Rule changes and competitive balance in Formula One motor racing

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This article provides an economic explanation of the frequent rule changes in the Formula One (F1) motor racing series. In a two-stage model, the FIA (the organizer of the F1) first decides whether to change the rules or not, and then the racing teams compete in a contest. It turns out that a rule change reduces the teams' performances, but also improves competitive balance between the teams. The rule change is implemented, if the FIA's revenue gain from the latter effect overcompensates the FIA's revenue loss from the former effect. We provide empirical evidence from F1 seasons in the period 1950 to 2005, which supports the main implications of the model.

I. Introduction

The Formula One (F1) motor racing series has become big business. It started with the 1950 season, in which seven races were followed by spectators at the circuits only. Today, a F1 season consists of 17 races and its television audience runs to billions. According to FIA (1999), for instance, the races of the 1999 season (including training and qualifying) attracted over 57 billion television viewers in 206 different countries. Most league sports like soccer or football have a smaller audience since they are usually subject to national interest only. The Soccer World Championship and the Olympic Games reach similar television rates. But they take place every 4 years only. The F1 series is therefore, one of the world's most followed sport events. By selling broadcasting rights and attracting sponsors, the organizer of the F1 series, the Fédération Internationale de l'Automobile (FIA), transforms this fan interest into a huge revenue. It is estimated that the FIA's average annual TV revenue (without other revenue from e.g. merchandising and sponsoring) amounts to 510 million US$.[1]

A remarkable feature of the F1 series is the tendency to frequent rule changes. In the past 15 years, there were on average nine changes per season.[2] It is apparent that these rule changes often impede the performance of the racing teams. Examples are all regulations which restrict the technical capability of the cars, e.g. the definition of a maximum bodywork height/width in 1969 and a minimum cockpit dimensions in 1972, the ban of electronic control in 1994 and the reduction of engine capacity in 1995. The FIA as the rule setting organization often justifies this kind of regulation by the safety of drivers and, indeed, the F1 races have become considerably safer. Today, only one in every

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300 accidents is serious or fatal, compared with one in every 10 accidents in the 1950s and 1960s. But there were other rule changes which can hardly be justified by safety arguments. In the 2003 season, for example, the number of qualifying rounds per driver was reduced to one and the teams were no longer allowed to change settings of the cars between the qualifying session and the race. Such rule changes usually reduce the performance of the teams, but obviously have less to do with driver safety.

The aim of this article is to provide an economic explanation of such rule changes. For that purpose, we develop a two-stage model, which reflects the specific features of a F1 season. In the first stage, the FIA decides whether to change the rules or not. In doing so, it maximizes its broadcasting revenue, which is positively correlated with the fan interest. The fan interest, in turn, is increasing in the (total or average) performance of the racing teams and in competitive balance between the teams. Performance is an index measuring, for example, the speed and horse power of the racing cars. Competitive balance is understood as the uncertainty of the winner of the F1 season. This winner is determined in the second stage of the model, where racing teams with different abilities in converting effort into performance compete for a trophy money which the FIA finances out of its broadcasting revenue. The team competition is modelled as an imperfectly discriminating contest first considered by Tullock (1980). A team expends effort in order to improve its performance and the probability of winning the season, but to a certain degree its success is also determined by chance.

Within this framework, we model a rule change either by a uniform reduction in the teams' abilities or by a decline in the discriminatory power of the contest. The focus is on these two types of rule changes, since they reflect almost all regulations we observe in the F1 series. All restrictions of the cars' technical properties like the ban of electronic control or the reduction in engine capacity can be interpreted as a fall in the teams' ability. A decrease in the discriminatory power means that the outcome of the F1 season is determined to a larger part by chance. This type of rule changes includes, for example, the reduction in the number of qualifying rounds as such a reduction increases the impact of external factors like the weather on the outcome of the single races and the whole season. Our theoretical analysis shows that both types of rule changes typically lower the teams' total and average performance, but also improve competitive balance since, they restrict the relative advantage of the stronger team. Hence, the FIA decides to implement the rule change, if the

revenue gain from the increase in balance outweighs the revenue loss from the reduction in performance.

Using a data set on the F1 seasons 1950–2005, we empirically test this theoretical model by estimating its two main implications. First, the theoretical model predicts that rule changes at the beginning of a season are the more likely and the more comprehensive, the smaller competitive balance has been in the previous season. We test this implication by using a Poisson model and show that a unit increase in the standard deviation (SD) of points scored by the teams in a F1 season significantly raises the expected number of rule changes in the next season by about 2.2%. Second, we use a 2SLS regression to test the implication that rule changes at the beginning of a season improve competitive balance during the season. The results confirm a positive relation. More specific, the FIA distinguishes 'safety regulations' and 'other regulations'. We show that a 10% increase in the number of safety regulations reduces the SD of points scored by the racing teams by 7.3%, while a 10% increase in the number of other regulations reduces this SD even by 7.8%.

Our article is closely related to the rapidly growing literature on sports economics. Excellent surveys on sports economics are given by Fort and Quirk (1995) and Szymanski (2003). But this literature mainly analyses the impact of specific measures like e.g. revenue sharing in league sports. We are unaware of any empirical or theoretical study focusing on (F1) motor racing. Our theoretical model is also related to the literature on contest design. Baik (1994, 2004) and Nti (1999) investigate asymmetric contests, which are similar to the team contest in the second stage of our model. However, there are several important differences to our analysis. First, they figure out the impact of changes in the teams' abilities on the teams' effort levels, not on the teams' performances. Focusing on effort is suitable in contests like rent-seeking, where the contest designer's objective is equal to the sum of bribes he receives. But in our framework, we have to consider performance since the FIA's revenue is increasing in the fan interest which, beside competitive balance, depends on e.g. the speed of the cars (performance) and not on the amount of money the teams invest (effort). Second, and related to the first point, their results cannot be used to explain the rule changes in F1, even if we would assume that the FIA's revenue depends on effort instead of performance. Baik (1994, 2004) shows that total/average effort is maximized in the even contest where competitive balance is the highest. Hence, if the FIA's revenue would be increasing in competitive balance and total effort (instead of performance), the FIA would always set the rules such that the team

competition is completely balanced. Empirically this is not the case, neither with respect to the *ex-ante* winning probabilities nor with respect to the *ex-post* winning percentage of the racing teams. In contrast, our model typically predicts a trade-off between competitive balance and total/average performance and, thus, even after a rule change the team contest is not completely balanced. Third, Baik (1994, 2004) does not investigate the role of the discriminatory power of the contest. This is done by, e.g. Michaels (1988), Dasgupta and Nti (1998), Amegashie (1999) and Nti (1999, 2004). But all these studies focus on symmetric contests and/or do not derive the effects of the discriminatory power on performance and competitive balance.

The artical is organized as follows. In Section II, we briefly describe the organization and the basic rules of the F1 series. Section III develops and analyses the theoretical model. The predictions of this model are tested in Section IV and Section V concludes.

II. Organization and Basic Rules of the F1

The controlling organization of the F1 motor racing series is the FIA.[3] One of the main tasks of the FIA is to set the rules of the F1 series. It usually decides before a new season whether and, if so, which rules should be changed. Another important task of the FIA is the marketing of the broadcasting rights of the F1 series. Until 1996, the FIA itself sold these rights to broadcasting stations. In 1996, the FIA handed these rights for a period of 14 years to private companies owned by Bernie Ecclestone. But Ecclestone is one of the vice presidents of the FIA, and in this position he is also jointly responsible for the rule setting. Hence, also after 1996 the rule setting institution (the FIA) is in some sense responsible for selling the broadcasting rights.

Several teams compete in the F1 series. A team is allowed to participate with two cars. It employs mechanics who set up the cars and the other technical equipment and drivers who are still important, although the success of a team is by now largely determined by the technical quality of the cars. The main revenue source of the teams is sponsoring. The leading teams usually experience comprehensive support from companies of the automobile industry. Payments received from the FIA represent another important revenue source of the racing teams. The FIA shares a part of its broadcasting revenue with the racing teams according to their rankings at the end of the season. This revenue source is significant as it covers about 20% of the teams' total costs.

The ranking of the teams is determined as follows. A F1 season usually consists of 17 events. An event lasts for 3 days. During the first 2 days, the drivers have free practice and qualifying sessions. The race itself takes place on the third day. The drivers' starting positions in the race are determined by their performance in the qualifying sessions. The driver who registers the fastest qualifying time starts from the pole position followed by the driver with the second qualifying time and so on. The drivers get points according to their rankings at the end of the race. For instance, in the season 2003 the first eight ranks of a race get points which go down from 10 to 1. At the end of a season, the FIA awards two titles. In the drivers' championship, drivers accumulate the points scored in all 17 races and the driver with the most points wins the title. In the constructors' championship, each team adds together the points scored by its drivers and the title is awarded to the team with the largest number of points.

III. Theoretical Model

Based on the information given in the previous section, we view a F1 season as a two-stage process. At the first stage, the FIA as the organizer of the F1 series decides whether to change the rules of the previous season or not. At the second stage, the racing teams take the rules as given and compete in a contest in hope of obtaining (a part of the) broadcasting revenue collected by the FIA. This two-stage process is solved recursively in order to obtain a subgame-perfect solution. In doing so, we assume that the FIA and the teams are profit maximizer. An argument in favour of profit-maximizing behaviour of the racing teams is that they are often under the control of profit-maximizing companies of the automobile industry. The transfer of the broadcasting rights to profit-maximizing companies may be seen as an indication that profit considerations play a role in the rule setting of the FIA.

Stage 2: team competition

The team competition is modelled as a contest. To make our point, it suffices to focus on a contest with two teams. We explicitly model the constructors'

[3] All the following information on the F1 series can be found at the website www.fia.com

championship only and ignore the drivers' championship. A team is therefore treated as a single player.

Effort of team $i = 1, 2$ is denoted by e_i. It reflects the salary of the drivers and the cost of developing and producing the cars (e.g. material cost and the salary of the mechanics). Team i's effective amount of effort is represented by $\alpha_i e_i$. The parameter α_i may be interpreted as team i's ability of transforming effort into effective units. We assume $\alpha_1 > \alpha_2$, i.e. team 1 is more able than team 2. Such a difference in abilities may reflect, for example, differences in the drivers' and engineers' skills. Another reason for heterogeneous abilities, which we will refer to below, is the different success in previous seasons. A team is often the more experienced and thus the more able in the present season, the more successful it has been in the past. Such a 'learning-by-winning' effect is in particular relevant for the F1 series, since the ability to realize a good performance of the cars and the drivers depends to a high degree on trial and error.

The performance of team i is denoted by h_i. It is an increasing function of team i's effective effort according to the relation $h_i = (\alpha_i e_i)^r$ with $r > 0$. Performance h_i can best be viewed as an aggregate of several indicators, which describe the characteristics of team i's cars and drivers. Examples for such indicators are the maximum speed, the horsepower or the air drag coefficient of team i's car, the physical and mental strength of team i's drivers, the minimum time a driver of team i needs for the qualifying round on a 'representative' circuit or the inverse of the failure rate of team i's cars during the races of the F1 season. More loosely speaking, h_i reflects the ability of team i to optimize the interaction between the drivers' and the cars' performance such that they perform well in a typical race of the F1 series.

The teams expend resources in hope of winning (a part of) the trophy money $v > 0$. This trophy money is financed by the FIA out of its revenue from selling the broadcasting rights. It is divided among the teams according to their success during the

season. To model such success-orientated payments in a simple way, we assume that each team obtains a share of v, which reflects the team's share at total points. For example, if a team achieves 20% of total points, it also gets 20% of the trophy money v. Furthermore, we assume that team i's share at total points, p_i, equals the share of its performance at total performance of both teams, i.e.

$$p_i = \frac{h_i}{h_i + h_j} = \frac{(\alpha_i e_i)^r}{(\alpha_i e_i)^r + (\alpha_j e_j)^r}, \quad i, j = 1, 2, \ i \neq j \quad (1)$$

The larger team i's performance relatively to team j's performance, the larger is team i's share at total points. From an *ex ante* point of view, p_i can be interpreted as team i's winning probability and $p_i v$ is expected trophy money of team i.[4]

According to Equation 1, the parameter r may be interpreted as discriminatory power of the contest. It measures to what extent the contest outcome is determined by chance and to what extent by the teams' effort levels. In the extreme case of $r \to \infty$, the contest is perfectly discriminating. Effort is then the only determinant of the contest outcome and the team with the higher effective effort level wins all points. For instance, if $\alpha_i e_i > \alpha_j e_j$, then $r \to \infty$ implies $p_i = 1$ and $p_j = 0$. In contrast, effort does not influence the contest outcome at all if $r \to 0$. The winning probabilities of the teams are then $p_i = p_j = 1/2$ and the contest outcome is determined solely by chance. To put it another way, the smaller the discriminatory power r, the less sensitive is the contest outcome to variations in effort levels and the larger is the influence of chance.

Expected profit of team i equals the team's expected trophy money less effort, i.e.[5]

$$\Pi^i(e_i, e_j) = p_i v - e_i$$
$$= \frac{(\alpha_i e_i)^r}{(\alpha_i e_i)^r + (\alpha_j e_j)^r} v - e_i, \quad i, j = 1, 2, \ i \neq j$$
$$(2)$$

Team i chooses effort such that its profit (Equation 2) is maximized. In doing so, it takes as given the effort of team j and the rules set by the FIA at stage 1 of the

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[4] Another modelling of the success-orientated payments is to explicitly assume that the FIA divides the whole trophy money v into a first prize for the winner and second prize for the looser. See e.g. Moldovanu and Sela (2001) and Szymanski and Valletti (2005). We prefer the above modelling for several reasons. First, the FIA usually does not award differentiated prizes. Second, our empirically analysis focuses on the explanation of the 'technical' rule changes, not on the prize policy of the FIA. It is therefore suitable to model the FIA's prize setting behaviour as simply as possible. Finally, our approach approximates the division of the trophy money into a first and second prize and, thus, it seems reasonable that our basic insights will not be changed if several prizes are modelled explicitly.

[5] For simplicity, we ignore other important revenue sources of the teams like sponsoring and advertising. It is straightforward to include these sources in our model. But this would merely complicate the analysis without adding further insights.

F1 season. We look for a pure-strategy equilibrium. The equilibrium is determined by the first- and second-order conditions of the teams' profit maximization. These conditions read

$$\Pi_{e_i}^i(e_i, e_j) = \frac{r\alpha_i(\alpha_i e_i)^{r-1}(\alpha_j e_j)^r}{[(\alpha_i e_i)^r + (\alpha_j e_j)^r]^2} v - 1 = 0 \qquad (3)$$

$$\Pi_{e_i e_i}^i(e_i, e_j) =$$
$$\frac{r\alpha_i^2(\alpha_i e_i)^{r-2}(\alpha_j e_j)^r[(r-1)(\alpha_j e_j)^r - (r+1)(\alpha_i e_i)^r]}{[(\alpha_i e_i)^r + (\alpha_j e_j)^r]^3} v < 0$$
$$(4)$$

for $i, j = 1, 2$ and $i \neq j$. The first-order condition (Equation 3) immediately implies that in equilibrium both teams choose the same effort, i.e. $e_1 = e_2 =: e^*$. The closed-form solution for equilibrium effort can be computed from Equation 3 as

$$e^* = \frac{r\alpha_1^r \alpha_2^r v}{(\alpha_1^r + \alpha_2^r)^2} \qquad (5)$$

Since team 1 is more able than team 2, it realizes a higher performance and a higher chance of winning. Inserting e^* into Equation 1 gives the equilibrium winning probabilities

$$p_1^* = \frac{\alpha_1^r}{\alpha_1^r + \alpha_2^r} > \frac{\alpha_2^r}{\alpha_1^r + \alpha_2^r} = p_2^* \qquad (6)$$

Using Equations 5 and 6 in Equation 2 yields equilibrium profits

$$\Pi^{1*} = \frac{\alpha_1^r[\alpha_1^r + (1-r)\alpha_2^r]}{(\alpha_1^r + \alpha_2^r)^2} v > \frac{\alpha_2^r[\alpha_2^r + (1-r)\alpha_1^r]}{(\alpha_1^r + \alpha_2^r)^2} v = \Pi^{2*}$$
$$(7)$$

Hence, equilibrium profit of team 1 is larger than that of team 2. For e^* to be a pure-strategy equilibrium, profits of both teams have to be nonnegative at e^*. Equation 7 implies that $\Pi^{1*} > \Pi^{2*} \geq 0$ if and only if

$$r \leq 1 + \frac{\alpha_2^r}{\alpha_1^r} < 2 \qquad (8)$$

We suppose the parameters r, α_1 and α_2 satisfy this condition throughout. Note that the second-order condition (Equation 4) is then satisfied as well, implying both teams attain a profit maximum at e^*. To sum up, if condition in Equation 8 is satisfied, then e^* from Equation 5 is the unique pure strategy Nash-equilibrium of the team contest.

Stage 1: contest regulation

Having solved the team contest, we now turn to the rule setting of the FIA at the first stage of the F1 season. The larger the fan interest in the F1 races, the larger is the profit a broadcasting station can realize with the TV coverage of the races and the larger is the willingness to pay of the station for the broadcasting rights of the F1 series. The revenue of the FIA from selling broadcasting rights is therefore positively correlated with the fan interest in the F1 series. The fan interest, in turn, is increasing in two variables. First, fans are interested in races with high performances of the teams. For example, if the maximum speed of the cars is high, the number of viewers will usually be larger than in case where the cars are quite gammy. Second, fans like close contests. The more uncertain the outcome of the F1 season, the more exciting is the season and the larger is the number of people who are willing to follow the races. To put it the other way round, if it is almost clear from the outset which team will win the championship, then the F1 season is rather uninteresting for the fans.

To model these properties, we assume that the FIA's revenue from selling the broadcasting rights is a function $R(a^*, b^*)$ where

$$a^* = h_1^* + h_2^* = \frac{(rv\alpha_1^r \alpha_2^r)^r}{(\alpha_1^r + \alpha_2^r)^{2r-1}} \qquad (9)$$

is total performance of both teams in the contest equilibrium and where

$$b^* = p_1^* - p_2^* = \frac{\alpha_1^r - \alpha_2^r}{\alpha_1^r + \alpha_2^r} \qquad (10)$$

is the equilibrium difference in winning probabilities of the teams. Note that $b^* > 0$ due to $\alpha_1 > \alpha_2$. The inverse of b^* can be viewed as a measure of the closeness of the F1 season or, equivalently, of competitive balance between the teams. The smaller b^*, the more equal are the winning probabilities of the teams and the closer or the more balanced is the championship. The revenue function R is supposed to satisfy

$$R_a(a^*, b^*) > 0, \quad R_{aa}(a^*, b^*) \leq 0 \qquad (11)$$

$$R_b(a^*, b^*) \gtreqless 0 \Leftrightarrow b \lesseqgtr 0, \quad R_{bb}(a^*, b^*) < 0 \qquad (12)$$

where subscripts indicate partial derivatives. Due to Equation 11, the FIA's revenue is increasing and nonconvex in total performance or, equivalently, average performance $a^*/2$. Equation 12 states that, for given performance, the revenue is maximized in the even contest with both teams having the same winning probability. Deviations from the even contest reduce

the revenue at increasing rates. These properties of R reflect the above mentioned impact of performance and competitive balance on the FIA's revenue.

Profit of the FIA may be written as $R(a^*, b^*) - v$. It equals the broadcasting revenue of the FIA less the trophy money divided among the teams. The FIA sets the rules of the F1 in order to maximize its profit. In doing so, it accounts for the impact the rules have on equilibrium performance and competitive balance specified in Equations 9 and 10, respectively. The rules of the contest determine the trophy money v, the discriminatory power r and the teams' abilities α_1 and α_2. To fix our ideas, we suppose throughout that the trophy money v is exogenously given. Profit maximization is then equivalent to maximization of revenue $R(a^*, b^*)$. Moreover, we investigate the regulation of the discriminatory power and the regulation of abilities separately. It should be noted, however, that our results qualitatively remain unchanged when the FIA determines v, r, α_1 and α_2 simultaneously.

Before investigating the FIA's rule setting decision, it should be noted that we will consider symmetric regulations only. This means that the FIA cannot discriminate between the stronger and the weaker team, for example, by imposing a handicap on the stronger team. The motivation for such an assumption is that the aim of our analysis is to explain the rule changes in F1 and that we did not observe asymmetric regulations in the past. The rule changes in F1 are always equally applied to all teams. One might wonder why the FIA does not use asymmetric regulations, especially if it cares about competitive balance. For instance, by restricting the ability of the stronger team only, the FIA might increase competitive balance without harming performance too much. In a contest with several teams, the FIA might even exclude the strongest team as this immediately improves competitive balance and also raises performance (e.g. Baye *et al.*, 1993). From our point of view, however, one important reason why the FIA does not use asymmetric regulations is that they will lower the fan interest and, thus, the FIA's broadcasting revenue. If the strongest team is handicapped or even excluded, a large number of fans (at least the fans of the strongest team and a large part of the neutral fans) will find the regulation unfair and so lose the interest in the F1 series. Our formal model captures this aspect, if we assume that an asymmetric rule change leads to a prohibitively high reduction in revenue R.

Regulation of the teams' abilities. Let us first suppose the discriminatory power r is

exogenously given. The rule setting of the FIA may then influence the teams' abilities α_1 and α_2 only. A prominent example is the one already mentioned in the 'Introduction'. Since the season 2003, the F1 teams are no longer allowed to change the setting of the cars after qualifying. It is therefore, not possible to employ experiences gained during the qualifying session in order to adjust the car to the specific conditions of the circuit. Obviously, this rule change negatively affects the teams' abilities α_1 and α_2. To model such a rule change, we assume

$$\alpha_i = \frac{1}{c_i + \tau}, \quad i = 1, 2, \text{ with } \tau \geq 0 \text{ and } c_1 < c_2 \quad (13)$$

The parameter c_i reflects the inverse ability of team i in the status quo, i.e. without a rule change of the FIA. The variable τ indicates the rule changes. If the FIA chooses $\tau = 0$, then the rules of the previous season remain unchanged. In contrast, $\tau > 0$ stands for the case in which the FIA decides to change the rules. This rule change is the more comprehensive, the larger is τ. The specification of the teams' abilities in Equation 13 seems to be very special. It has, however, a straightforward interpretation. If we define $x_i = \alpha_i e_i$, then $e_i = (c_i + \tau)x_i$. Inserting this into team i's profit function, Equation 2, yields $\Pi^i(\cdot) = p_i v - (c_i + \tau)x_i$. Hence, c_i may be interpreted as team i's unit cost of effort and the rule change parameter τ works like an increase in unit cost.

The FIA sets τ such that its revenue is maximized. The maximization problem is

$$\max_{\tau} R(a^*, b^*) \quad \text{s.t. Equations 9, 10 and 13} \quad (14)$$

We want to know whether the optimal value of τ is zero (no rule change) or strictly positive (rule change). To solve the maximization problem, the FIA needs to figure out the impact of the rule change parameter on total performance and competitive balance in the contest equilibrium at stage 2. From Equations 9, 10 and 13 we obtain

$$\text{sign}\left\{\frac{da^*}{d\tau}\right\}$$

$$= \text{sign}\left\{r(c_2 - c_1) - \frac{(c_2 + \tau)^{1+r} + (c_1 + \tau)^{1+r}}{(c_2 + \tau)^{1+r} - (c_1 + \tau)^{1+r}}\right\} = -1 \quad (15)$$

$$\text{sign}\left\{\frac{db^*}{d\tau}\right\} = \text{sign}\{c_1 - c_2\} = -1 \quad (16)$$

The sign in Equation 15 follows from the existence condition in Equation 8. It implies that performance is harmed when rules are changed, i.e. when τ increases from zero to a strictly positive value. But this is not the only consequence of a rule change. According to Equation 16, competitive balance is improved. The reason is that the relative advantage of team 1 (measured by $\alpha_1/\alpha_2 = (c_2 + \tau)/(c_1 + \tau)$) declines. In sum, a rule change induces a tradeoff as it worsens performance and at the same time improves competitive balance.[6]

This trade-off implies that a rule change has two opposing effects on the FIA's revenue. On the one hand, the reduction in performance lowers the revenue, since viewers prefer teams with high performance. On the other hand, the improvement in competitive balance raises the revenue, since viewers like close races. If the second effect over-compensates the first effect, then the FIA has an incentive to change the rules of the previous season. To formally prove this assertion, we consider the Kuhn–Tucker conditions for the profit maximization problem in Equation 14. These conditions read

$$
R_a(\cdot)\frac{\mathrm{d}a^*}{\mathrm{d}\tau} + R_b(\cdot)\frac{\mathrm{d}b^*}{\mathrm{d}\tau} \le 0,
$$
$$
\tau\left[R_a(\cdot)\frac{\mathrm{d}a^*}{\mathrm{d}\tau} + R_b(\cdot)\frac{\mathrm{d}b^*}{\mathrm{d}\tau}\right] = 0, \quad \tau \ge 0 \tag{17}
$$

The term containing R_a represents the revenue loss of a rule change due to the decrease in total performance. Equations 11 and 15 imply that this term is negative. The term containing R_b stands for the revenue gain of a rule change due to the improvement in competitive balance. It is positive according to $b^* > 0$, and Equations 12 and 16. If the latter effect is negligible, then the solution to the Kuhn–Tucker conditions is $\tau^* = 0$ i.e. no rule change. In contrast, if the revenue gain from the increase in competitive balance is large enough, then $\tau^* > 0$ and the FIA changes the rules of the previous season.

For our empirical analysis, it is desirable to know how the difference in the teams' abilities influences the optimal choice of the FIA. Unfortunately, our model does not allow a closed-form solution for τ since the discriminatory power r is not necessarily equal to 1. But we can gain some insights if we

Table 1. Simulation results for the regulation of abilities

c_1	9	8	7	6	5	4	3	2	1
c_2	10	10	10	10	10	10	10	10	10
τ^*	0	0	0	3.59	7.83	12.26	16.86	21.61	26.49

choose a specific functional form of the revenue function and then simulate the FIA's decision. Consider the linear-quadratic revenue function $R(a,b) = \gamma a - \delta b^2$. Setting $v = 1000$, $r = 0.4$, $\gamma = 1$ and $\delta = 200$, we obtain the simulation result summarized in Table 1. These results indicate that a rule change is the more likely and the more comprehensive, the larger the difference in abilities. The intuition is straightforward. For a small difference in abilities, the team contest is relatively balanced even without a rule change. The negative effect of a rule change on total performance would be more important than the positive effect on competitive balance and the FIA does not have an incentive to alter the rules. In contrast, if team 1's predominance is large enough, competitive balance without a rule change is quite bad. The FIA can then gain more revenue if she tightens the rules such that the teams' abilities decline and the races become closer. Further simulations show that this result is very robust against variations in the parameter values. In fact, we did not succeed in constructing a counterexample.

Regulation of the discriminatory power. Suppose now the abilities of the teams are fixed and the FIA only has the option of regulating the discriminatory power r. The FIA frequently used this kind of regulation in the past. The most obvious example has already been mentioned in the 'Introduction'. Since the season 2003, the qualifying on the day before the race consists of one round per driver only. The outcome of the qualifying and, thus, the outcome of the race itself is therefore, much more influenced by chance. For example, if a driver makes a mistake in his only qualifying round or if the weather conditions in this round are fairly bad, it is no longer possible

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[6] Two remarks are in order. First, from Equations 5 and 13 it is also straightforward to show that total/average effort of the teams is increasing in the rule change parameter, i.e. $\mathrm{d}e^*/\mathrm{d}\tau > 0$. This insight confirms the result of Baik (1994, 2004) that higher the total effort, the more equal the players are. As explained in the 'Introduction', however, in our framework it is more suitable to focus on performance. Second, it is well-known that comparative static results in contest models may not be robust to variations in the functional forms and that some perverse effects may occur. See, for example, Nti (1997). Of course, this is also true for our model, but our empirical results will confirm the prediction of the theoretical model so that the problem is less severe.

to try better in another round. This kind of regulation can be modelled by assuming

$$r = \rho - \sigma \quad \text{with } \sigma \geq 0 \tag{18}$$

ρ reflects the discriminatory power in the status quo without a rule change. The rule change variable is now represented by σ. If the FIA chooses $\sigma = 0$, then the rules remain unchanged. In contrast, the case $\sigma > 0$ indicates a rule change, which reduces the discriminatory power, i.e. which makes the contest outcome more dependent on chance and less dependent on the teams' effort levels.

The FIA's profit maximization now reads

$$\max_{\sigma} R(a^*, b^*) \quad \text{s.t. Equations 9, 10 and 18} \tag{19}$$

To solve this problem, the FIA needs to know the impact of the rule-change parameter σ on the equilibrium of the team contest. In contrast to the regulation of the teams' abilities, Equations 9 and 18 now imply that the impact of σ on equilibrium performance is not unique. But with respect to competitive balance we obtain from Equations 10 and 18

$$\text{sign}\left\{\frac{db^*}{d\sigma}\right\} = \text{sign}\{\ln \alpha_2 - \ln \alpha_1\} < 0 \tag{20}$$

A reduction in the discriminatory power means that the outcome of the team contest is less sensitive to variations in the teams' effort levels. As a consequence, the relative advantage of team 1 due to its higher ability becomes less important and the competition closer. This implies that competitive balance increases as proven by Equation 20.

This positive effect of reducing the discriminatory power allows a similar argument as in case of ability regulation. Tightening the rules may exert a negative effect on the FIA's revenue, if total performance declines. But there is also a positive effect on the FIA's revenue, since the championship becomes closer. If the latter effect overcompensates the former, then the FIA has an incentive to change the rules of the previous season. Formally, this can be seen from the Kuhn–Tucker conditions of problem Equation 19. These conditions are the same as the conditions in Equation 17, except for replacing τ by σ.

To figure out the impact of the difference in abilities on the FIA's choice, we are again restricted to numerical simulation. Consider the linear-quadratic specification of the revenue function and suppose $v = 20$ and $\rho = \gamma = \delta = 1$. The simulation results are summarized in Table 2. They are very similar to the case of ability regulation. The more asymmetric the teams are, the more likely is it that the FIA changes the rules of the previous season

Table 2. Simulation results for the regulation of discriminatory power

α_1	10	30	50	70	90	110	130	150	170
α_2	1	1	1	1	1	1	1	1	1
σ^*	0	0	0	0.03	0.06	0.08	0.10	0.11	0.12

and the more comprehensive are the rule changes. The intuition is again that for large asymmetries, the increase in the FIA's revenue due to the improvement of competitive balance is large enough to outweigh the (possible) revenue decrease due to a decline in the performance of the teams.

IV. Empirical Analysis

In order to empirically test the theoretical model, we offer the following interpretation of the results. Tables 1 and 2 show that rule changes are the more likely and the more comprehensive, the larger the difference in abilities of the racing teams. Moreover, we argued that the difference in abilities is influenced, among other things, by the different success of the teams in the previous season. Hence, if competitive balance in the previous season was low (i.e. the difference in success was large), then the difference in abilities in the present season is large and the FIA is strongly inclined to change rules before the season. In sum, we obtain

Hypothesis 1: The smaller competitive balance in season $t - 1$, the more likely and the more comprehensive are rule changes at the beginning of season t.

A second prediction of the model concerns the impact of rule changes on the equilibrium of the team contest. Equations 16 and 20 show that competitive balance is improved by rule changes and that this improvement is the larger, the more comprehensive the rule changes. Hence, we obtain

Hypothesis 2: The more comprehensive rule changes at the beginning of season t, the better is competitive balance between the teams during season t.

After a rule change, the teams will try to improve their performance within the new set of rules. Since a more able team will do this with more success than a less able team, after a while (say, one or two seasons later) competitive balance is worsened again. If the decrease in competitive balance is too large, we return to Hypothesis 1 and the FIA receives an incentive to change rules again. By Hypothesis 2 this would again improve competitive balance and so on. In sum, we

obtain a kind of cat-and-mouse game between the teams and the FIA. This game might explain the frequent rule changes we observe in the F1 series.[7] To test Hypothesis 1 and 2, we use data on F1 seasons from 1950 to 2005. The data comprise information on safety and technical regulations at the beginning of each season, on points scored by the teams during each season and on the number of fatal accidents during each season.[8]

Testing Hypothesis 1

Hypothesis 1 identifies competitive balance in season $t-1$ as a motivation for rule changes at the beginning of season t. The safety of drivers is another motivation for rule changes. We did not take into account this motivation in our theoretical model, but in the empirical analysis we have to control for it since the FIA often justifies rule changes by safety consideration. Hence, the explanatory variables in testing Hypothesis 1 are competitive balance and the safety of drivers in season $t-1$. Competitive balance in season $t-1$ is measured by the SD of points scored by the teams in season $t-1$. This is the same indicator of competitive balance as we used in the theoretical model.[9] The drivers' safety in season $t-1$ is measured by the number of serious or fatal accidents in season $t-1$.

The dependent variable in testing Hypothesis 1 is the magnitude of rule changes at the beginning of season t. Rule changes comprise both the introduction of new rules and the modification or abolition of existing rules. Of course, the rule changes differ with respect to their impact on the outcome of the races. For example, the restriction of the engine capacity usually has another impact as the definition of a maximum bodywork height. But it is impossible to exactly determine the impact of every single rule change. We therefore, choose a pragmatic procedure and measure the magnitude of rule changes in season t simply by the number of rules which are modified, introduced or abolished at the beginning of season t.

The underlying assumption is that the average impact of the rule changes is the same in all seasons.

The number of rule changes is a discrete variable. Such count data are usually treated within a Poisson regression model (e.g. Amemiya, 1986; Greene, 1993). Following this approach, we denote the number of rule changes at the beginning of season t by RC_t and the probability that RC_t is equal to $n_t \in \{0, 1, 2, \ldots\}$ by

$$\text{Prob}(RC_t = n_t) = \frac{e^{-\lambda_t}\lambda_t^{n_t}}{n_t!} \tag{21}$$

where $\ln \lambda_t = \boldsymbol{\beta x'_t} - 1$. The vector $\boldsymbol{\beta} = (\beta_3, \beta_1, \beta_2, \beta_0)$ contains the coefficients to be estimated. The explanatory variables are listed in $\boldsymbol{x_{t-1}} = (1, AC_{t-1}, D_{t-1}AC_{t-1}, SD_{t-1})$ where SD_{t-1} and AC_{t-1} denote the SD of points scored by the teams in season $t-1$ and the number of serious or fatal accidents in season $t-1$, respectively. The number of accidents enters our regression directly and by the composed variable $D_{t-1}AC_{t-1}$ where D_{t-1} is a dummy variable equal to 0 for $t \leq 1970$ and 1 for $t > 1970$. For the seasons up to 1969, the impact of the number of accidents on the rule setting of the FIA is therefore represented by β_1 while for the seasons after 1969, it is represented by $\beta_1 + \beta_2$. The motivation for this specification is that in the F1 seasons up to 1969, many drivers were killed in the races, but the FIA did not react with safety regulations. Only thereafter, the FIA became aware of the danger for the drivers and introduced more safety regulations.

For the interpretation of the coefficients $\boldsymbol{\beta}$, note that $E(RC_t) = VAR(RC_t) = \lambda_t = e^{\boldsymbol{\beta x'_t}-1}$. It follows $\boldsymbol{\beta} = [\partial E(RC_t)/\partial \boldsymbol{x_{t-1}}]/E(RC_t)$. Hence, $\boldsymbol{\beta}$ shows the percentage change in the expected number of rule changes at the beginning of season t caused by a unit increase in the explanatory variables. Estimating the coefficient yields the results depicted in Table 3. All coefficients are significant and the signs are as expected. Before 1970, the lagged number of accidents had a negative impact on the expected number of rule changes, since the FIA did not care about

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[7] Such an argument assumes some kind of myopic behaviour of the FIA and the racing teams. A closer look at the rule changes in the past suggests that this assumption is not unrealistic. Modelling rule changes in dynamic sports contests are left for future research.

[8] The data on points have been collected from the official F1 website at http://www.formulaone.free-online. co.uk/index.html. The remaining data can be found on the websites at http://www.f1technical.-net, http://www.formula1.com, http://www.motorsm.com and http://www.atlasf1.com, which reports on official studies of the FIA.

[9] In the two-player contest, the SD of p_i^* equals $b^*/2$. The SD of winning percentage is a widely used measure of competitive balance in sports contests (Fort and Quirk, 1995; Szymanski, 2003). Other measures include the SD of winning percentage relative to an idealized SD (Scully, 1989; Quirk and Fort, 1992; Vrooman, 1995), the Gini coefficient (Quirk and Fort, 1992), relative entropy (Horowitz, 1997), the Hirschman–Herfindahl index (Depken, 2002) and the ratio of the sum of SD of team performance through time to the sum of within season SDs of win percentage (Humphreys, 2002).

Table 3. Poisson model for testing Hypothesis 1

	Coeff.	SE	t-Statistic	p-Value	95% conf. interval
Dependent variable: RC_t					
Constant (β_0)	0.719	0.080	8.960	0.000	[0.562; 0.877]
AC_{t-1} (β_1)	−0.234	0.026	−9.110	0.000	[−0.285; −0.184]
$D_{t-1}AC_{t-1}$ (β_2)	0.431	0.026	16.270	0.000	[0.379; 0.483]
SD_{t-1} (β_3)	0.022	0.002	14.430	0.000	[0.019; 0.025]

Notes: Observations = 55, log-likelihood = −1671.657; pseudo $R^2 = 0.148$.

the safety of drivers. The impact of the number of accidents on the FIA's rule setting after 1970 is represented by $\beta_1 + \beta_2 = -0.234 + 0.431 = 0.203$. Hence, an additional fatal accident increases the expected number of rule changes by 20%. This confirms that safety considerations play a role in the rule setting of the FIA. However, the coefficient of the lagged SD of points is also positive. This implies that the expected number of rule changes at the beginning of a season is the larger, the smaller competitive balance has been in the previous season. More specific, a unit increase in the SD of points increases the expected number of rule changes by 2.2%. This result provides empirical evidence for Hypothesis 1 derived from our theoretical model.[10]

The results in Table 3 identify the drivers' safety and competitive balance as motivation for rule changes in the F1 series. To figure out which of these two motivations was more important in the past, we have to compare the number of accidents and the variation in competitive balance. During the seasons 1970–1989, 24 drivers lost their lives in fatal accidents, whereas the SD in the dispersion of points amounted to 8.223. Hence, during this time period the drivers' safety was the main motivation for the frequent rule changes in the F1 series. In contrast, in the seasons 1990–2005 only two drivers were killed, but the SD in the dispersion of points was 10.588. Consequently, relatively to the drivers' safety, competitive balance became much more important as motivation for rule changes.

Testing Hypothesis 2

The second hypothesis states that rule changes at the beginning of a F1 season improves competitive balance during the season. For testing this

hypothesis, the number of rule changes at the beginning of a season is chosen as explanatory variable. Since, the rule changes in our data set are divided into rule changes regarding the driver safety and other rule changes, we use this information and distinguish between the number of safety regulations in season t, SRC_t and the number of other regulations at the beginning of season t, ORC_t. The dependent variable is competitive balance in season t, again measured by the SD of points scored by the teams, SD_t. In sum, we obtain the regression equation

$$\ln SD_t = \beta_0 + \beta_1 \ln SRC_t + \beta_2 \ln ORC_t + \epsilon_t \quad (22)$$

Since this equation is formulated in log-values, the coefficients β_1 and β_2 represent the elasticity of the SD of points with respect to the number of safety regulations and the number of other regulations, respectively.

The distinction between safety and other regulations is taken from the FIA. Of course, we do not know whether the motivation for the safety regulation is really driver-safety. To cope with this problem and to disentangle the true safety regulation from the other regulation, we use an Instrumental-Variables-2SLS model to estimate Equation 22.[11] The number of accidents in the period $t-1$ is used as instrumental variable for the number of safety regulation in period t. The results are displayed in Table 4. These results provide clear evidence for Hypothesis 2. An increase in the number of rule changes at the beginning of a season makes competition closer and improves competitive balance during the season. More specific, a 10% increase in the number of other regulations reduces the dispersion of points by 7.8%. The coefficient is highly significant at the 1% level. A little bit surprisingly, even safety regulations have a positive impact on competitive balance. The coefficient is also significant

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[10] We also test for overdispersion in the Poisson regression model. The hypothesis that $E(RC_t) = Var(RC_t)$ cannot be rejected on the basis of the likelihood ratio test.
[11] Note also that the correlation between safety regulations and other regulations is low as the correlation coefficient between SRC_t and ORC_t amounts to 0.34.

Table 4. Instrumental variable (2SLS) model for testing Hypothesis 2

	Coeff.	SE	t-Statistic	p-Value	95% conf. interval
Dependent variable: $\ln SD_t$					
Constant (β_0)	5.747	0.350	16.44	0.000	[5.056; 6.438]
$\ln SRC_t$ (β_1)	−0.731	0.129	−5.670	0.000	[−0.986; −0.476]
$\ln ORC_t$ (β_2)	−0.776	0.157	−4.940	0.007	[−1.086; −0.465]

Notes: Instrumented: $\ln SRC_t$; instruments: AC_{t-1}, $D_{t-1}AC_{t-1}$; observations: 55; $Prob > F = 0.0000$.

at the 1% level and implies that a 10% increase in the number of safety regulations reduces the SD of points by 7.3%. This result supports Hypothesis 2 and shows that the FIA can indeed use safety regulations in order to improve competitive balance.

V. Conclusion

This study provides for the first time an economic analysis of the F1 motor racing series. The main question was to theoretically and empirically determine the motivation for the frequent rule changes in the F1 series. In the first part, we developed a theoretical model in which the motivation for rule changes was competitive balance between the racing teams. In this model, a rule change at the beginning of a F1 season has two effects. It reduces the performance of the teams and improves competitive balance. The broadcasting revenue of the organizer, the FIA, is reduced by the former effect and increased by the latter. Hence, if the revenue gain from the increase in competitive balance is sufficiently large, the FIA has an incentive to change the rules. In the second part, we empirically estimated this theory for the F1 seasons 1950–2005. It turned out that, beside the drivers' safety, competitive balance is a significant determinant of rule setting in F1. The expected number of rule changes at the beginning of a season is high, when competitive balance in the previous season has been low. Moreover, rule changes at the beginning of a season exert a significant positive impact on competitive balance during the season, even if the rule changes are declared as safety regulation.

Beside the contribution to sports economics, our article also highlights the usefulness of sports data in order to test the predictions of contest models. Most of the empirical work has been on the related tournament model introduced by Lazear and Rosen (1981). There are also some laboratory experiments on contests like the one used in our article, for example, Potters *et al.* (1998). But field experiments on contests are rare. The reason might be that contest models are often applied to nonobservable phenomena like rent-seeking or lobbying for which data are hardly available. In contrast, data on sports contests are easily obtained and, thus, can help to improve our understanding of contests. The survey of Szymanski (2003) shows the large potential sports data have for the empirical estimation of contest models and we hope that our article further encourage research into this direction.

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