120.6m	\$1,719k	\$2,441k	0.5818	2.582	7.156	4.036
2013	\$123.0m	\$1,791k	\$2,513k	0.5885	2.550	7.301	4.167
2014	\$133.0m	\$1,900k	\$2,704k	0.5927	2.566	7.170	4.444
2015	\$143.3m	\$2,009k	\$2,842k	0.5984	2.757	7.369	4.620
Pooled		\$1,843k	\$2,587k	0.5870	2.665	7.070	4.352
Pooled QB		\$3,744k	\$5,075k	0.6352	1.501	10.427	8.519

[a] "Dead money" is charged to the cap if the player is cut. Signing bonuses are paid upon signing. Roster bonuses are conditional upon making the active roster.
[b] All wages in nominal values. 90by50 divides wages at the 90th percentile by the 50th percentile.

Offensive Linesmen to 83.6% of Linebackers going the whole season uninjured. Injuries to Punters and Kickers in the *Special Teams* are rare.

How has the incidence of injury changed over time? The NFL has become more conscious of "player safety" over the time. Recent medical research (Mez et al. 2017, 2020) has documented a high incidence of chronic traumatic encephalopathy in the brains of deceased NFL players. Although the extent of risk associated with playing in the NFL is contested by some studies (Deshpande et al. 2017), Manley et al. (2017) review the literature and conclude that multiple prior concussions are related with depression and cognitive deficits later in life. In April 2016, a federal appeals court upheld an out of court settlement between the NFL and concussion lawsuits filed by former players. The settlement is thought to be worth approximately US\$1 billion and will cover approximately 20,000 players. Since 2009, the NFL has introduced a "concussion protocol" and tightened its rules on concussions. However, it is unclear whether this will increase or decrease the number of observed cases of injury in the data. While the true injury risk is likely to be reduced, the recorded number of injuries might increase because the ability to diagnose this type of injury has improved.[13] Hanson, Jolly, and Peterson (2017) analyze the "Crown of the Helmet" rule introduced in the 2013–2014 season that made certain head collisions on offensive players illegal. They find that while concussion reports among defensive players fell by approximately 30%, lower extremity injuries for offensive players increased by a similar amount. Other restrictions on blocking and tackling have also been introduced over time to decrease the likelihood of an injury occurring.[14]

Referring to panel B of Table 2 which pools data across the years 2011–2015, the incidence of being injured for the whole season is 2 percentage points higher for QBs compared to the 1995–2001 period. While a small increase in absolute terms, this is two-thirds higher than the prior period. It appears the reduced injury risk has been offset by the increased rate of injury detection (and perhaps an increased fear of litigation) between the two periods. However, the

13. As of 2016, whenever a potential concussion is identified the player is removed from the game and an independent Neurotrauma consultant will examine the player.

14. For example, in 2016, the "chop block," where a player blocks another high on the body, while a teammate hits the same player low, became illegal due to risk of knee injuries.

TABLE 2
Player Injuries

Panel A: 1995–2001

Position	*N*	*N* injured	Injury Frequency			
			Missed 16	**Missed 7–15**	**Missed 1–6**	**Missed 0**
Offense						
Quarterback	522	142	0.029	0.081	0.163	0.728
Running back	1,051	187	0.021	0.031	0.126	0.822
Wide receiver	1,102	190	0.018	0.038	0.116	0.828
O Line	2,423	503	0.022	0.043	0.144	0.791
Defense						
D Line	1,717	312	0.019	0.026	0.137	0.818
Line backer	1,431	237	0.018	0.030	0.117	0.836
D cover	1,958	335	0.018	0.030	0.122	0.829
Special Teams	261	5	0.019	0.000	0.000	0.981

Panel B: 2011–2015

Position	*N*	*N* injured	Injury Frequency			
			Missed 16	**Missed 7–15**	**Missed 1–6**	**Missed 0**
Offense						
Quarterback	349	92	0.049	0.106	0.109	0.736
Running back	574	115	0.017	0.052	0.130	0.801
Wide receiver	796	167	0.013	0.053	0.145	0.790
O Line	1,635	439	0.026	0.072	0.174	0.731
Defense						
D Line	1,144	227	0.013	0.047	0.140	0.801
Line backer	991	230	0.019	0.052	0.159	0.770
Cover	1,384	328	0.017	0.062	0.160	0.762
Special Teams	163	1	0.006	0.000	0.000	0.994

Notes: 1. Data on games missed are calculated from sports-reference.com. *N* counts the number of player-seasons at each position. 2. *N* injured counts the number of player-seasons with any injury of any duration. 3. Injury frequency is the proportion of players who missed any part of *X* number of games that year. For example, in panel A, only 2.9% of QBs missed the entire season but only 72.8% of QBs went the entire season without missing any playing time due to injury. 4. *O Line* comprises guards, centers, tackles, and tight ends. *D Line* comprises defensive ends and tackles. *Cover* comprises safeties and corners and defensive backs. *Special Teams* comprises kickers, punters, and long snappers.

likelihood of the QB going the entire season uninjured is marginally higher in the later period. Together, these descriptive statistics are consistent with increased protection of the QB position so that minor injuries occur less often, but when major injuries do occur they are treated more seriously and force longer absences from the field of play.

The differences between the time periods at other positions are not so clear. The rates of season long injury are broadly similar in the second period and marginally fewer players go the entire season uninjured. It would appear that it has been the QBs who have been the main beneficiaries of the rule changes that have targeted player safety. It is clear then that QBs are not only paid very differently to other players but also experience injuries differently as well. This motivates a separate analysis of injuries and wages to QBs below.

Table 3 uses more detailed data on injuries from mangameslost.com for the period 2011–2015. Here, injuries are defined as those that made the weekly injury report declared to the NFL. The data identify the area of the body hurt but not the specific diagnosis of the injury or cause of the injury.[15] Duration is calculated by taking the number of days from being declared injured until the date of the next game when the player was available for selection and the mean number of weeks is reported. Duration is right censored at 7 days after end of the regular season. Knee injuries are the most common injuries and keep players out for a relatively long period of time, almost 9 weeks on average. Only 6.5% of injuries that lead to missed game time were due to concussions and these players were rested for an average of 3 weeks. Given the particular interest in concussion injuries in the NFL,

15. For example, the data did not distinguish between arm injuries that are bone fractures and arm injuries that are muscular.

TABLE 3
Injury Types 2011:2015

Injury	*N*	Percent	Duration (Weeks)	SD
Knee	1,224	21.22	8.85	13.08
Ankle	710	12.31	4.45	6.71
Hamstring	668	11.58	3.22	4.44
Leg	408	7.07	5.48	11.37
Shoulder	380	6.59	5.96	8.55
Concussion	377	6.54	3.27	6.07
Foot	375	6.50	7.25	9.60
Groin	240	4.16	2.81	3.01
Hand	203	3.52	4.72	4.92
Back	174	3.02	5.24	9.04
Chest	158	2.74	5.24	7.50
Hip	132	2.29	7.15	12.09
Illness	132	2.29	4.98	12.19
Neck	103	1.79	6.22	10.64
Undisclosed	99	1.72	12.70	10.48
Achilles	96	1.66	14.11	11.57
Arm	85	1.47	9.44	5.75
Head	84	1.46	2.57	3.51
Elbow	60	1.04	4.41	5.12
Other	60	1.04	3.33	3.26
Total	5,768	100.00	5.95	9.58

Notes: 1. The data are from mangameslost.com and cover the main period of analysis 2011–2015. 2. *N* counts the number of unique injuries to players in the NFL between 2011 and 2015. Percent is the percentage of all injuries accounted for by the injury type. 3. In 2.7% of cases, two body parts were identified as injured. To avoid double counting, the injury was assigned to the first recorded category. For example, "knee/ankle" was classified as a knee injury, whereas "ankle/knee" was classified as an ankle injury.

TABLE 4
Concussion Injuries 2011:2015

Position	*N*	Percent	Ave Duration (Weeks)
Non-quarterback			
2011	58	5.37	3.77
2012	61	5.22	3.62
2013	64	6.40	2.31
2014	67	5.45	3.24
2015	103	9.25	2.27
All seasons	353	6.34	2.94
Quarterback			
2011	2	6.25	7
2012	4	12.90	2.92
2013	7	13.33	3.65
2014	3	8.33	5.33
2015	10	21.74	2.28
All seasons	26	13.16	3.76

Notes: 1. Compiled using injury data from mangameslost.com. *N* counts the number of concussion injuries to players in the NFL between 2011 and 2015, where the concussion placed the player on injury report for at least one game. Players who were treated for concussion but reported fit and did not miss any game time are not recorded as having concussion in the data. 2. Percent is the percentage of all injuries (in the year) accounted for by concussions.

Table 4 breaks down the concussion injuries by season for both QBs and non-QBs. Reported concussions account for a greater proportion of injuries among QBs and increase over time for both groups.

B. Injuries and the Probability of Winning: Game Level

The data allow estimation of the impact of injuries on the probability of winning at different levels of aggregation. A season-level analysis using data from 1995 to 2001 is provided in the Appendix. Therein, total injuries of the course of the season are shown impact the win percentage over the 16 games of the regular season. However, a limitation of analysis at the season level is that it aggregates information across all the games in the season. Important determinants of match outcomes, such as which team is playing, the market odds prior to kick off, whether or not the team is playing at home can only be controlled for on a game by game basis.

For the purposes of identification, injuries that occur to QBs within the game itself represent the tightest specification. Prior to this, let it be shown that injuries to all players prior to match day also have an impact on the likelihood of winning that particular match. Table 5 reports the game level analysis where each of the 32 NFL franchises plays 16 games over 5 regular seasons, 2011–2015. Additionally, the wage data available in the period 2011–2015 are more detailed than that from 1995 to 2001 because the data record the official "cap number" that represents the charge to the salary cap for the franchise over that season.

For each game, the dependent variable takes the value of 1 if a win is recorded and zero otherwise. Estimation is by logit and a conditional logit which controls for team level fixed effects. Controlling for fixed effects over a 5-year period should be a reasonably tight specification because unobservables such as training facilities and franchise culture should not vary a great deal over this time period. *Ln Injured Money* (*net*) is the natural log of total wages for players who were unable to play that game net of their opposition's injured wages. This variable mirrors the injury shock $c.\mu_i$ outlined in the theory section above. Table 5 reports the estimated coefficients and marginal effects for the main variables of interest are interpreted below.

TABLE 5
Injuries on the Probability of Winning: Game Level 2011:2015

	Logit			Logit FE		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Ln Injured Money (net)	−0.31***	−0.19***	−0.12**	−0.31***	−0.20***	−0.12*
	(−5.63)	(−3.21)	(−2.07)	(−5.33)	(−3.31)	(−1.96)
Control variables						
Starter Gini (net)		−0.53	0.0069		−0.70	0.00021
		(−1.09)	(0.014)		(−1.22)	(0.00035)
Starter/nonstarter (net)		0.19	0.11		0.19	0.10
		(1.52)	(0.86)		(1.42)	(0.72)
Away		−0.64***	0.025		−0.65***	−0.014
		(−7.69)	(0.25)		(−7.63)	(−0.14)
Ln Wage Bill (net)		1.27***	0.49		1.44***	0.75
		(2.86)	(1.09)		(2.98)	(1.51)
Rest Days (net)		0.0026	−0.011		0.0012	−0.011
		(0.15)	(−0.62)		(0.072)	(−0.64)
Win $\%_{t-1}$ (net)		1.05***	−0.11		0.80***	−0.20
		(8.10)	(−0.72)		(6.25)	(−1.32)
Prior Season Win % (net)		0.75***	0.078		0.35**	−0.11
		(4.92)	(0.47)		(2.03)	(−0.61)
Prior Season Super Bowl Win (net)		0.47**	0.19		0.43**	0.22
		(2.57)	(1.00)		(2.22)	(1.09)
Vegas Spread			0.14***			0.13***
			(13.1)			(11.6)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,555	2,555	2,555	2,555	2,555	2,555
Number of teams	32	32	32	32	32	32

Notes: Estimated coefficients reported not marginal effects. The estimated coefficient of *Ln Injured Money* (*net*) in column 1 implies a marginal effect of −0.076. *t* statistics in parentheses (adjusted for clustering at team level). *$p<0.1$; **$p<.05$; ***$p<.01$.

The estimated coefficient of the raw effect of *Ln Injured Money* (*net*) in column 1 implies an average marginal effect (AME) of −0.076. A one standard deviation increase in this variable ($15.25M) implies a 9 percentage point reduction in the probability of winning that game (unconditional). With 16 games in the season, the one standard deviation injury shock implies losing 1.47 games in the season. To equate wages with marginal revenue product a single win for the franchise would need to be equal to $10.4M.

The control variables that play an important role in win probability include *Away*, a dummy which equals 1 for an Away fixture (AME 0.13) and the total wage bill of the franchise net of the opponent (AME 0.28) in the relevant year. Two measures on inequality within the franchise are included; the Gini coefficient among starting players and the ratio of the starters wage bill to nonstarters. However, neither of these variables is statistically significant. Three variables capturing the form of the team, net of their opposition are included: the win percentage during the season up to the game in question, the win percentage of the prior season and an indicator for the prior season Super Bowl champions. Each of these variables predicts a win with current season performance being the most informative.

The most important control variable for the analysis is the Vegas Spread for each game which is included in columns 3 and 6. This provides the market's expectation of the probability of winning. For each game, an under/over spread is offered on either team. If A plays B and the Vegas Spread is +7, then the market is predicting that A has a 50% chance of winning by 7 or more points and that B has a 50% chance of winning or losing by 7 or less. Card and Dahl (2011) show this variable is an unbiased predictor of match outcomes and a replication of their test with this more recent data period is shown in the Appendix. The estimated coefficient in column 6 implies an extra point on the spread is worth 3% in win probability. As all the control variables in Table 5 are known to the market prior to kick off, one would expect them to be priced in to the Vegas Spread, otherwise it would imply outstanding arbitrage opportunities. As shown in columns 3 and 6, the control variables are no longer predictive of the match outcome once the Vegas Spread is accounted for. However, there remains an effect on the margin of statistical significance for the main variable of interest *Ln Injured Money* (*net*). This is likely due to some uncertainty prior to kick off surrounding the extent of injury to some players. Whether a player misses a game due to injury is coded retrospectively as a one or zero and it is not known whether the market gave an a player who is coded injured some chance of playing prior to kick off. Potential for measurement error arises in cases of recurring injuries. In other words, the market is unable to price in all injuries perfectly prior to kick off. These imperfections motivate a more precise analysis using injuries to QBs during the game itself in the following section.

IV. MAIN RESULTS

A. *Injuries and the Probability of Winning: Within Game Analysis*

The most critical position in the NFL is the QB. They are the highest paid and play a unique role in the side as they are responsible for play selection as well as play execution.[16] More so than a captain in association football or a point guard in basketball, QBs have a major bearing on the outcome of the game. In their 53 man squad (roster), a team will employ a starting QB and at least one and sometimes two or three backup QBs in case of an injury to the starting QB. As such an injury within a game to the starting QB represents the cleanest shock to labor productivity in the NFL.

For the period 2011–2015, it is observed in the data whether the starting QB was replaced by the backup QB during the game. This information is cross-referenced to data on injuries from mangameslost.com where the nature of the injury and its duration (as shown in Table 3) are observed. This allows one to exclude instances of "tactical substitutions," where the starting QB is not really injured but replaced by the backup QB for performance reasons. On occasions, QBs are substituted late in the game when the contest is already won and these can be excluded when there is no subsequent reported injury.[17]

Table 6 shows the results. When the backup QB is required to take the field the team is more likely to lose by 28 percentage points (AME "Injured QB" column 1). Likewise if the opponent's QB steps in the team is more likely to win by 28 percentage points. These estimated effects are equivalent to giving the other team 9.5 points on the spread. Column 2 confirms that this injury is not predicted by the market prior to kick-off and column 3 shows this is unaltered by unobserved franchise fixed effects. An injury to the starting QB is clearly a major shock to the franchise.[18]

Most starting QBs experience variation in form over their career and therefore their contribution relative to a backup QB is likely to vary. It is possible to control for how well a QB played during the game with their official "passing rating." Passing rating is measured on a scale from 0 to 158.3 points for a perfect game.[19] The estimated coefficient on passing rating in column 4 shows how important the QB's performance is to the probability of winning. A one standard deviation increase in the passing rating corresponds to a 19% point increase in the likelihood of winning. Backup QBs replacing injured QBs on average have 16 fewer points in passing rating per game, which equates to 12 fewer percentage points in the likelihood of winning each game. Passing rating is capturing approximately half of the effect of substituting in the Backup QB. Of course, in any one game a Backup QBs can play well and help their team win.[20] However, given the same passing rating in the game, an injury to the starting QB further reduces the likelihood of winning. It is likely that the weaker passing game of the backup QB allows the opposition defense to line up against running plays with greater certainty, rendering non-passing plays less effective.

16. Plays are also designed and selected by the head coach and offensive coordinator.

17. One limitation is that the time of injury in the game is not recorded. One might expect an earlier injury to have a larger impact than a later injury. Table A7 in the Appendix explores this using match reports from sports-reference.com for a subsample of QBs and finds that: injuries in all quarters have a significant impact on match outcome, later injuries are more common and earlier injuries are not significantly more impactful than later injuries.

18. "Injured QB" was also interacted with year dummies to test for variation in the relationship over time. None of the year interactions were significant. Results available on request.

19. Four categories are used as a basis for compiling a rating: percentage of completions per attempt, average yards gained per attempt, percentage of touchdown passes per attempt, and percentage of interceptions per attempt. A passing rating of over 100 is considered a very good performance http://www.nfl.com/help/quarterbackratingformula.

20. Nick Foles won the most valuable player award in his winning Super Bowl appearance in 2017 as a backup QB with an excellent passing rating of 106.1, 15 points above the average for a starting QB and 26 points above the average for a backup QB.

TABLE 6
Injuries on the Probability of Winning: Within Game QBs 2011:2015

	(1)	(2)	(3)	(4)	(5)
Injured QB	−1.18***	−1.28***	−1.24***	−0.72***	
	(−6.69)	(−6.83)	(−6.53)	(−2.96)	
Injured QB (opp)	1.19***	1.31***	1.34***	0.84***	
	(6.80)	(7.02)	(7.14)	(3.43)	
Vegas Spread		0.15***	0.14***	0.099***	0.099***
		(18.6)	(16.0)	(6.67)	(6.68)
Passing rating				0.056***	0.056***
				(19.3)	(19.3)
Passing rating (opp)				−0.058***	−0.058***
				(−19.2)	(−19.2)
Δ Injured-Backup QB wage					−0.048***
					(−2.98)
Δ Injured-Backup QB wage (opp)					0.055***
					(3.46)
Control variables					
Ln Injured Money (net)				−0.019	−0.020
				(−0.22)	(−0.23)
Gini coefficient (net)				1.02	1.05
				(1.29)	(1.33)
Starter/nonstarter (net)				0.058	0.058
				(0.32)	(0.32)
Away				−0.23*	−0.22*
				(−1.70)	(−1.69)
Ln Wage Bill (net)				0.46	0.45
				(0.73)	(0.71)
Rest days (net)				−0.00019	−0.00044
				(−0.0085)	(−0.020)
Win $\%_{t-1}$ (net)				−0.12	−0.12
				(−0.61)	(−0.60)
Prior Season Win % (net)				−0.20	−0.19
				(−0.82)	(−0.79)
Prior Season Super Bowl Win (net)				0.35	0.35
				(1.38)	(1.37)
Year dummies	No	No	No	Yes	Yes
Fixed effects	No	No	Yes	Yes	Yes
Observations	2,555	2,555	2,555	2,555	2,555
Teams	32	32	32	32	32

Notes: Estimated coefficients after logit (conditional logit for FE) reported. *t* statistics in parentheses (adjusted for clustering at team level). $^*p < 0.1$; $^{**}p < .05$; $^{***}p < .01$.

Additionally, to the extent that the starting QBs may possess superior leadership skills, are better at changing the play at the line of scrimmage or are better at running the ball themselves, franchises may benefit from these attributes.

There is considerable variation between franchises in the difference in wages between starting and backup QBs and therefore the shock of losing the starting QB to injury is also expected to vary. Column 5 examines "Δ Injured-Backup QB wage" which interacts an injury to the starting QB during the game with the wage differential between the starting QB and backup QB who replaced them. The estimated coefficient for this variable implies a one standard deviation increase in the wage differential is associated with a loss of 7 percentage points in the likelihood of winning, conditional upon the starting QB getting injured during the game. For illustrative purposes, a one standard deviation in wage differential is approximately \$11M at the median. Therefore, the implied marginal productivity for \$10M of QB wages would equal approximately 6.6 percentage points in the likelihood of winning each game, or approximately 1 game over the course of the regular season. Therefore, a win would need to be worth approximately \$10M to the franchise in order to equate median QB wages with their marginal revenue product. This is almost exactly the same as the estimates obtained above when adding up the wage bill of injuries at all playing positions, albeit the identification on QB injuries is much more precise.

As expected, the effects sizes in Table 6 are symmetric for the opposition variables (none of the differences in magnitude of the estimated coefficients are statistically significant). The control variables act upon the match outcome in a similar way as in Table 5. The Vegas Spread remains the most important predictor of the match outcome, albeit the magnitude, conditional on what the QB achieved the game, is reduced in columns 4 and 5. This is expected as the market cannot predict perfectly how a QB will perform in any one game. After controlling for *Vegas Spread*, none of the control variables are expected to be statistically significant as all these variables are public information prior to kickoff. However, a negative coefficient on *Away* emerges because the specification requires passing rating (which is not known prior to kick off) to be held constant. Because passing rating is systematically lower when QBs play away from home, holding this constant introduces collinearity with *Away*. If passing rating is omitted, then the coefficient on *Away* returns to being statistically insignificant from zero.

Altogether, these estimates imply that an injury to the starting QB has a major bearing on the outcome of the match and the impact and the size of the effect is proportional to the wage differential between the starting QB and backup QB. Note that the impact of the amount of injured money *Ln Injured Money* (*net*) is no longer statistically significant after conditioning on the QB's performance during the game and the Vegas Spread. Therefore, the most relevant identifier of a shock to labor productivity among NFL players appears to be an injury to the starting QB. As stated above, the estimates imply that a win will need to be worth approximately $10M to justify the marginal difference in wages between the starting and backup QBs. The next section seeks to determine whether or not this is the case.

B. How Much Is a Win Worth?

Starting QBs are paid on average approximately 10 times the amount of the backup QB. However, it has been shown above that the team is not 10 times less likely to win without their starting QB, rather approximately 28 percentage points less likely to win each game. If the median 8-8 team was forced to go the entire season with the backup QB they would still be predicted to win between 3 or 4 games in the season. Such a team would not make the postseason playoffs but how much does winning matter for the revenue of the team? If wages are, on average, equal to marginal product, the prediction is that the four to five win difference over the season is worth the difference in wages between the backup and starting QB.

While the precise value of a win is likely to be fairly volatile between franchises it is possible to obtain a reasonable estimate for the sample period from data on franchise finances provided by Forbes. Forbes provided the author with franchise book values for the years 1995–2017 and franchise revenues for the years 2000 and 2005. Additionally, revenues and operating income are currently publicly available on the Forbes website for the years 2008–2017. Table 7 shows the large increase in mean revenues and book values experienced NFL franchises by between 2000 and 2017 alongside the increase in the salary cap.

One complication in estimating the elasticity of revenue to a win is that approximately 60% of franchise revenues are pooled and then redistributed. This is principally through a collective arrangement to share media revenue. The increase in revenues observed in Table 7 is predominately driven by media revenue and the growth in book values is heavily influenced by the public subsidization of new NFL venues. Franchises earn approximately 20% of their revenue from their venue which is unshared (Vrooman 2012). As there are only 16 games in the regular season, the elasticity of game day attendance to winning is somewhat muted in the short run (see Table A6). This is consistent with Bradbury (2019) who shows that revenues in the NFL are insensitive to the current and prior season on-field performances.

However, over a longer period of time, a franchise can generate additional revenues steadily building up its core support. This raises revenue through game-day gate receipts and merchandise. Additionally, as the NFL has increased its market reach over the sample period, with regular season games occurring internationally, in the United kingdom and Mexico, the more successful teams are the better positioned teams to attract new international support. Additionally, support for the public subsidization of NFL infrastructure and franchise stadia is arguably related to the intensity of local support. But to what extent is winning important in this revenue development? Vrooman (1995) estimates a 3-year win elasticity over the period 1990–1992 of .12, which implies if the average win rate doubles over these 4 years franchise revenues would increase by 12%. Vrooman (1995) and

TABLE 7
Franchise Revenues and Income

		Revenue		Book Value		Operating Income		
Year	***N***	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Salary Cap**
2000	31	$116.20m	19.61	$423.45m	107.45	$15.54m	15.20	$62.17m
2005	32	$188.41m	26.41	$818.97m	134.61	$32.43m	13.14	$85.50m
2008	32	$221.56m	26.73	$1,040.00m	177.92	$24.66m	12.30	$116.00m
2009	32	$236.66m	27.60	$1,042.50m	188.63	$32.26m	20.54	$123.00m
2010	32	$250.50m	41.34	$1,022.44m	223.83	$33.31m	29.57	—
2011	32	$260.78m	39.06	$1,036.31m	237.50	$30.60m	23.30	$120.00m
2012	32	$275.72m	55.13	$1,106.72m	284.43	$41.11m	44.50	$120.60m
2013	32	$286.47m	60.85	$1,165.47m	316.56	$44.03m	48.18	$123.00m
2014	32	$299.22m	63.46	$1,427.81m	532.47	$53.32m	50.35	$133.00m
2015	32	$346.59m	69.52	$1966.96m	628.05	$76.21m	50.45	$143.28m
2016	32	$379.91m	75.98	$2,338.44m	570.12	$91.53m	52.51	$155.27m
2017	32	$411.13m	92.76	$2,522.03m	626.20	$101.38m	58.96	$167.00m
% change		254%		496%		483%		169%

Notes: 1. NFL franchises owners opted out of the collective bargaining agreement in 2010 that provides for the salary cap. 2. There is a mechanical relationship between league wide revenues and the salary cap under the NFL's collective bargaining agreement between the NFL franchises and the player's union the NFLPA. Under the current agreement, the salary cap is approximately 48.5% of total league revenues.

Source: Forbes.

Bradbury (2019) show that NFL revenues are considerably less win elastic than the other major U.S. sports. However, if measured over a longer period of time, the arguments laid out in (Vrooman 2012) would imply higher win elasticities.

Table 8 shows the impact of winning on franchise book values and revenues as measured by a rolling average of the franchise's win percentage between 2000 and 2017. Column 1 reports the unconditional coefficient suggesting a 10 percentage point increase in the rolling win rate is associated with approximately $50m in the annual book value over the sample period. A 10% point increase is equal to the median 8-8 team improving to 9.6 wins on average period season, which is coincidentally almost exactly a one standard deviation increase. A two standard deviation increase is broadly equivalent to an 11-5 season on average and worth approximately $100m in book value and $30m in revenue per annum. Therefore, a single win in the regular season would be worth c.$10m per annum, on average in the long run. Recall, from the estimates in Section 4.1, a win would need to be worth approximately $10m for the median QB wages to be equal to their marginal revenue product. Even allowing for a degree of imprecision in these regression estimates it is remarkable that such a tight connection between wages and marginal revenue product has emerged.[21]

Columns 2 and 5 demonstrate the result is robust to the inclusion of a wide set of observable controls[22] while columns 3 and 6 control for unobserved franchise fixed effects. The set of year dummies capture the growth in book values and revenues reported in Table 7 and contribute to the high R^2 values.

C. *Wages and Productivity: Heterogeneity between Rookies and Veterans*

From the estimates in Section 4.1, a win needed to be worth $10m for the median QB wages to be approximately equal to their

21. It should be noted that the threats to identification such as reverse causality and omitted variable bias that motivated the empirical strategy in the first stage are not as critical when estimating how much a win is worth. With respect to reverse causality, the ability of higher revenue franchises to increase their win-rate is significantly curtailed by the operation of the hard salary cap. With respect to time-varying heterogeneity, the fundamental heterogeneity between franchises that drives revenue potential is the size of the population in the local metropolitan area (Fort and Quirk 1995) and this is stable over time. The largest franchises in 2000 (Dallas Cowboys, New York Giants) remain the largest franchises in 2017. What drives the majority of variation in revenue is the win-rate of the franchise and the demand for the media product which is common to all franchises. As a consequence, the simple ordinary least squares analysis in Table 8 is able to account for a very large proportion of the variation in franchise revenues over the sample period. Moreover, since the salary cap is mechanically tied to league revenue growth, one can be confident that the relationship between winning and revenue will hold as the nominal value of a win changes in the future due to market growth.

22. The set of control variables in Table 8 are also interesting. A set of controls for the initial conditions of the franchise in 1995 are included to capture long term legacy

TABLE 8
Sensitivity of Winning to Revenues and Book Values

	Book Value			Revenue		
	OLS (1)	**OLS (2)**	**FE (3)**	**OLS (4)**	**OLS (5)**	**FE (6)**
Rolling win percentage	498***	352***	377***	152***	85.8***	147***
	(4.52)	(3.67)	(2.69)	(4.65)	(3.58)	(3.18)
Initial conditions in 1995						
No. wins		0.33			−0.059	
		(0.77)			(−0.64)	
No. Super Bowls		63.0***			13.6***	
		(7.14)			(7.11)	
No. post season years		1.94			1.28*	
		(0.55)			(1.70)	
Franchise age		−4.25*			−0.43	
		(−1.93)			(−0.91)	
Stadium variables						
Capacity		10.00***			2.96***	
		(8.06)			(10.5)	
Ln (total build cost)		71.0***			15.9***	
		(6.50)			(5.67)	
New stadium		108***	252***		21.8***	45.3***
		(4.68)	(8.99)		(3.95)	(7.15)
Yrs since expansion		−3.66**			−0.36	
		(−2.31)			(−0.86)	
Metropolitan area controls						
Ln population		49.5***			7.44**	
		(3.31)			(2.37)	
Population growth rate		−4.16			−3.52	
		(−0.27)			(−1.05)	
Only franchise		295***			72.0***	
		(7.41)			(8.31)	
Main franchise		118**			12.5	
		(2.20)			(1.08)	
No. substitutes		60.6***			16.2***	
		(4.20)			(5.14)	
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	721	721	721	383	383	383
R^2	0.835	0.899	0.912	0.694	0.867	0.905
No. teams	32	32	32	32	32	32

Notes: 1. Book values available 1995–2017. Revenues available for 2000, 2005, 2008–2017. 2. All monetary variables in December 2017 prices. 3. The estimated coefficient in column 3 and 6 implies 10 percentage point increase in the rolling win rate increases book values by \$50M and revenues by \$15M respectively. 4. The R^2 range between 69.4% and 91.2%. These high values are due to the large growth in franchise book values and revenues that occurred over the sample period. This this growth is captured by the set of year dummies. Excluding the year dummies reduces the R^2 to between 0.4% and 46.2%.

effects. The total number of historical wins and the age of the franchise do not impact book value or revenue but a historical Super Bowl win is worth approximately \$63M (\$13M in revenue). The stadium variables are statistically and economically significant. An extra 1,000 in capacity is associated with \$10M in value and \$3M in revenue. More expensive stadia raise revenues and book values (a 10% increase in build cost is associated with \$7M in book value and any stadia related debt is excluded from the book values). Building a new stadium in the franchise period is associated with \$252M of value on average for that franchise (FE estimate) and each year the stadia is not renewed costs the franchise \$3.6M in book value. Turning to the Metropolitan area controls: a 10% increase in local population is associated with c.\$5M in franchise value albeit the growth rate of the local area does not impact franchise values. Holding a monopoly over the local metropolitan area is worth \$295M relative to secondary franchises in the area (e.g., the New York Jets) and \$177M more than primary franchises (e.g., the New York Giants). The number of substitute franchises from the other three main sports,

marginal revenue product and the estimates above suggest this is the case. However, it is important to emphasize that the estimates of marginal productivity are derived from point estimates at the mean. As such, it can be stated with reasonable confidence that QBs close to the mean of the wage distribution appear to be paid their close to their marginal revenue product. However, this result may mask heterogeneity

Baseball, Basketball, and Hockey is positively associated with NFL franchise values and revenues. This reflects the fact that franchise location is endogenous in the United States and there are several examples of NFL franchises relocating to higher demand local areas. In sports outside of the United States, such as the English Premier League, team location is more plausibly exogenous and one might expect an inverse correlation between revenues and the number of substitute sporting events in the local area.

in the relationship between wages and productivity elsewhere in the distribution. As shown in Section 3, there is a wide distribution of wages both within the QB position and between QBs and other positions. To what extent can these differences be explained by differences in productivity?

There are reasons to suspect that some players represent better value for money than others. In particular, an important institutional friction of the NFL is a player's eligibility for free agency. Newly drafted players out of college, known as "rookies," are not free to leave the franchise to which they are drafted under the terms of their first contract which typically lasts 4 years. After serving their rookie contract, players become unrestricted "free agents."[23] The franchise however can cut a player at any time. Although rookies can try to renegotiate the terms of their rookie contract before their contract is over, there remains a considerable difference in bargaining power between rookies and veteran players. Furthermore, veterans are in short supply because many rookies will leave the NFL before being eligible for free agency, either because they have a career ending injury or, more likely, because they fail to make the roster of their franchise. This has been highlighted by Vrooman (2012, 8) who argues "It is common for veteran players to coalesce with management to bargain away the rights of future generations of disenfranchised rookies and forgotten former players. This creates a twisted bilateral monopoly where veteran players are often overpaid because of upper-tier monopoly power, while rookies are exploited because of owners" lower-tier monopsony power'.

Table 9 shows the impact of being a rookie on wages across all positions and within each position. Rookies are paid 46% (exp(0.62) − 1) less on average than veteran players. It is important to note that this difference remains after controlling for individual productivity and team level fixed effects. Productivity up to the season in which wages are determined is captured by the "approximate value" (AV) metric. This metric is supplied by sports-reference.com and accounts for the points achieved (conceded) per drive and distributes these points based on the contribution of the player, in their position, to those points. While AV is indeed "approximate" and between position comparisons are noisy, it is an objective and verifiable measure of every player's productivity for each season that they play and is consistently measured within position and overtime. AV is recorded on a scale of 0–26, with the mean of 4 and a standard deviation of 3.72. Therefore a one standard deviation in productivity results in an increase in wages of approximately 44%. It is also noteworthy that there is no impact of being placed on injured reserve. This shows that the wages of injured players are indeed honored for the year and that the exclusion restriction requiring that wages do not predict injuries appears to hold. Overall, the large differences in rookie and veterans wages cannot be solely explained by differences in their productivity. Given that it was argued above that the median player is being paid close to their marginal revenue product, it is highly likely that rookies, (on average), are below their marginal product and veterans above it. This is consistent with monopsonistic exploitation of rookies as advanced by Vrooman (2012).

Alternatively, underpayment relative to marginal revenue product for rookies and overpayment for veterans could reflect a non-exploitative model of deferred compensation as in (Lazear 1979). One possible view of the large increase to player wages that occurs when players become free agents is as an incentive mechanism for players to exert full effort both before and after free agency. As rookies, players exert effort to maximize their marketability when they enter free agency. If less than full effort is supplied the rookie risks dropping out of the league before their big pay day. After entering free agency, veterans will also exert full effort because pay at their franchise would exceed their outside option of their marginal product and so do not want to risk being traded. Rookies are not exploited in this model because the optional value of deferred compensation offsets the underpayment in wages. However, deferred compensation contracts are more readily applicable to working environments where monitoring productivity is prohibitively costly (Huck, Seltzer, and Wallace 2011). Because rookie performances are easily observed and under-performing rookies easily dismissed, it is hard to explain why a franchise would need to adopt this incentive mechanism. Moreover, deferred compensation contracts are expensive. Given the high degree of uncertainty associated with surviving until free agency rookies will discount the optional value of the free agency pay-day by a considerable amount. A precise estimate of the option value is difficult because

23. Under current rules, franchises are also allowed to restrict the movement of one free agent known as the "franchise tag."

TABLE 9
Wages: Rookies Versus Veterans

	All	QB	D Line	D Cover	LB	O Line	RB	WR
Rookie	−0.62***	−0.53***	−0.48***	−0.63***	−0.60***	−0.65***	−0.39***	−0.63***
	(−20.0)	(−3.92)	(−7.19)	(−8.97)	(−10.0)	(−14.3)	(−4.22)	(−6.62)
$ApproximateValue_t - 1$	0.12***	0.15***	0.17***	0.16***	0.12***	0.099***	0.096***	0.18***
	(16.4)	(4.98)	(8.17)	(8.81)	(8.93)	(8.29)	(4.55)	(7.90)
$ProBowl_t - 1$	0.32***	−0.072	0.40***	0.23	0.17	0.35***	0.41**	0.28**
	(6.82)	(−0.41)	(4.75)	(1.40)	(1.39)	(3.41)	(2.08)	(2.35)
Injury reserve	0.0099	−0.061	0.19***	−0.037	0.015	−0.0087	−0.26***	0.014
	(0.38)	(−0.23)	(3.62)	(−0.71)	(0.26)	(−0.18)	(−3.14)	(0.20)
$No.games_t - 1$	0.018***	0.0086	0.013**	0.036***	0.015**	0.016***	0.0027	−0.0083
	(7.18)	(0.46)	(2.22)	(4.58)	(2.26)	(3.39)	(0.27)	(−0.73)
Draft round (first round omitted)								
Second round	−0.38***	−0.36	−0.37***	−0.22	−0.35***	−0.36***	−0.37*	−0.25
	(−9.27)	(−1.59)	(−4.31)	(−1.65)	(−2.97)	(−3.75)	(−1.76)	(−1.66)
Third round	−0.60***	−0.85***	−0.45***	−0.37***	−0.78***	−0.67***	−0.49**	−0.24
	(−11.6)	(−2.85)	(−3.81)	(−3.29)	(−8.16)	(−5.31)	(−2.58)	(−1.34)
Fourth round	−0.60***	−0.95**	−0.51***	−0.28**	−0.73***	−0.61***	−0.76***	−0.56***
	(−10.1)	(−2.67)	(−4.22)	(−2.18)	(−6.30)	(−5.93)	(−3.11)	(−2.79)
Fifth round	−0.74***	−1.24***	−0.68***	−0.32**	−0.99***	−0.96***	−0.73***	−0.53***
	(−10.5)	(−2.89)	(−6.71)	(−2.13)	(−5.05)	(−8.98)	(−2.94)	(−2.80)
Sixth round	−0.76***	−0.60**	−0.53***	−0.41***	−1.02***	−0.87***	−0.70***	−0.043
	(−13.1)	(−2.44)	(−3.51)	(−2.88)	(−7.52)	(−6.41)	(−2.91)	(−0.13)
Seventh round	−0.83***	0.10	−0.87***	−0.62***	−1.05***	−0.83***	−0.65***	−0.31
	(−14.7)	(0.33)	(−6.49)	(−5.32)	(−9.92)	(−5.64)	(−3.49)	(−1.34)
Position dummies	Yes	—	—	—	—	—	—	
Team fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,928	193	746	616	596	946	314	406
R^2	0.548	0.686	0.587	0.552	0.592	0.531	0.511	0.585

Notes: 1. The dependent variable is the natural log of the variable "CAPHIT" which is the official amount of wages charged to the franchise's salary cap for the year. 2. Rookie is a dummy identifying players on restricted contracts which typically last 4 or 5 years. Most players enter the league at 21/22 years old and so players are typically 25/26 when they enter free agency. The estimates imply that overall rookies are paid c.46% less than veterans for the same level of performance as measured by their approximate value, albeit this varies by position. Approximate value is supplied by sports-reference.com and combines detailed information about on the field performances of players at all positions. *Probowl* identifies players who were invited to the Pro Bowl which celebrates the best players in the two leagues (AFC and NFC) in that season. 3. There is a tight relationship between draft pick order and rookie wages because initial wages in the first year out of the draft are set by collective bargaining. Undrafted players are excluded from the analysis because they immediately become free agents but did not make the draft selection. *t* statistics in parentheses (adjusted for clustering at team level). $*p < 0.1$; $**p < .05$; $***p < .01$.

survival rates vary significantly by player quality and will be distorted by idiosyncratic risk preferences. However, using the draft pick as a proxy for player quality, 77.4% of first round picks survive 4 years, while only 21.7% of seventh round picks survive. 34.3% of the median draft pick survives 4 years in the league.[24] Therefore the c.46% wage premium that veterans enjoy on average relative to rookies will be discounted by average rookie by approximately 65% (assuming risk neutrality). As such it is safe to conclude that most rookies are underpaid relative to their marginal product even considering the option value of the free agency payday. Additionally, it is observed that players move regularly between franchises when they enter free agency implying that their current franchise is not prepared to offer them a veteran contract above their outside option, which would be required under the deferred compensation model.

24. See https://www.milehighreport.com/2014/5/13/5713996/how-long-does-the-average-draft-pick-stick-around.

V. CONCLUSION

The estimates obtained here for the marginal productivity of NFL players suggests that, notwithstanding heterogeneity between rookies and veteran players, sportsmen in the NFL are paid, on average, at a rate which is very close to their marginal contribution to the franchise's revenue. This was identified by observing the lost value from the reduction in win probability from injured players being approximately equal to the wages earned by those injured players. *A dollar of injured talent is a dollar of productivity lost*. This result provides empirical support for models of sporting leagues such as (Fort and Quirk 1995) where talent is hired at a market clearing rate which is also equal to the firm's marginal revenue of talent. More generally, it provides evidence for a tight connection between wages and productivity even when specific institutional constraints, in this case a salary cap and restricted rookie contracts, act to hold down wages for some workers. The connection between wages and marginal revenue product appears remarkably robust despite these frictions.

The unique institutional features of the NFL that permit identification of the wage-productivity relationship unfortunately also limit the scope of the analysis to generalize to other industries. Labor markets with highly talented workers whose injury significantly reduces firm-level productivity and where bilateral bargaining over wages occurs probably represent the closet domain outside of professional sportsmen. Indeed, executive labor markets are also subject to regulatory frictions and while there is no cap on executive wages, it has been argued that political scrutiny of high profile executives can act as a soft constraint (Murphy 1999).

An opportunity to extend the research here is to build a dataset that links the timing of an on-field injury to the real time movement of in-play betting odds. While historical in-play odds are not currently publicly available, private betting companies own datasets containing such information. This would provide an unambiguous connection between the injury to the player and the change in the probability of winning the game. If access to such data was opened up to academics for research purposes, this would allow one to more precisely identify the immediate impact of injury on the probability of winning by using the market reaction as a close proxy for the change in probability. These movements could then be compared the player's wages.

A second opportunity to build upon the research here would be to explore the role of nonproductivity related characteristics such as the race of the player. Although race is not identified in this data, the NFLPA collects self-identified demographic information on NFL players. If access to this data was made available to academics, given the detailed individual level data on productivity already in the public domain, it would be possible to determine the extent to which race played or continues to play a role in the wages of NFL players and the success of NFL franchises.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1. Supporting information