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Abstract

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JEL Classification: I12

Keywords: N/A

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An economic approach to sports injury policies

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Abstract: We propose an analysis of sports injury interventions founded on the assertion that sports injuries may be due to both uncontrollable risks (accidents from participating in sports) and controllable risks (athlete's deliberate choices in risk-taking). Athletes under-adopt injury interventions that increase the cost of taking risk and over-adopt those that decrease this cost. We apply this insight to discuss several interventions used in practice and provide a tool to assess injury policies. We argue that interventions that de-escalate risk, such as return-to-play rules, should be favoured relative to those that tend to escalate risk, such as a treatment program.

Keywords: Sports injury, injury intervention, injury policy, risk-taking, mandatory equipment, return to play, safe play, prevention, treatment.

JEL Classification: Z28, I12.

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1-Introduction

Injuries impose massive costs in amateur and professional sports. Fair and Champa (2019) estimate that up to $18.4 billion USD could be saved per year if contact was eliminated from college sports. According to Eliakim et al. (2020), the English Premier League of association football loses a combined £900 million GBP per season from "injury-related decrement in performance". Verhagen (2010) estimates that the annual costs of sports injuries in the Netherlands alone was over €3 billion EUR. These figures do not capture many of all long-term health consequences of injuries (e.g., decreased cognitive acuity and depression associated with concussions). It is no surprise that sport injuries are a major concern.

The medical and sports management literatures largely view Injuries as misfortunate events that are an unwanted, yet inevitable, by-product of participating in sports. A wide variety of interventions attempt to minimize injury costs, including prevention, treatment, protective equipment, or changes in a sport's rules (Finch 2006). A good intervention is said to be one that reduces the chance of an injury occurring or that attenuates its severity (Chalmers et al 2004). However, the underlying assumption of this approach is that athletes are but passive victims of injuries.

This paper offers a complementary perspective to analyse injury policies. Our analysis focuses on athletes risk-taking decisions in competitive sports. We start from the recognition that some injuries occur because athletes take risk in pursuit of exceptional performance. In choosing a level of risk to undertake, athletes balance the benefits from increased performance with the cost from increased chance of injury, including failing health, time lost from play, decrease in future performance, lower salaries, and so on and so forth.

Combining these views suggests that an injury intervention operates through two channels: first, it lowers the 'baseline injury cost,' a cost that does not depend on an athletes' behaviour. Second, an injury intervention may change athletes' incentives to take risk. We argue it is incorrect to evaluate an intervention by focusing solely on its impact on the former channel: the latter channel determines whether the intervention de-escalates—or possibly escalates—the athlete's choice of risk.

Consider the example of a 'return-to-play' rule that attempts to attenuate the consequences of a concussion (Putukian et al. 2019). Such a rule requires players to wait for the outcome of medical examinations before they can again participate in their sport after a suspected concussion. Stricter rules, such as those that impose longer delays, increase the cost borne by the athlete and should thereby reduce risk-taking. In summation, return-to-play rules have two impacts on injury costs: a direct impact of reducing the possibility of re-aggravation and an indirect impact due to decreased risk-taking. Conversely, a treatment program that helps mitigate the consequence of an injury, thus reducing the chance of lower performance or of forgone play, encourages athletes to take more risks. These two examples illustrate diverging outcomes: return-to-play rules increase, while treatment programs decrease, the athlete's cost of taking risk.

Based on this insight, we study the decision to adopt an *injury intervention* aimed at reducing the cost of injury. The concept of injury intervention covers a wide range of responses to injuries studied in the literature (training, treatment, prevention, protection equipment, return-to-play rules, game rules…) and discussed in this work. We compare the adoption decision that maximizes athletes' welfare with the adoption decision made by the athletes themselves. We say that an injury policy, that mandate or prohibit adoption, increases welfare when these two decisions are incongruent. The analysis sorts injury interventions based on whether athletes correctly or incorrectly adopt or fail to adopt an intervention.

Economists have dedicated some attention to risk-taking in sports (e.g., Potter 2011; Lybbert et al 2012; DeAngelis and Viscusi 2020) and to the overall cost of injuries in youth sports (Fair and Champa 2019).

However, we are not aware of any analysis of the design of sports injury policies and their effectiveness at reducing injury costs as done here.

Our approach delivers surprising insights, which we illustrate with numerous case study evidence from a wide variety of sports, in addition to testable predictions for future research. For example, our model suggests athletes may resist interventions that increase welfare. This is consistent with the observation that athletes under-report their own injuries to avoid the consequences of long return-to-play rules or that recommending protective equipment is often not reason enough for wide-spread adoption, explaining why the use of such equipment typically must be mandated. Another surprising result is that an injury intervention can increase overall injury cost, even though it decreases the baseline injury cost. This finding is consistent with the weak, or even negative impact, of some injury policies studied in the literature (Parkkari 2001). Other findings suggest that return-to-play rules are less effective when game stakes are elevated or at the end of the season when the consequence on lost play is reduced.

Our work offers an alternative approach to the risk compensation theory (a.k.a risk homeostasis theory; Wilde 1982) which stipulates that athletes adjust risk in light of policy interventions to remain at their preferred level of risk (Hagel and Meeuwisse 2004). According to this view, little can be done to influence risk-taking. In contrast, our analysis says that athletes re-optimise their behaviour in response to the change in incentives they face. The correct change in incentives, such as return-to-play rules in the previous example, can successfully reduce risk-taking. The analysis is also related to the consumer protection literature. The notion of risk escalation is reminiscent of Peltzman's 'offseting effect' (1975) and his controversial conclusion that a safety regulation may have the opposite impact than its intended one.

The remainder of this study is organized as follows: the next section reviews the literature and motivates our approach. Section 3 presents the model. Section 4 derives the main results and discusses applications to various sport injury interventions. The final section offers concluding remarks and a discussion of remaining issues for future research.

2-Literature background: Sports injuries and injury interventions

Most sports professionals agree that participation in sport should be made as safe as possible (Parkkari et al. 2001).[3] They typically view injuries as unfortunate yet largely unavoidable accidents that result from a complex interaction of risk factors, pre-conditions, and external circumstances. Scholars have studied the prevalence and cause of injuries from participating in sports, estimated the health consequences, and, ultimately, proposed changes in hopes of making professional, amateur, and youth sports safer.

The literature has looked at many sports (including contact and non-contact varieties) and studied different types of injuries (e.g., concussions or soft-tissue knee injuries among others) and their impacts on the performance, health, and earnings of athletes (Secrist et al. 2016). Findings can vary by sport. For example, evidence from the National Football League (NFL) shows that a concussion decreases future performance (Heintz et al. 2020b), play time (Heintz et al. 2020a; Wennberg and Tator 2008), and player salary (Navarro et al. 2017). Conversely, no evidence of decreased performance post-concussion has been found in basketball (Yengo-Kahn et al. 2016) while results are mixed in baseball (Turbyfill et al. 2021).

Policy research tends to focus on injury information, awareness, prevention, training, detection, assessment, and treatment (Van Mechelen et al. 1992, Soomro et al. 2016). Prevention includes

[3] Entertainment in some sports partly derive from exposition to extreme danger (e.g. mixed martial arts) and we will return to this in the conclusion.

recording and monitoring (Deubert et al. 2017), guidelines for warm-up, training, practice, and competition, screening, and compliance enforcement (Van Tiggelen et al, 2008). The medical field has also debated when professional athletes should return-to-play after an injury (Reams et al, 2017) and the process followed to make this decision (Brayton et al. 2019, Deubert et al. 2017).

Professional sports bodies have independently implemented sports injury prevention programs (Kim et al. 2017; Quarrie et al. 2020), although there is much debate that such programs are sufficient (Parkkari 2001).[4] This has occasionally led to legislative injunctions: following a rise in awareness of the dangers of concussions in youth sports in the mid-2000's (Rotolo and Lengefeld 2020), all fifty U.S. states unilaterally passed regulations stipulating rules detailing when youth athletes can return to play after an injury diagnosis (Kim et al. 2017).

Motivation: risk-taking, injuries, and incentives

We first recognise that athletes face different types of risks, some within and some beyond their control. Injuries can happen for many reasons such as chance (i.e., bad luck), external circumstances (e.g., weather or playing surface; Myer et al. 2014), rules of engagement (Fair et al. 2018), or because an athlete takes excessive risk. This last cause, which we label *controllable risk*, can manifest itself as, among other mechanisms, an athlete expending maximal exertion, switching to strategies that put strain on the body or that involve more body-contact, or investing less in injury prevention and recovery. There is much evidence for the association between controllable risk, exceptional performance, and injuries (e.g., Turner et al. 2004; Verhagen et al. 2010; Chen et al. 2019; Bolling et al. 2020).

Contest theory offers a theoretical framework to understand risk-taking in competitive sports. In this paradigm, athletes participate in a contest to win some payoff. Contestants make investments to increase their chance of success, which may include training, concentration, or exertion (Frick 2003). These investments are all captured in the literature under the label of 'effort' (Kahn 2000). We add to this the stipulation that effort also includes the athlete's willingness to take risks. The next section offers a model that connects athletes' incentives, risk-taking choices, and injury outcomes to analyse the impact of injury interventions.

3-Model

We consider a game with a principal and two agents, which we respectively label the sport's organizer and competitors. Although the model has two individual athletes, few caveats are required to generalise to team sports.[5] We assume the competitors to be risk neutral: this greatly simplifies the analysis as the principal needs only consider expected injury costs, yet we note that the main insights generalise to risk aversion.

We use a simple three-action contest setup where risk-taking increases the chance of winning. To keep matters simple, we assume that the payoff function is the same for both athletes. Let p_{ij} denote the payoff that an athlete receives if they select strategy i and their opponent selects strategy j with $i, j \in \{L, M, H\}$ corresponding to low, medium, or high risk, respectively. This payoff includes the returns from all possible sources, such as cash prizes, the intrinsic value of wining, and the increase in future career opportunities. We assume that the payoff function is zero-sum: $p_{ij} + p_{ji} = K$ for all (i, j). (Section 4.4 revisits this assumption.) Furthermore, let Δ_L denote the incremental prize that athlete i obtains from

[4] Players may under-estimate the risk of injury with systematic bias regarding their prevalence and consequence, due to underreporting and complicity in ignoring the cost of injuries (Cusimano et al. 2017), and with the unfortunate consequence of under-treatment (Torres et al. 2013).

[5] For example, team sports add executive risk associated with coaches' game-play strategies (Teramoto et al., 2015) and fratricidal risk (e.g., a pass from one teammate to another that puts them in a vulnerable position to receive body contact).

unilaterally switching from low to medium risk where $\Delta_L = p_{Mj} - p_{Lj}$. Similarly, Δ_H denotes the incremental prize of switching from medium to high risk $\Delta_H = p_{Hj} - p_{Mj}$. The gains from risk-taking are additive, $p_{Hj} - p_{Lj} = \Delta_L + \Delta_H$.

Higher risk by either athlete increases the expected cost of injury. The injury cost function describes the utility loss suffered by an athlete who selects risk level i: [6]

$$c_i = c_0 + \begin{cases} r \text{ } if \text{ } i = H \\ 0 \text{ } if \text{ } i = M \\ -r \text{ } if \text{ } i = L \end{cases} \qquad (1)$$

The injury cost function depends on athletes' actions and on the cost vector $C = (c_0, r) \in \mathbb{R}^+$. Each element in C is non-negative and may depend on the sport and the environment. c_0 is the baseline injury cost of participating in sports under medium-risk strategies and r is the incremental cost of taking risk. Athletes maximize expected payoff net of the expected injury cost and the sport's organizer maximizes the athletes' surplus. When the athlete payoff function is zero-sum, the sport's organizer minimizes athletes' expected injury costs, $c_i + c_j$. We assume:

Assumption 1: $0 < \Delta_H < r < \Delta_L$.

These inequalities state that taking risk increases payoffs and the specific order of parameters implies that M is the unique Nash equilibrium, which will be the starting point for the analysis. An injury intervention is defined next:

Definition: An injury intervention is a triplet $I = (F, \tilde{c}_0, \tilde{r})$ such that investment F per player changes the cost vector to $\tilde{C} = (c_0 - \tilde{c}_0, r - \tilde{r})$.

Injury intervention is a general concept that encapsulates many responses to injury studied in the literature. See Table 1 for a list of examples of injury interventions. $\tilde{c}_0$ is the baseline cost-savings of participating in sports, which we assume to be non-negative, and $\tilde{r}$ is the cost-savings associated with risk-taking. The parameter $\tilde{r}$ may be zero, positive, or negative depending on the intervention under consideration, as will be clear in the examples. F captures all implementation costs (e.g., cost of protective equipment, health care, or coach or referee time). For now, we only assume that an injury intervention can at most offset each source of injury cost:

Assumption 2: $0 \leq \tilde{c}_0 \leq c_0$ and $\tilde{r} \leq r$.

Different interventions are characterized by different triplets I. The central assumption of this work is that it is only possible to adopt or reject a triplet as a package (i.e., the elements $\tilde{r}$ and $\tilde{c}_0$ in vector I are determined simultaneously and inseparably). The sport's organizer must consider both the impact of an injury intervention on the baseline injury cost and on the costs associated with the athletes' choices of risk. Once adopted, an injury intervention is said to generate a behavioural response if it causes an athlete to change their risk strategy, $(i, j) \neq (\tilde{\imath}, \tilde{\jmath})$, where (i, j) and $(\tilde{\imath}, \tilde{\jmath})$ are the risk strategies before and after adopting the injury intervention. Assumption 2 implies that an injury intervention reduces total injury costs if it keeps risk-taking constant, $(i, j) = (\tilde{\imath}, \tilde{\jmath})$. This is the benchmark used in the sports medicine literature.

[6] In contact sports, injury sometimes occur because of adversarial risks due to the opponent's decision (e.g., opponent taking risk or engaging in predatorial gameplay). The analysis easily extends to cost externalities in risk taking (an athlete's cost function also depends on the risk choice of their competitor).

4-Analysis

We consider two scenarios. In the first scenario, the sport organizer decides whether to adopt an injury intervention. After observing the sports organizer's adoption decision, athletes respond by simultaneously choosing a risk level. We solve for the Nash equilibrium. The sport's organizer adopts the injury intervention if the athletes' welfare net of the implementation cost increases under the new Nash equilibrium. This first scenario sheds light on injury interventions that can only be implemented by the sport's organizer, such as is the case with, for example, game rules.

The second scenario extends the analysis to injury interventions that can be voluntarily adopted by athletes, which comprise many injury interventions considered in the literature. Athletes first simultaneously decide whether to adopt the injury intervention with the second stage remaining unchanged. We compare the adoption decisions of the sport's organizer and athletes. We say that an injury policy, which may mandate or prohibit adoption, is required if the two adoption decisions differ.

4-1 Baseline model

We derive the Nash equilibrium choice of risk in the baseline model where the injury intervention is not available. The Nash equilibrium depends on the value of the cost of risk.

Lemma 1: There exists a unique Nash equilibrium: (a) When $\Delta_L \leq r$, competitors play (L, L); (b) When $\Delta_H \geq r$, competitors play (H, H); (c) When $\Delta_H < r < \Delta_L$, competitors play (M, M).[7]

Players have a unique dominant strategy for any value of the cost of risk. When Assumption 1 holds, medium risk is the unique Nash Equilibrium. Although contestants would be better off playing low risk, they face a prisoner's dilemma: they cannot coordinate to achieve the strictly Pareto dominant strategy (L, L) because each has an incentive to unilaterally deviate to M.

The adoption of an injury intervention changes the cost of risk to the new value $r - \tilde{r}$. Applying the result in the above Lemma, we obtain that medium risk remains the unique Nash equilibrium for small changes in the cost of risk. For large changes, however, the intervention causes a behavioural response. Athletes take more risk for sufficiently large decreases in the cost of risk, and less risk for large increases.

Proposition 1: An injury intervention triggers a decrease in risk-taking when $\tilde{r} < r - \Delta_L$, an increase in risk-taking when $\tilde{r} > r - \Delta_H$, and no behavioural response when $r - \Delta_L < \tilde{r} < r - \Delta_H$.

Proposition 1 characterizes when injury interventions trigger behavioural responses. These responses have been largely overlooked in the analysis and design of injury intervention despite the existence of a large body of anecdotal evidence documenting unintended responses in sports. We discuss a few examples of change in risk-taking in response to injury interventions:

1. Formula One drivers increase risk-taking as cars become safer (Potter 2011).
2. Mandatory safety equipment is designed to reduce the gravity of an injury and to protect athletes but can also trigger behavioural responses with ambiguous effects: protective equipment that impairs players' abilities may reduce risk-taking, such as a helmet impeding spatial and auditory perception or additional thigh or hip pads slowing the wearer down in American football (Bradley 2013). Conversely, the 'gladiator effect' speculates that protective equipment can instead increase risk-taking.[8]

[7] The equilibrium is unique when $\Delta_L = r$ because actions L and M give identical payoffs. The same hold for $\Delta_H = r$ and actions H and M.

[8] Torg et al. (1979) argue that the introduction of helmets and facemasks in American football triggered a change in injury patterns: the number of serious head injuries decreased (due to the enhanced protective capabilities of

3. Injury rates are higher among children playing organised sport with soft-core baseballs as opposed to a standard baseball (Pasternak et al. 1996), suggesting the former are willing to risk the chance of injury from fielding a ball or an incoming wild pitch (Hagel and Meeuwisse 2004).
4. Ulnar collateral ligament (UCL) reconstruction surgery, colloquial known as 'Tommy John surgery,' to repair elbow injuries of baseball players has been jocularly referred to as 'a pitcher's best friend' as it has remedied what was previously a career-ending injury (Dodd 2003). The procedure has been so successful that it has altered the perception of elbow injuries and the risk factors thereof: many parents, high-school and collegiate athletes, as well as coaches falsely believe that young players should no longer avoid an undue volume of pitches or throwing motions that put great amounts of strain on the elbow (Ahmad et al. 2015).[9]
5. Batters hit by a pitch in amateur and professional baseball are awarded first base, yet safe play rules require that the batter make a reasonable effort to avoid being hit. Pitches that would have otherwise been called a strike (but for the batsman interceding the pitch) do not result in a free pass to first base. This safe-play rule incentivises players to de-escalate risk.
6. Due to high risk of injuries from crashes in sledding sports (i.e., bobsleigh, luge, and skeleton), organizers limit the number of training runs permissible on a track prior to competition (McCradden and Cusimano 2018). While this sets an upper bound on the time at risk, it also limits the athlete's familiarity and comfort with the track during competition when the stakes are high.

Proposition 1 offers an alternative view of behavioural response to the one offered under risk compensation theory, according to which athletes have "a target level of risk they are willing to accept" (Hagel and Meeuwisse 2004). According to this view, injury interventions that reduce the perceived level of risk lead athletes to adjust their behaviour to take on additional risks (Thomson and Carlson 2015). Using the language of our model, the risk compensation theory says that athletes respond to an intervention that decreases the cost of participating in sports ($\tilde{c}_0$) by increasing risk-taking such that the experienced cost of risk remains constant ($\tilde{c}_{ij} = c_{ij}$). In contrast, Proposition 1 says that the choice of risk is not influenced by cost-savings of participation ($\tilde{c}_0$) but by the marginal effect of risk-taking on injury cost ($r - \tilde{r}$). Proposition 1 also extends Peltzman (1975) analysis of safety regulations, which focused on the case $\tilde{r} > 0$. Proposition 1 says that athletes escalate risk (when $\tilde{r} > r - \Delta_H$) and doing so offsets, using Peltzman's terminology, the reduction in the baseline cost of injury. Our analysis reveals that when $\tilde{r} < 0$, the opposite of a behavioural offset occurs: athletes respond to the intervention by de-escalating risk.

4-2 When should an injury intervention be adopted?

This section investigates whether an injury intervention can improve athletes' welfare. The sport's organizer implements injury intervention I if $\tilde{c}_i + \tilde{c}_j - F > 2c_M$, where $\tilde{c}_i$ and $\tilde{c}_j$ are the per athlete cost under the new equilibrium and using the new cost function (computed using equation (1) and cost vector $\tilde{C}$).

According to Proposition 1, athletes do not change their choices of risk for small positive or negative values of the cost-savings of risk ($r - \Delta_L < \tilde{r} < r - \Delta_H$). There is no behavioural response and, therefore, the total injury costs decrease by the change in the baseline cost-savings net of implementation cost. This corresponds to the mainstream case considered in the sports medicine

the new helmet) yet the number of serious spinal injuries increased (due to increased use of the head as the primary point of contact in blocking, tackling, and head-butting, i.e., 'spearing').

[9] Coaches and young athletes have gone so far as to incorrectly believe that surgery can strengthen an otherwise-healthy elbow leading some to seek out the procedure prior to any UCL damage (Longman 2007).

literature, which assumes that an injury intervention does not generate any behavioural response. Under this scenario, the injury intervention tautologically reduces injury costs when $\tilde{c}_0 > F$.

Athletes take less risk for sufficiently large increases in the cost of risk ($r - \tilde{r} > \Delta_L$). Such interventions are more likely to be welfare improving because injury costs are reduced by a larger amount. Conversely, athletes take more risk for sufficiently large decreases in the cost of risk ($r - \tilde{r} < \Delta_H$). Here, an injury intervention is less likely to be beneficial.

Proposition 2: An injury intervention increases welfare when: (a) $\tilde{r} < r - \Delta_L$ and $\tilde{c}_0 > F - r + \tilde{r}$; (b) $r - \Delta_L < \tilde{r} < r - \Delta_H$ and $\tilde{c}_0 > F$; or (c) $\tilde{r} > r - \Delta_H$ and $\tilde{c}_0 > F + r - \tilde{r}$.

This proposition offers a tool to compare injury interventions. Whether adoption reduces injury costs depends on numerous parameters, some that are both risk and intervention specific (e.g., $\tilde{c}_0, \tilde{r}, F$) while others only risk specific (e.g., r, Δ_L, Δ_H) . Two different interventions designed to reduce concussion costs, for example, share the same values of (r, Δ_L, Δ_H) but typically have different values of $(\tilde{c}_0, \tilde{r}, F)$.

Table 1 applies the key insight of Proposition 1 and 2 to injury interventions used in practice. Columns 2 and 3 of the table report the two effects of an injury intervention: the direct change in the expected injury cost (i.e., reduce the likelihood of injury and/or its health consequences) and the indirect change through a behavioural response.

Table 1: Comparison of injury interventions

Injury intervention	Baseline Cost-Savings ($\tilde{c}_0$)	Behavioural response (risk-taking)
Return to play	+ (improves recovery)	De-escalate ($\tilde{r} < 0$)
Mandatory equipment	+ (protect athlete)	Ambiguous
Treatment	+ (health benefit)	Escalate ($\tilde{r} > 0$)
Prevention	+ (reduces chance of injury)	Escalate ($\tilde{r} > 0$)
Health Insurance	+ (risk aversion)	Escalate ($\tilde{r} > 0$)
Safe play rules	Unchanged	De-escalate ($\tilde{r} < 0$)
Game rules	Unchanged	Ambiguous

Return-to-play rule is presented in the first row. This rule require that a player be removed from a game and put under observation in the event of a suspected concussion. The injured athlete can only return to play after medical clearance. Recovery periods can last a couple of weeks or even longer: National Football League (NFL) players miss on average one game following a concussion event (Heintz et al. 2020a) while National Hockey League (NHL) players miss between 8 to 13 games (Wennberg and Tator 2008).[10] Return-to-play rules are meant to reduce the chance of injury aggravation. This corresponds to a reduction in the baseline cost of injury ($\tilde{c}_0 > 0$). However, long periods of absence increase the opportunity cost of risk-taking ($\tilde{r} < 0$) because they penalize players who experience an injury by increasing the cost of forgone income. Although both the direct and indirect effects reduce injury costs, the return-to-play literature has largely overlooked the latter effect. For our purposes, we note both the

[10] One egregious example of a lengthy inactive period due to return to play rules is the case of star professional hockey player Sidney Crosby who missed 69 NHL games over a period of 320 days due to lingering concussion symptoms. Some athletes are forced to end their careers due to concussions.

direct and indirect effects are beneficial and we conclude that the overall impact of this intervention is unambiguously beneficial (a decrease in the per-athlete cost of injuries). The rest of the table replicates this analysis to other injury interventions.

Mandatory equipment are designed to provide baseline cost-savings, but as noted earlier, their use can trigger positive or negative behavioural changes in risk-taking. We conclude that the overall impact of mandatory equipment rules may be positive or negative. Treatment and prevention are the most commonly studied interventions in the medical literature. These interventions are meant to reduce the expected health cost of sports injuries. Our analysis says that such interventions can also have a negative behavioural response because they increase the private incentive to take risk. Again, we conclude that the overall impact of these interventions is ambiguous. A treatment or prevention intervention could result in athletes taking more risk and bearing a greater injury cost.

Compensation contracts often include insurance clauses. Christopherson (2020) documents several types of guarantees for NFL players during contract negotiations, two of which are of interest: injury guarantees insuring against injuries that prevent participation in competition; and skill guarantees insuring against poor performance by the athlete. The introduction of an injury guarantee without a skill guarantee is likely to increase risk-taking as the insurance offsets the expected costs of injury under a high-risk strategy. In the language of our model, an injury guarantee reduces the cost of risk ($\tilde{r} \approx r$). Adding the skill guarantee reduces the gains from high performance. This corresponds to a reduction in Δ_H and the athlete may choose to remain at the equilibrium risk level. The final two interventions of Table 1 are discussed in detail later.

Returning to Proposition 2, an injury intervention can surprisingly increase total injury costs even if it reduces the baseline injury cost.

Proposition 3: An injury intervention increases total injury costs when $\tilde{r} > r - \Delta_H$ and $\tilde{c}_0 < r - \tilde{r}$.

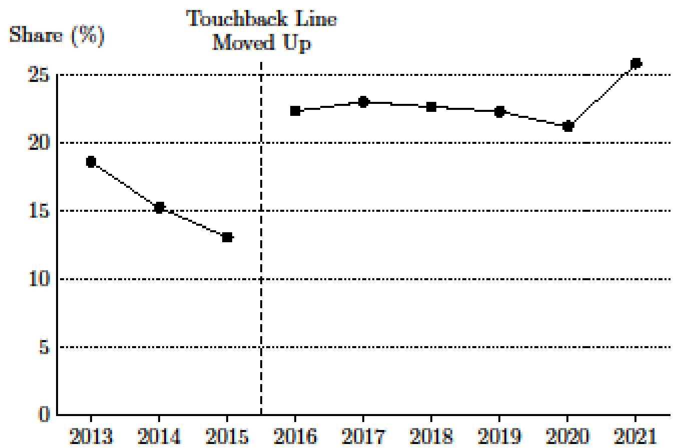
An implication is that an ill-designed injury intervention, i.e., one that ignores behavioural responses, may not deliver its intended effect of reducing injury costs. This possibility is supported by the research that argues that some interventions have little to no effect on health outcomes (Parkkari 2001). Explanations for this null finding include implementation flaws or over-estimating the reduction in injury cost (e.g., the realised $\tilde{c}_0$ is much smaller than its anticipated value). Our analysis adds another explanation for unexpectedly low, or even negative, impacts of some injury interventions: the gain from the reducing the baseline cost of participating in sports can be nullified by the cost of unintended responses.

An application of Proposition 3 are modification of game rules that attempt to reduce injury costs by changing athletes' behaviour. Arias (2011) states that the main rationale for rule modification is to prevent injuries, yet surprisingly finds this intended goal is achieved less than half the time. The main challenge with altering game rules is unintended responses. Such responses can explain why well-intended policies sometimes lower welfare and can even increase total injury costs. There are many examples of unintended responses, and for the sake of brevity, we discuss here only two sports.[11] First, cycling introduced a system whereby competitors involved in crashes in the final kilometre of a race were granted the same finishing time as the peloton they were in (later updated to final three kilometres). This rule was introduced to reduce risk-taking near the end of a race. However, Lybbert et al. (2012) showed that the occurrence of crashes occurring in the final kilometre increased after implementation. Proposition 3 says that the rule effectively offsets the costs of a high-risk strategy in the final leg of a race ($\tilde{r} \approx r$ and no change in the baseline injury cost $\tilde{c}_0 = 0$).

[11] For additional illustrations, see, for example, Wright 2014 or Potter 2011.

Next, consider the 2016 NFL rule change that saw the touch-back line moved up from the 20- to the 25-yard line to reduce the prevalence of injury during kick-returns (kick-offs are the highest risk play for concussion, Mack et al. 2021). This rule change was designed to reward kick-returners for choosing to take a touch-back instead of attempting to advance the ball up the field of play and risk injury. However, it unintentionally provided the kicking team the incentive to kick the ball into the field of play as the kick-returner was now more likely to be tackled before the 25-yard line. As seen in Figure 3, this rule change actually led to an increase in the number of kick-offs landing the field of play.

Figure 3: Share of NFL Kick-Offs Landing in the Field of Play (2013-2021)



Notes: Prior to the 2016 NFL season, a touch-back resulted in the football being placed on the 20-yard line of the receiving team; since 2016, a touch-back results in the football being placed on the 25-yard line of the receiving team, incentivising the receiving team to take a touch-back (rewarding lower-risk strategy) yet incentivising the kicking team to kick the football into the field of play (increasing risk). Graph includes all regular-season kick-offs from the kicking team's 35-yard line.

Source: "Advanced NFL Statistics," NFLSavant.com.

4-3 Athlete's adoption and welfare improving policies

Little prevents athletes' unilateral adoption of most of the injury interventions discussed in the literature with the exclusion of those that regulate a sport's rules. It is thus important to investigate athletes' adoption decisions. We study the two-stage game where athletes first simultaneously decide whether to adopt the injury intervention and subsequently simultaneously select a risk level. The next result characterizes the Nash equilibrium in the two-stage game:

Proposition 4: The Nash equilibrium is: (a) Adoption and low risk when $\tilde{r} < r - \Delta_L$ and $\tilde{c}_0 > \tilde{r} - r + \Delta_L + F$; Adoption and medium risk when $\Delta_L < \tilde{r} < r - \Delta_H$ and $\tilde{c}_0 > F$; Adoption and high risk when $\tilde{r} > r - \Delta_H$ and $\tilde{c}_0 > r - \tilde{r} - \Delta_H + F$. Otherwise, players do not adopt and select medium risk.

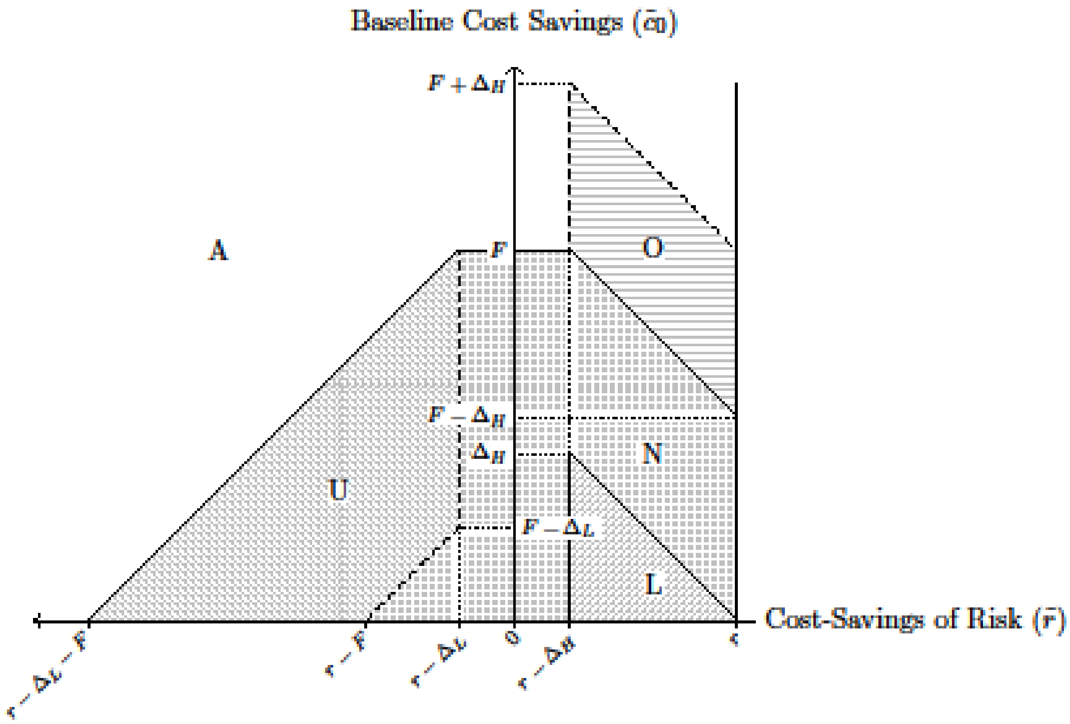
Next, we compare the adoption decisions made by the sports organizer and athletes. We say that an injury policy, forcing or prohibiting adoption, is required when the two decisions are incongruent. We state our main result on injury policies:

Proposition 5: Forced adoption is the optimal injury policy when $\tilde{r} < r - \Delta_L$ and $\tilde{r} - r + F + \Delta_L > \tilde{c}_0 > \tilde{r} - r + F$. Prohibiting adoption is the optimal injury policy when $\tilde{r} > r - \Delta_H$ and $r - \tilde{r} + F - \Delta_H < \tilde{c}_0 < r - \tilde{r} + F$.

Athletes may wrongly adopt, or wrongly fail to adopt, an injury intervention. Such inefficiencies may occur because athletes do not internalize the impact of adoption and risk choice on their competitor's welfare. The sport's organizer wants to discourage adopting injury interventions that lower the cost of risk, and encourage adopting those that increase the cost of risk. As expected, there is no need for policy intervention for large decreases in the baseline cost of injury (large values of $\tilde{c}_0$) because both the sport's organizer and athletes are in favour of adoption.

Figure 1 represents the impact of adoption on welfare in the two-dimensional parameter space $(\tilde{r}, \tilde{c}_0)$. The vertical axis represents the baseline cost savings of an intervention, $(0 < \tilde{c}_0 \leq c_0)$, while the horizontal axis represents the cost savings of risk, $(\tilde{r} \leq r)$. Welfare does not change for all points on the broken dashed line (beginning at $(r - F, 0)$ and ending at (r, F)), increases for points located above and decreases for points located below. The figure also offers a visual representation of Proposition 3, 4 and 5. It sorts injury interventions into five categories: (A) correct adoption (no need for intervention); (O) over-adoption (intervention required); (U) under-adoption (intervention required); (N) incorrect intervention with net negative welfare and no increase in overall injury costs; (L) incorrect intervention with net negative welfare and increase in injury costs (see Proposition 3).

Figure 1: Impact of an injury intervention on injury cost



In regards to Category A, note that athletes go a long way to reduce expected injury costs by engaging in activities that are not mandated, or necessarily even recommended, by sports' organization. For example, athletes dedicate much time to warming-up, training and physiotherapy with little external incentive to do so. As another example, many athletes choose to follow unwritten rules regarding safe play even if they face no punishment for violations.

Over-adoption (Category O) is relevant to many drug treatments and medical interventions. Athletes who take risks can use legal substances (such as opioids or Cortisone and Toradol shots among other drugs) to relieve the pain of an injury. Although these drugs allow players to ignore their injuries in the short term, their use can lead to long-term consequences including dependency and/or substance-use disorder. Over-adoption of drug treatments explain why many sports organizations have adopted the standards promoted by the World Anti-Doping Agency, to restrict the use of performance-enhancing drugs. For example, the NFL recently circulated a memo asking teams to voluntarily limit the use of some pain relievers (Goldberg, 2021). Regarding medical treatment interventions, our model suggests athletes should bear much of the cost of medical interventions that have been shown to cure injuries associated with risk-taking (e.g., UCL surgery discussed earlier).

Some protective equipment illustrates the under-adoption problem (Category U). For example, after a pitcher was severely injured from a ball striking his head, MLB permitted the use of a protective cap for any pitcher: as of this publication, only a single player, Alex Torres, has opted to wear the cap during game play.[12] New protective equipment often is mandated by sports organizations because athletes resist adoption when doing so interferes with performance. The NHL has mandated visors for all players entering the league since 2013, but due to a 'grandfather clause,' some older players continue to play without one (Seravalli 2019).[13]

Safe-play and return-to play rules also illustrate the under-adoption problem. Safe-play rules regulate reckless behaviour (e.g., body contact). These interventions have no impact on the baseline cost but are meant to influence behaviour by prohibiting dangerous gameplay and punishing athletes who take risk ($\tilde{r} < 0$). We therefore obtain the trivial prediction that safe-play rules unambiguously decrease injury costs. Regarding return-to play-rules, there is much evidence showing that such rules are difficult to enforce. After being the victim of an injury, many athletes prefer to continue playing even if doing so means concealing the injury. Athletes have also been found to avoid self-reporting injuries because they do not want to lose playing time or to miss future games (Torres et al. 2013).

A paradoxical implication of the model is that a wrongly adopted injury intervention can decrease welfare (Categories N and L) or even increase injury costs (Category L). The two applications (from cycling and NFL) discussed after Proposition 3 illustrate this paradox. One may argue that prevention programs, which are meant to reduce the expected health cost of sports injuries, could also fall in these categories if they trigger a large risk response. This does not seem to be the case in the broad set of injury prevention programs reviewed by Soomro et al. (2016): the study finds an overall reduction in injury rates. A prescriptive implication of Proposition 5 is that prevention programs that increase (or keep constant) the cost of risk should be favoured (ceteris paribus).

The last proposition describes how game stake influences the need for policy interventions. The size of area N increases as Δ_L increases and the size of area O increases as Δ_H increases.

Proposition 6: The need for policy intervention increases with the return to risk (Δ_L, Δ_H).

According to Proposition 6, return-to-play rules are less effective at preventing injuries at the end of a season or at the end of an athlete's career as the cost of missing a game is lower.[14] These rules (as well as other game rules) should be stringently enforced in high-stakes games due to the increased incentive to take risk. Proposition 6 also explains the increase in injuries in professionalized and commoditized sports. Taking a broader perspective, another approach to tackling injuries in sports would promote reducing the return to risk.

An example of a policy intervention that was designed to address the perverse effect of an increase in game stakes is the safe-play rule introduced by the NFL to reduce concussions in pre-season practices. Prior to the beginning of each playing season, teams hold formal training camps to evaluate athletes and

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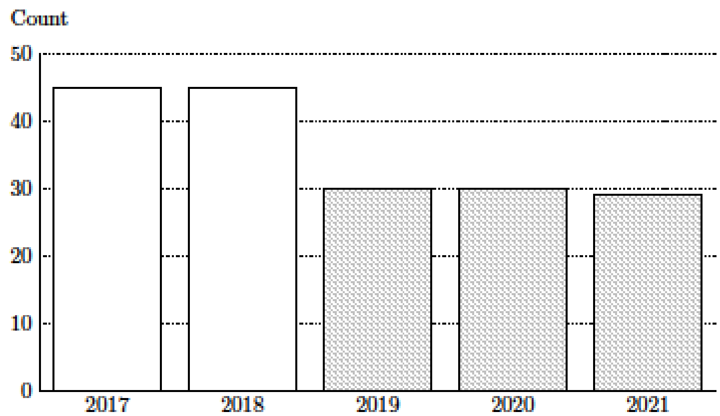
[12] The player struck by the baseball was Mr. Torres' teammate, Alex Cobb. Mr. Cobb required 61 days to recover and, as of publication, has never worn the protective cap himself.

[13] A similar phenomenon occurred when the NHL mandated the use of helmets in 1979 (Witz 2014).

[14] A complication with return-to-play rules deals with the perverse incentive wherein athletes can gain an advantage by forcing the removal of their opponent . Some anecdotes support this: in 2016, a concussion spotter removed an NHL goaltender from play after a collision with an opponent in the late stages of a tied game, leading to the team's eventual loss (Seravalli 2016); and from 2009 to 2011, NFL coaches of the New Orleans Saints paid its players bonuses for explicitly injuring its opponents as part of a scandal known as 'bounty-gate' (Terrell 2012).

assess individual athletic skills. Due to the high-stakes nature of these effective auditions for employment, severe injuries, such as concussions or soft-tissue knee injuries, are not uncommon. To address the growing concern of concussions, the NFL collectively banned the practice of three contact-intensive drills prior to the beginning of the 2019 pre-season with one additional drill banned the following year. Figure 2 shows that a significant decrease in the number of concussions sustained during pre-season practice took place after the introduction of safe play rules.

Figure 2: Concussions in NFL pre-season practices (2017-2019)



Notes: Prior to the 2019 NFL pre-season, three drills were banned from practice: the 'Oklahoma,' 'Bull in the Ring' or 'King of the Circle,' and 'Half-Line' drills. Prior to the 2020 pre-season, 'In-Line Run Blocking' drills, or the 'Board Drill,' was also banned.

Source: NFL Player Health and Safety Injury Data.

4-4 Discussion

We revisit two properties of the athletes' payoff functions. Athletes face a prisoner's dilemma in competitive sports because the payoff functions depend on both athletes' choice of risk. An injury policy is never required when this is not the case, that is, when payoffs are such that $p_{ij} = p$ for all i and j or when game stakes (Δ_l, Δ_h) are low. This is the case in recreational sports to the extent that an athlete's payoff is intrinsic and does not depend so much on winning. Examples includes many activities such as fitness, yoga, hiking, and to a large extent to competitive sports with low stakes such as an exhibition game, a fundraising event, or a friendly match. The athletes and sport's organizer have the same objective function. This is consistent with the observation that many injury regulations apply to competitive activities where risk escalation is a concern.

Injury concerns do exist in non-competitive sports but these fall under the standard analysis of consumer protection regulations to reduce accidents (e.g. cyclist wearing helmets or restriction on ski slopes).[15] The model argues that many injury interventions are specific to competitive sports where risk escalation is an important consideration. This point also talks to the observation that injuries are about equally likely to occur in training and competition and this is despite the fact that athletes spend a relatively small time competing (Parkkari et al. 2001): the return to risk (Δ_H) is higher in competition than training.

Another feature of the model is the zero-sum, winner-takes-all, assumption in the payoff function. This is a strong assumption that rules out the possibility that risk has an entertainment benefit when the

[15] Behavioral responses also exist in non-competitive sports. Widening ski slopes to avoid over-crowding and collisions give some skiers the perception that it has become safer to speed downhill (Verhagen et al. 2010). The use of helmets is correlated with increased risky behaviour in alpine skiing and snowboarding (Thomson and Carlson 2015). Inefficient risk escalation, however, is not an issue in these applications.

public values the excitement associated with risk. This could be included in the analysis and the operating principle that athletes do not internalize the impact of risk-taking on competitor welfare would remain. The difference is that sports organizations must also appraise fan excitement when they assess risk in sports. Accounting for the entertainment value of risk will shrink the size of Categories U and O in Figure 1 but it will not change the rationale for policy intervention.

5-Conclusions

To evaluate the impact of an injury intervention in competitive sports, we propose a simple model that considers an athlete's incentives to take risk. The analysis considers an injury intervention that may be adopted by athletes or by a sport's organizer. In the equilibrium that results after adoption, athletes may escalate risk-taking (as in the case of an injury treatment program) or de-escalate risk-taking (as in the case of a return-to-play rule). Athletes under-adopt injury interventions that increase the cost of taking risk and over-adopt those that decrease this cost. Such adoption distortions are more likely to occur in high stakes competitions. We apply this insight to several interventions used in practice and studied in the literature. A paradoxical implication of the model is that a wrongly adopted injury intervention can increase injury costs and this will happen when the risk-escalating behavioural response dominates the baseline impact of the intervention.

Our approach offers an alternative view to the one found in the sports medicine literature that ignores the contribution of risk-taking in total injury costs. Although there are significant personal costs associated with injuries, these costs alone do not deter athletes from engaging in risky play. When risk-taking contributes to severe injuries (e.g., concussions), an effective way to contain injuries is to design injury interventions that increase the cost of taking risk. We argue that the adoption of strict return-to-play rules by many sports organizations act as a deterrence to risk-taking.

We end this paper by touching on points being beyond the scope of this research but worthy of future attention. First, some interventions are difficult to enforce resulting in low athlete compliance. For example, concussion spotters are required to remove players from a competition and enforce, arguably imperfectly, return-to-play rules. We have also alluded to the fact that some interventions are subject to unintended adversarial manipulations.

The results in this study complement other economic rationales for injury interventions not considered here such as the need to protect athletes against cognitive bias and the difficulty to assess the life-time costs of injuries.[16] Finally, our model does not capture the non-pecuniary prizes athletes compete for (the 'thrill of victory'). Reminiscent of other sports controversies, such as cheating and doping, injuries will forever be a consequence of the eagerness to take risk in the pursuit of extraordinary performance.

[16] Information and awareness programs increase the perception of costs associated with risk-taking, although they no not change the actual cost of injury. For example, Beidler et al. (2021) find that concussion information programs increases willingness for amateur athletes to self-report their symptoms.

References

Ahmad, C. S., Grantham, W. J., & Greiwe, R. M. (2012). Public perceptions of Tommy John surgery. The Physician and sportsmedicine, 40(2), 64-72.Arias, Jose L., Francisco M. Argudo, and Jose I. Alonso. "Review of rule modification in sport." Journal of sports science & medicine 10, no. 1 (2011): 1.

Beidler, E., Wallace, J., Alghwiri, A. A., & O'Connor, S. (2021). Collegiate athletes' concussion awareness, understanding, and-reporting behaviors in different countries with varying concussion publicity. Journal of athletic training, 56(1), 77-84.

Bolling, C., Barboza, S. D., Van Mechelen, W., & Pasman, H. R. (2020). Letting the cat out of the bag: athletes, coaches and physiotherapists share their perspectives on injury prevention in elite sports. British journal of sports medicine, 54(14), 871-877.

Bradley, Bill. "New NFL rules: Leg, thigh pads are mandatory to protect players." NFL.com, September 4, 2013. https://www.nfl.com/news/new-nfl-rules-leg-thigh-pads-are-mandatory-to-protect-players-0ap1000000238075.

Brayton, S., Helstein, M. T., Ramsey, M., & Rickards, N. (2019). Exploring the missing link between the concussion "crisis" and labor politics in professional sports. Communication & Sport, 7(1), 110-131.

Chalmers, D. J., Simpson, J. C., & Depree, R. (2004). Tackling rugby injury: lessons learned from the implementation of a five-year sports injury prevention program. Journal of science and medicine in sport, 7(1), 74-84.

Chen, Y., Buggy, C., & Kelly, S. (2019). Winning at all costs: a review of risk-taking behaviour and sporting injury from an occupational safety and health perspective. Sports medicine-open, 5(1), 1-21.

Christopherson, Conner. "The Art of NFL Contracts Part 1: The Basics." Sports Illustrated, May 9, 2020. https://www.si.com/nfl/chiefs/gm-report/the-art-of-nfl-contracts-part-1-the-basics.

Cusimano, M. D., Topolovec-Vranic, J., Zhang, S., Mullen, S. J., Wong, M., & Ilie, G. (2017). Factors influencing the underreporting of concussion in sports: a qualitative study of minor hockey participants. Clinical journal of sport medicine, 27(4), 375-380.

DeAngelis, S., & Viscusi, W. K. (2020). When to Walk Away and When to Risk It All. Journal of Sports Economics, 21(5), 525-547.

Deubert, C., Cohen, I. G., & Lynch, H. F. (2017). Comparing health-related policies & practices in sports: The NFL and other professional leagues. Comparing Health-Related Policies & Practices in Sports: The NFL and Other Professional Leagues.

Dodd, Mike. "Tommy John surgery: Pitcher's best friend." USA TODAY, July 29, 2003. usatoday.com.

Eliakim, E., Morgulev, E., Lidor, R., & Meckel, Y. (2020). Estimation of injury costs: financial damage of English Premier League teams' underachievement due to injuries. BMJ Open Sport & Exercise Medicine, 6(1), e000675.

Fair, R. C., & Champa, C. (2019). Estimated costs of contact in college and high school male sports. Journal of Sports Economics, 20(5), 690-717.

Finch, C. (2006). A new framework for research leading to sports injury prevention. Journal of science and medicine in sport, 9(1-2), 3-9.

Frick, B. (2003). Contest theory and sport. Oxford Review of Economic Policy, 19(4), 512-529.

Goldberg, Rob. "NFLPA Says in Memo That Toradol Shouldn't Be Used Because of Risk of Bleeding." Bleacher Report. June 4, 2021. https://bleacherreport.com/articles/10004746-nflpa-says-in-memo-that-toradol-shouldnt-be-used-because-of-risk-of-bleeding.

Hagel, B., & Meeuwisse, W. (2004). Risk compensation: a "side effect" of sport injury prevention?. Clinical journal of sport medicine, 14(4), 193-196.

Heintz, E. C., Breaux, L., Lewis, A., & Foreman, J. J. (2020a). Determinants of missed games following concussions in the National Football League. Frontiers in sports and active living, 2, 595445.

Heintz, E. C., Foret, E. F., & Foreman, J. J. (2020b). Effect of concussions on National Football League quarterback performance. International Journal of Kinesiology and Sports Science, 8(4), 19-24.

Kahn, L. M. (2000). The sports business as a labor market laboratory. Journal of economic perspectives, 14(3), 75-94.

Katherine Terrell, The Times-Picayune. “New Orleans Saints Bounty Scandal Timeline.” December 12, 2012. https://www.nola.com/sports/saints/article_b20803a9-40e4-5a67-a99e-826e5bf66a27.html.

Kim, S., Connaughton, D. P., Spengler, J., & Lee, J. H. (2017). Legislative efforts to reduce concussions in youth sports: an analysis of state concussion statutes. J. Legal Aspects Sport, 27, 162.

Longman, Jeré. “Fit Yong Pitchers See Elbow Repair as Cure-All.” The New York Times (2017). https://www.nytimes.com/2007/07/20/sports/baseball/20surgery.html

Lybbert, T. J., Lybbert, T. C., Smith, A., & Warren, S. (2012). Does the red flag rule induce risk taking in sprint finishes? Moral Hazard crashes in cycling’s grand tours. Journal of sports economics, 13(6), 603-618.

McCradden, M. D., & Cusimano, M. D. (2018). Concussions in sledding sports and the unrecognized “Sled Head”: a systematic review. Frontiers in neurology, 9, 772.

Mack, C. D., Solomon, G., Covassin, T., Theodore, N., Cárdenas, J., & Sills, A. (2021). Epidemiology of concussion in the National Football League, 2015-2019. Sports health, 13(5), 423-430.

Myer, G. D., Smith, D., Barber Foss, K. D., Dicesare, C. A., Kiefer, A. W., Kushner, A. M., ... & Khoury, J. C. (2014). Rates of concussion are lower in National Football League games played at higher altitudes. journal of orthopaedic & sports physical therapy, 44(3), 164-172.

Navarro, S. M., Sokunbi, O. F., Haeberle, H. S., Schickendantz, M. S., Mont, M. A., Figler, R. A., & Ramkumar, P. N. (2017). Short-term outcomes following concussion in the NFL: a study of player longevity, performance, and financial loss. Orthopaedic journal of sports medicine, 5(11), 2325967117740847.

Parkkari, J., Kujala, U. M., & Kannus, P. (2001). Is it possible to prevent sports injuries?. Sports medicine, 31(14), 985-995.

Pasternack, J. S., Veenema, K. R., & Callahan, C. M. (1996). Baseball injuries: a Little League survey. Pediatrics, 98(3), 445-448.

Peltzman, S. (1975). The effects of automobile safety regulation. Journal of political Economy, 83(4), 677-725.

Potter, J. M. (2011). Estimating the offsetting effects of driver behavior in response to safety regulation: The case of formula one racing. Journal of Quantitative Analysis in Sports, 7(3).

Putukian, M., Echemendia, R. J., Chiampas, G., Dvorak, J., Mandelbaum, B., Lemak, L. J., & Kirkendall, D. (2019). Head Injury in Soccer: From Science to the Field; summary of the head injury summit held in April 2017 in New York City, New York. British journal of sports medicine, 53(21), 1332-1332.

Quarrie, K., Gianotti, S., Murphy, I., Harold, P., Salmon, D., & Harawira, J. (2020). RugbySmart: challenges and lessons from the implementation of a nationwide sports injury prevention partnership programme. Sports medicine, 50(2), 227-230.

Reams, N., Hayward, R. A., Kutcher, J. S., & Burke, J. F. (2017). Effect of concussion on performance of National Football League players. International journal of sports physiology and performance, 12(8), 1100-1104.

Rotolo, Thomas, and Michael Lengefeld. "Clearing the cobwebs: An analysis of the timing of youth concussion legislation in US states." Social Science & Medicine 265 (2020): 113491.

Seravalli, Frank. “NHL Won't Budge on Current Concussion Protocol.” TSN, December 5, 2016. https://www.tsn.ca/nhl-won-t-budge-on-current-concussion-protocol-1.624128?tsn-amp.

Secrist, E. S., Bhat, S. B., & Dodson, C. C. (2016). The financial and professional impact of anterior cruciate ligament injuries in National Football League athletes. Orthopaedic journal of sports medicine, 4(8), 2325967116663921.

Soomro, N., Sanders, R., Hackett, D., Hubka, T., Ebrahimi, S., Freeston, J., & Cobley, S. (2016). The efficacy of injury prevention programs in adolescent team sports: a meta-analysis. The American Journal of Sports Medicine, 44(9), 2415-2424.

Teramoto, M., Petron, D. J., Cross, C. L., & Willick, S. E. (2015). Style of play and rate of concussions in the National Football League. Orthopaedic journal of sports medicine, 3(12), 2325967115620365.

Thomson, C. J., & Carlson, S. R. (2015). Increased patterns of risky behaviours among helmet wearers in skiing and snowboarding. Accident Analysis & Prevention, 75, 179-183.

Torg JS, Truex R, Quedenfeld TC, et al. The national football head and neck injury registry: report and conclusions 1978. JAMA 1979; 241: 1477-9

Torres, D. M., Galetta, K. M., Phillips, H. W., Dziemianowicz, E. M. S., Wilson, J. A., Dorman, E. S., ... & Balcer, L. J. (2013). Sports-related concussion: anonymous survey of a collegiate cohort. Neurology: Clinical Practice, 3(4), 279-287.

Turbyfill, L. R., Hatley, L. J., & Needle, A. R. (2021). The effects of concussions on batting performance in major league baseball players: a critically appraised topic. Journal of sport rehabilitation, 31(4), 495-500.

Turner, C., McClure, R., & Pirozzo, S. (2004). Injury and risk-taking behavior—a systematic review. Accident Analysis & Prevention, 36(1), 93-101.

Van Mechelen, W., Hlobil, H., & Kemper, H. C. (1992). Incidence, severity, aetiology and prevention of sports injuries. Sports medicine, 14(2), 82-99.

Van Tiggelen, D., Wickes, S., Stevens, V., Roosen, P., & Witvrouw, E. (2008). Effective prevention of sports injuries: a model integrating efficacy, efficiency, compliance and risk-taking behaviour. British journal of sports medicine, 42(8), 648-652.

Verhagen, E. (2010). The cost of sports injuries. Journal of Science and Medicine in Sport, 13, e40.

Verhagen, E. A., van Stralen, M. M., & Van Mechelen, W. (2010). Behaviour, the key factor for sports injury prevention. Sports medicine, 40(11), 899-906.

Wennberg, R. A., & Tator, C. H. (2008). Concussion incidence and time lost from play in the NHL during the past ten years. Canadian journal of neurological sciences, 35(5), 647-651.

Wilde, G. J. (1982). The theory of risk homeostasis: implications for safety and health. Risk analysis, 2(4), 209-225.

Witz, Billy. "The Top Priority: Safety or Vanity?" The New York Times. The New York Times, July 23, 2014. https://www.nytimes.com/2014/07/23/sports/baseball/alex-torres-is-alone-in-mlb-wearing-isoblox-hat.html.

Wright, M. (2014). OR analysis of sporting rules–A survey. European Journal of Operational Research, 232(1), 1-8.

Yengo-Kahn, A. M., Zuckerman, S. L., Stotts, J., Zalneraitis, B. H., Gardner, R. M., Kerr, Z. Y., & Solomon, G. S. (2016). Performance following a first professional concussion among National Basketball Association players. The Physician and Sportsmedicine, 44(3), 297-303.

Appendix: Proofs

We first characterize the equilibrium (Lemma 1). We then apply the equilibrium characterisation to derive Propositions 1 to 5. Before proceeding, we derive the athletes' payoffs. Since the game is symmetric, it is sufficient to consider one of the competitors' payoffs. For simplicity, we focus on the payoff matrix of the row player. Under the zero-sum payoff assumption, the competitors' payoff are $\frac{K}{2}$ when both competitors select action M. Using the definition of Δ_L and Δ_H and the payoff additivity assumption, we obtain the payoff matrix.

Table: Raw player's payoffs net of injury costs

	L	M	H
L	$\frac{K}{2} - c_0 + r$	$\frac{K}{2} - \Delta_L - c_0 + r$	$\frac{K}{2} - \Delta_L - \Delta_H - c_0 + r$
M	$\frac{K}{2} + \Delta_L - c_0$	$\frac{K}{2} - c_0$	$\frac{K}{2} - \Delta_H - c_0$
H	$\frac{K}{2} + \Delta_L + \Delta_H - c_0 - r$	$\frac{K}{2} + \Delta_H - c_0 - r$	$\frac{K}{2} - c_0 - r$

Proof of Lemma 1.

Claim 1: L is a dominant strategy when $\Delta_L \leq r$.

L dominates M independently of the competitor's strategy when $\Delta_L \leq r$.

L dominates H independently of the competitor's strategy when $\Delta_L + \Delta_H \leq 2r$. This inequality is implied by $\Delta_L \leq r$ and $\Delta_H \leq \Delta_L$.

Claim 2: M is a dominant strategy when $\Delta_H \leq r \leq \Delta_L$.

M dominates L independently of the competitor's strategy when $\mathrm{r} \leq \Delta_L$.

M dominates H independently of the competitor's strategy when $\Delta_H \leq r$.

We conclude that M is a dominant strategy when $\Delta_H \leq r \leq \Delta_L$.

Claim 3: H is a dominant strategy when $r \leq \Delta_H$.

H dominates M independently of the competitor's strategy when $\leq \Delta_H$.

H dominates L independently of the competitor's strategy when $2r \leq \Delta_L + \Delta_H$. This inequality is implied by $r \leq \Delta_H$ and $\Delta_H \leq \Delta_L$.

This concludes the proof of Lemma 1.

Proof of proposition 1.

Proposition 1 follows from Lemma 1 after recognizing that the parameter vector changes to $\tilde{C}$ after the injury intervention.

Proof of proposition 2.

We compare the athletes' payoffs with and without adoption. We distinguish three cases:

(a) Case $\tilde{r} < r - \Delta_L$. The equilibrium changes from M to L with adoption. Athlete surplus is $\frac{K}{2} - c_0$ without adoption and $\frac{K}{2} - c_0 + \tilde{c}_0 + \mathrm{r} - \tilde{r} - \mathrm{F}$ with adoption. Welfare increases if $\tilde{c}_0 > F - \mathrm{r} + \tilde{r}$.

(b) Case $r - \Delta_L < \tilde{r} < r - \Delta_H$. The equilibrium does not change with adoption. Athlete surplus is $\frac{K}{2} - c_0$ without adoption and $\frac{K}{2} - c_0 + \tilde{c}_0 - \mathrm{F}$ with adoption. Welfare increases if $\tilde{c}_0 > F$.

(c) Case $\tilde{r} > r - \Delta_H$. The equilibrium changes from M to H with adoption. Athlete surplus is $\frac{K}{2} - c_0$ without adoption and $\frac{K}{2} - c_0 + \tilde{c}_0 - \mathrm{r} + \tilde{r} - \mathrm{F}$ with adoption. Welfare increases if $\tilde{c}_0 > F + r - \tilde{r}$.

Proof of proposition 3.

Total injury costs can increase if and only if athletes increase risk, that is, $\tilde{r} > r - \Delta_H$. Total injury cost is c_0 without adoption and $c_0 - \tilde{c}_0 + \mathrm{r} - \tilde{r}$ with adoption. Total injury cost increases if $\tilde{c}_0 < r - \tilde{r}$.

Proof of proposition 4.

We distinguish three cases:

(a) Case $\tilde{r} < r - \Delta_L$. Consider stage 2's choice of risk. According to Lemma 1, L is a dominant strategy for an adopter and M is a dominant strategy for a non-adopter. Next, we prove that adoption is a dominant strategy in stage 1 when $\tilde{c}_0 > \tilde{r} - r + \Delta_L + F$. Say the column player has not adopted. The raw player gets $\frac{K}{2} - c_0$ by not adopting and $\frac{K}{2} - \Delta_L - c_0 + \tilde{c}_0 + \mathrm{r} - \tilde{r} - F$ by adopting. Adoption is optimal when $\tilde{c}_0 > \tilde{r} - r + \Delta_L + F$. Say the column player has adopted. The raw player gets $\frac{K}{2} + \Delta_L - c_0$ by not adopting and $\frac{K}{2} - c_0 + \tilde{c}_0 + \mathrm{r} - \tilde{r} - F$ by adopting. Adoption is optimal when $\tilde{c}_0 > \tilde{r} - r + \Delta_L + F$. We obtain case (a) in the Proposition. Using the same reasoning, non-adoption is a dominant strategy when $\tilde{c}_0 < \tilde{r} - r + \Delta_L + F$.

(b) Case $\Delta_L < \tilde{r} < r - \Delta_H$. Now Lemma 1 says that M is a dominant strategy under adoption and non-adoption. A player's payoff is $\frac{K}{2} - c_0 + \tilde{c}_0 - F$ under adoption and $\frac{K}{2} - c_0$ under non-adoption. Adoption dominates non-adoption when $\tilde{c}_0 > F$.

(c) Case $\tilde{r} > r - \Delta_H$. Consider stage 2's choice of risk in stage 2. According to Lemma 1, H is a dominant strategy for an adopter and M is a dominant strategy for a non-adopter. Follow the reasoning in case (a) to show that adoption is a dominant strategy when $\tilde{c}_0 > r - \tilde{r} - \Delta_H + F$. We obtain case (c) in the proposition: When $\tilde{c}_0 < r - \tilde{r} - \Delta_H + F$, non-adoption is a dominant strategy.

Proof of proposition 5.

We distinguish eight cases:

(a) Case $\tilde{r} < r - \Delta_L$ and $\tilde{r} - r + F + \Delta_L > \tilde{c}_0 > \tilde{r} - r + F$. Adoption maximizes welfare but athletes do not adopt.

(b) Case $\tilde{r} < r - \Delta_L$ and $\tilde{c}_0 > \tilde{r} - r + F + \Delta_L$. Both the athlete and the sport organizer adopt.

(c) Case $\tilde{r} < r - \Delta_L$ and $\tilde{c}_0 < \tilde{r} - r + F$. Both the athlete and the sport organizer do not adopt.

(d) Case $r - \Delta_L < \tilde{r} < r - \Delta_H$ and $\tilde{c}_0 > F$. Both the athlete and the sport organizer adopt.

(e) Case $r - \Delta_L < \tilde{r} < r - \Delta_H$ and $\tilde{c}_0 < F$. Both the athlete and the sport organizer do not adopt.

(f) Case $\tilde{r} > r - \Delta_H$ and $r - \tilde{r} + F - \Delta_H < \tilde{c}_0 < r - \tilde{r} + F$. Athletes adopt but non-adoption maximizes welfare.

(g) Case $\tilde{r} > r - \Delta_H$ and $r - \tilde{r} + F < \tilde{c}_0$. Both the athlete and the sport organizer adopt.

(h) Case $\tilde{r} > r - \Delta_H$ and $\tilde{c}_0 < r - \tilde{r} + F - \Delta_H$. Both the athlete and the sport organizer do not adopt.

Proposition 5 reports the only two cases, specifically cases (a) and (f), where the athlete and the sports organizer disagree over adoption.