MAGKS
Aachen Siegen Gießen Marburg Kassel Göttingen

Joint Discussion Paper
Series in Economics

by the Universities of

Aachen · Gießen · Göttingen
Kassel · Marburg · Siegen

ISSN 1867-3678

No. 56-2014

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# Professional Cycling and the Fight against Doping

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October 27, 2014

**Abstract**

Doping seems to be well-organized and inherent in the system of professional cycling. This paper provides a theoretical approach, by using a multi-task (training and doping) principal-agent (team manager and cyclist) model, to illustrate the information asymmetry and conflicting objectives between both actors. Three settings are used to represent different situations in which the fight against doping takes place with varying intensity. The comparison of the equilibria in each setting reveals the influence of the fight against doping on the team members' behaviour. The analysis shows that team managers are interested in doping, and that current anti-doping institutions cannot suppress the abuse of forbidden drugs.

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†I thank Nadege Azebaze, Evelyn Korn, Michael Perdue, Elisabeth Schulte, Matthias Verbeck, Johannes Ziesecke, participants of the MACIE workshop on "The Economics of Formal and Informal Institutions" and participants of the 6th European Conference in Sports Economics for their helpful comments.

# 1 Introduction

In professional sports, athletes always claim that they dislike the abuse of performance-enhancing drugs (PED) due to potential health risks and the concern for fair competitions. This opinion is shared by many stakeholders who are involved in professional sports. Sports associations, sponsors, teams and coaches emphasize their interest in a clean and fair sport. Nevertheless, there are many reported doping cases in professional sports. This is true for professional cycling as well which is the focus of this paper. However, it follows that this analysis can be applied to other sports, too.

Professional cycling offers a well-documented history of drug abuse. Mischke (2007) gives an overview of positive doping tests and doping scandals in cycling from 1940 to 2006. Christiansen (2005) describes the development of doping using modern technology. The most recent incident is the revelation of Lance Armstrong's sophisticated doping system within the U.S. Postal Service Pro Cycling Team. In addition to Lance Armstrong, the team director, Johan Bruyneel, was also involved in doping. The U.S. Anti-Doping Agency (USADA) provided a detailed account of this system in 2012. Thus, doping scandals are omnipresent in the history of cycling.

Stakeholders' consensus for a clean and fair sport is in contrast to the level of doping in cycling. The difference between what is said and what is observed begs the question, are all these doping cases only exceptions in the otherwise clean cycling community, or is doping well-organized and incentivised by the system? Differentiating between individual incentives and systematic effects allows for answering the question and evaluating the doping scandals in professional cycling.

Many stakeholders are involved in cycling, and the underlying interdependencies and conflicting objectives complicate the analysis of drug abuse. Therefore, a first step is to analyse the interdependencies of two of the main actors, namely the team manager and the cyclist. A mutli-task (training and doping) principal-agent (team manager and cyclist) model with moral hazard is used to investigate the underlying interdependencies.

The fight against doping is an external institution that influences the doping behaviour of the actors involved. Institutional economics show the importance of rules and enforcement on individual decisions. Thus, understanding the decision making process requires a careful consideration of the institutions in charge. This is done by comparing three institutional settings that reflect the varying intensity in the fight against doping.

Overall, this paper concentrates on the cyclist, the team manager and the ban on doping. The consideration of two actors and one institution gives an initial answer to the question of whether doping is an exception, or is inherent in professional cycling. To find out if doping is inherent in the system, these questions are addressed. Do cycling teams have an incentive to provide a doping friendly infrastructure? Can the current fight against doping provide a means to suppress doping? Is there any chance for cycling teams to implement a doping-free sport?

The theoretical analysis reveals, that doping is inherent in professional cycling. The cycling team is interested in doping. Team managers provide a doping-friendly infrastructure by designing contracts that support drug abuse. The current anti-doping fight cannot suppress the teams' interest in doping. However, the fight against doping reduces the extent of drug abuse. The last insight is that the team managers cannot design contracts that stop the drug abuse of cyclists.

My analysis proceeds as follows. In the next section I will present professional cycling and the participating actors. I am going to highlight the underlying interdependencies and describe the fight against doping. Afterwards, I will give a short review of the literature on doping. The following section will outline the model and the underlying assumptions and characterise the different institutional settings. Section 5 will present the equilibria in all settings, and section 6 will present the results by comparing the equilibria of all settings. This approach allows the identification of the teams' doping incentives and the review of the current anti-doping fight. In the last part of this paper I will conclude and indicate new directions for future research.

## 2 Professional Cycling

Professional cycling is developed and promoted by the Union Cycliste Internationale (UCI). The UCI is cycling's international federation and was founded in Paris in 1900. Rules and regulations for professional road racing are defined by the UCI. These rules describe, e.g. the different types of races during the year and the conditions for professional cycling teams in detail. In addition, the UCI names all team members, and defines their rights and responsibilities. The main actors are the riders, the team managers, the sponsors, the coach, the team doctor and the mechanics.

The team management is responsible for organising the team and hiring the team members. Therefore, the team management is the decision maker who acts in a regulatory framework that is designed by the UCI. Rebeggiani and Tondani (2008) give a good description of the underlying structure and the team financing. According to them, the team's budget is mainly financed by sponsors who are interested in good publicity. This publicity is created by successful riders in competitions who are hired by the team manager. Thus, the team manager and the riders are the most important team members and the team manager maximises the team's budget by hiring successful riders.

The contractual relationship between the team manager and the cyclists are defined by the UCI. In the UCI Cycling Regulations the riders compensation scheme is specified:

> Art. 10
>
> The rider shall be entitled to a fixed remuneration, ...
>
> Art. 12
>
> The team and the rider may agree, in addition to the fixed salary, the payment of bonuses and other benefits that depend on the

rider's individual results and performance or the results and performance of the team.

Such a compensation scheme allows a direct connection between competition results and payments. UCI's regulations implement payments in professional cycling that are designed according to classical incentive models. The cyclist acts, as an employee, in accordance to the signed contracts which are offered by the team manager, as employer.

The cyclists' that are part of the team are interested in good competition results. Success increases the cyclists' current wage. Moreover, good competition results increase the riders' power in future wage negotiations and the likelihood of direct sponsorship.

The cyclists' performance and competition results are influenced by many factors. Riders' talent, riders' effort and luck are the main factors that influence the outcome of the races. The cyclists independently monitor their effort spent in training and doping. Both means increase the overall performance in competitions. Thus, the probability of winning increases in training and doping efforts.

Lucía, Hoyos and Chicharro (2001), Brewer (2002) and Christiansen (2005) characterise training, doping and racing in professional cycling. They argue that the training and doping regimes in cycling have become more and more scientific and that specialized personnel are indispensable. The use of medical and technological expertise has increased, and doping is organised within or outside of the cycling teams in doping networks.

The abuse of performance-enhancing drugs is forbidden, and the World Anti-Doping Agency (WADA) engages against doping. Waddington and Smith (2009) give a good description of the fight against doping which focuses on the athletes: the athletes are tested and positive tested athletes are punished. Nevertheless, athletes can use substances that are not detectable. Thus, they are able to circumvent the testing process in order to prevent punishment. This imperfect monitoring system along with sophisticated doping networks offer the possibility that drug using athletes are not detected.

The description of professional cycling leads to the following properties which are reflected in my model. First of all, the most important players in the game are the team manager and the cyclist. The team manager hires the cyclist based on a contract with a fixed salary and a payment of bonuses. The cyclist's performance during competition is observable. In contrast to this, the team manager cannot observe the athlete's actual training and doping effort. The training regime, the doping networks and the employment of specialised personnel make it very difficult for the team manager to observe and verify the riders' training and doping effort. This creates asymmetric information with the cyclist having an information advantage. Thus, the situation in professional cycling can be described by a multi-task principal-agent model in which moral hazard occurs.

The next chapter reviews the literature. It presents the concepts that are used in explaining the doping behaviour and shows that principal agent models are rarely used.

# 3 Literature

In the economic analysis of doping, there is a focus on the athletes' doping decision and the deterrence effect of the fight against doping. Dilger, Frick and Tolsdorf (2007) review the most important models and summarize empirical evidence on doping.

The game theoretic point of view was introduced by Breivik (1987). He describes the doping decision as a prisoner's dilemma in which doping is the dominant strategy. Afterwards, game theory helped to understand the interdependency between athletes and the their incentives for drug abuse (see, for instance Eber and Thépot (1999), Haugen (2004), Eber (2008)). Economists are interested in the fight against doping, too. Therefore, the influence of the anti-doping policies on doping incentives are investigated (see, for instance, Berentsen (2002), Maennig (2002), Preston and Szymanski (2003), Berentsen and Lengweiler (2004), Berentsen, Bruegger and Loertscher (2008), Kirstein

(2012)). The competition between athletes in tournaments and the underlying incentive structure is modelled and analysed with the help of tournament theory (see Konrad (2005), Kräkel (2007), Curry and Mongrain (2009), Gilpatric (2011) and Ryvkin (2013)). Professional cycling is investigated in detail, too. The doping behaviour and anti-doping policies in cycling are described and analysed by Reed (2003), Christiansen (2005), Morrow and Idle (2008), Strulik (2012), and Korn and Robeck (2013).

None of the afore mentioned publications in economics use a principal-agent framework. In contrast to this, a general framework is used in sociology but without a detailed specification of the underlying model. Sociologists concentrate on the systems in which doping occurs. Bette and Schimank (2001) use a multi-layer principal-agent approach for identifying stakeholders that are involved in the doping dilemma, and Hoberman (2002) explains physicians' involvement in doping as a result of adverse selection. The focus on doping systems shows the importance of stakeholders in doping, but it ignores the analysis of individual adoption. Conflicting objectives and information asymmetries between both actors determine individual behaviour, and the investigation of this behaviour in a principal agent framework is the contribution of this paper.

The description of professional cycling shows that the doping decision within teams has many similarities to problems analysed with accounting theory. In classical accounting models, shareholders employ a manager who is responsible for running their business. The shareholders must ensure that the manager chooses the right means to maximise firm success. "Right" here has different meanings in a similar style to the doping problem seen before. Managers are welcome to use fraudulent means as long as they are productive and are compliant to regulations, at least on the surface.

Due to the similarity in the research question, it is useful to draw on the model structure established to address it. The model used in this paper is based on the so-called LEN model introduced by Spremann, in Bamberg et al. (1987). It is a principal-agent model which employs three main assumptions: the compensation scheme is linear (L), the agent's utility function is exponential (E) and the uncertainty is normally distributed (N). Holmstrom and Milgrom (1987, 1991) developed a similar model independently. They refute counterarguments that question the restriction to linear compensation schemes which were raised by Mirrlees in Balch et al. (1974).

The next chapter introduces the LEN model that describes the situation in professional cycling. The underlying assumptions are stated, and the three institutional settings are presented.

# 4 The model

The situation in professional cycling can be described by a multi-task principal-agent model with a linear compensation scheme. The team manager[1] (as principal) maximises the team's profit by hiring an athlete (as agent) for participating in competitions. The media reports on races and successful riders. This publicity attracts new sponsors and generates a benefit for the team manager. Therefore, a winning cyclist increases the team manager's profit, and the team manager is interested in a successful cyclist. It is possible to interpret the team manager's benefit as the cyclist's success and performance in competition and I will use them as synonyms from now on. The cyclist is paid by the team, and his wage represents the team manager's cost. The wage scheme is linear which reflects the UCI rule mentioned before. Overall, the team manager is interested in good competition results and low wages.

The employed cyclist receives a wage payment which represents the benefit in his objective function. He can spend effort in training and doping. Both actions increase his success in competition and, at the same time, they are costly for the cyclist. As a consequence, the cyclist likes high wages and dislikes effort.

Additionally, the cyclist's training and doping behaviour is not observable

[1] I shall use feminine pronouns for the principal and masculine ones for the agent.

by the team manager; she can only observe the competition results. This information asymmetry and the conflict of interest between athlete and team manager lead to a situation which is characterised by moral hazard.

The stages of the game are as follows:

1. The team manager, as principal, offers a contract to the cyclist.

2. The cyclist can decide whether to accept the contract, or not. (If he accepts the contract the game will be continued, otherwise the game ends and players receive the exogenous value of their outside option.)

3. If the contract is signed, the cyclist chooses a training and doping level, which is not observable by the team manager, in order to maximise his expected utility.

Afterwards, uncertainty is resolved, the performance is calculated, and this determines the payments to principal and agent.

This moral hazard problem is solved by backward induction. Due to the information asymmetry, the team manager takes into account a participation and an incentive constraint. These constraints are used to solve the team manager's maximisation problem, thus the optimal contract is characterised.

The optimal contract is influenced by the fight against doping. To capture this dependency I will distinguish between three different settings with different assumptions: two benchmark settings *No-Doping* and *Inclusion-of-Doping* and the setting which represents reality *Imperfect-Monitoring*. The first benchmark describes a situation in which the ban on doping is perfect and a drug free sport is implemented (e.g. the fight against doping detects all doped athletes). The second benchmark represents an environment in which doping is available and legal. As a consequence, there is no fight against doping, and all actors are aware of the fact that athletes may compete with the help of drugs. Both benchmark settings put into perspective the last institutional setting; the setting in which the fight against doping takes place. This setting captures the current fight against doping in which deterrence is imperfect (e.g. tests are not precise and/or sanctions are not severe).

The separation into three settings is necessary to evaluate the actual fight against doping. Below I present the underlying assumptions of all three settings.

## 4.1 Benchmark setting: ***No-Doping*** $(ND)$

This benchmark setting represents the situation in which the fight against doping is perfect. Thus, cheating is always detected and penalised with a lifetime ban in professional sports. The doping-test cost outweighs the benefit from doping, and the athlete does not have an incentive to use forbidden drugs. As a consequence, the cyclist can only choose his training level in order to be successful in competitions.

In reality it is hardly possible to implement such a tight fight against doping. At the moment, there exists forbidden performance-enhancing drugs that are not detectable at all, and other substances are only detectable for a short time period. Nevertheless, this benchmark setting is often used by sports stakeholders (e.g. competition organizers and sponsors) to present sports competitions to the public. Although it is unlikely to have a perfect fight against doping, this setting is useful as a benchmark for the actual fight against doping.

This setting represents a classical one-task principal-agent model with a linear compensation scheme. The assumptions concerning the asymmetric information and the stages of the game lead to a well-known moral hazard problem.

The next step is to characterise this setting in more detail. Let $q$ denote the team manager's benefit. The team manager employs an athlete, and the benefit $q$ represents the cyclist's performance and success in competition. In this setting, I assume that success in competition depends on two variables: training $a$ and uncertainty $\varepsilon_1$.

$$q\left(a\right) = v_1 a + \varepsilon_1, \tag{1}$$

where $\varepsilon_1 \sim N(0, \sigma_1^2)$ and $v_1 > 0$ describes the marginal benefit from training. More training improves the athlete's performance and his chance of winning. Thus, publicity grows and the team manager's benefit increases in training, too. Uncertainty is an important part of cycling races, because many factors (e.g. competitors' performance, weather and luck) influence the competition result, and $\varepsilon_1$ is the realisation of this noise.

An important simplification in my model is the focus on one team manager and one cyclist. This simplification allows for analysing the team structure. By assuming that $q$ represents the cyclist's success, the competition between athletes and teams is ignored because the characterisation of the competition is of second interest. In sports, marginal differences in individual performance are responsible for the competition results. Therefore, the absolute value of performance is only important in comparison to the competitors' performance. This is due to the fact that marginal differences in performance can decide between victory and defeat. The definition of $q$ is related to success in the competition because a high performance represents a higher winning probability. In reality the competition will define an upper level of doping due to decreasing marginal benefits from drug abuse. Thus, the influence of luck on the competition result increases, and the absolute value of performance is an approximation for the competition between riders.

I assume that the team manager offers a linear incentive contract $w(q)$ to the athlete:

$$w(q) = t + s(q), \qquad (2)$$

where $t$ is a fixed compensation level and $s$ is the performance-related component of the wage $w$. This compensation function reflects the requirements stated by the UCI and represents the team manager's cost. The combination of the team manager's benefit and cost leads to the team manager's utility function $V(q, w)$ under the assumption that the team manager is risk-neutral:

$$V(q, w) = q(a) - w(q). \qquad (3)$$

The next step is to formulate the cyclist's utility function. Due to the necessity to begin training in early years, the cyclist has specific skills which are only useful as a professional athlete. Athletes concentrate on their sport alone, and as a consequence there are no good and worthwhile outside options available. This concentration and specialisation is described by Bette and Schimank (2006) as path dependency that occurs in professional sports careers. Thus, I assume that the cyclist is a risk-averse player which is represented by a negative exponential utility function. The utility depends in a positive way on the wage $w$ he can earn and is negatively influenced by the training effort which creates costs $C\left(a\right)$ for him:

$$U\left(w,a\right)=-e^{-\eta\left[w-C\left(a\right)\right]}, \tag{4}$$

where $\eta$ is the coefficient of absolute risk aversion ($\eta>0$). The rider's cost depends on his training level $a\geqslant 0$, and the cost function is convex in training. The cost function is

$$C(a)=\frac{1}{2}c_1a^2, \tag{5}$$

where $c_1>0$. The cyclist's training cost increases in the training level due to an increased training intensity which is more costly. Moreover, the level of $c_1$ represents the cyclist's talent and a lower level of $c_1$ represents a more talented rider. His overall utility (4) depends on his own risk attitude, the wage and his costs caused by training. The athlete maximises his utility given the contract that was signed.

The team manager maximises her expected utility by choosing the optimal contract:

$$E[V\left(q,w\right)]=E\left(q\left(a\right)-w\left(q\right)\right), \tag{6}$$

The team manager cannot observe the athlete's training effort, but she observes the athlete's performance, and she knows the game structure. Therefore, the optimisation problem is solvable by applying backward induction.

To do so, the team manager formulates the participation constraint and the incentive constraint. The participation constraint ensures that the cyclist accepts the contract, and that the expected utility is bigger than or equal to the utility of his outside option $\underline{w} > 0$. The incentive constraint reflects the situation that the rider maximises his own expected utility after the contract is signed. Thus, the team manager maximises her expected utility with respect to a participation constraint and an incentive constraint.

Before the solution to this maximisation problem is shown, the two remaining institutional settings are presented and characterised. This helps to understand the difference between the three settings making it possible to analyse the fight against doping.

## 4.2 Benchmark setting: ***Inclusion-of-Doping*** $(D)$

In this setting I assume that training and doping are options in influencing the cyclist's performance. By introducing a second task – doping – the game becomes a standard multi-task principal-agent model. The characteristics of this setting is an environment where doping is possible and sanctions are not imposed. Doping is accepted by all stakeholders; thus, doping and training are legal means to boost performance. The new variable, doping, is unobservable by the team manager as well.

The only difference between the first and second benchmark setting is the additional task of doping. All other parts of the model are unchanged. The new expected profit function $q$ of the team depends on doping and training. The influence of training $a$ and of an uncertain event $\varepsilon_1$ (e.g. competitors' performance and luck) are unchanged in comparison to the setting *No-Doping*, and the new performance function is given by

$$q\,(a) = v_1 a + v_2 d + \varepsilon_1, \tag{7}$$

where $\varepsilon_1 \sim N(0, \sigma_1^2)$, $v_1 > 0$ and $v_2 > 0$. The marginal benefit from training and doping are represented by $v_1$ and $v_2$. An increase in doping boosts the cyclist's performance and his chance of winning. Thus, the team manager's marginal utility is positive in training and doping.

The team manager's benefit function is additive, therefore training without doping can produce benefits for the team. In reality the influence of doping on training is not straightforward. Individual differences lead to different effects of doping, and it can happen that the most talented cyclists gain little advantage from drug abuse. Thus, an increase in doping can reduce the marginal benefit from training. The uncertainty about the interaction of doping and training is not captured in this model. The benefit function allows the cyclist to compete without drugs, and the model concentrates on the first-order effects of training and doping.

As before, a fixed compensation level and a performance-related component are part of the wage function, and the team manager's utility function is the difference between performance $q$ and wage $w$. Due to the possibility of doping the cyclist's utility function changes to

$$U(w,a,d) = -e^{-\eta[w-C(a,d)]}; \tag{8}$$

the cost function also depends on doping and is given by

$$C\left(a,d\right) = \frac{1}{2}c_1 a^2 + \frac{1}{2}c_2 d^2, \tag{9}$$

where $c_1$ and $c_2$ are positive, and as a consequence, the athlete's cost is convex in training and doping. An increase in the doping level is possible by using additional doping substances. The costs for these substances increases due to the difficulty associated with getting access to new performance-enhancing drugs. Therefore the marginal doping costs increase with the doping level.

Given these properties, the team manager maximises her expected utility subject to the participation and incentive constraint. This maximisation process is identical to the steps which are presented in the setting *No-Doping*.

This setting presents the second benchmark setting. In reality a fight against doping takes place. If such a fight is implemented, the actors' incentives to use drugs will be influenced. Thus, the next setting considers the fight against doping.

### 4.3 Anti-Doping setting: ***Imperfect-Monitoring*** $(AD)$

In the third setting I use a multi-task principal-agent model which is similar to the model in the setting *Inclusion-of-Doping.* The new property is the introduction of a fight against doping. As a consequence, doping is no longer a legal means to boost performance. The fight against doping concentrates on the cyclist, and the cyclist is punished if he tests positive. In comparison to the first benchmark setting, the doping fight is not perfect and it can happen that a doped cyclist passes the drug test (false negative)[2]. This imperfect fight against doping influences the athlete's and the team manager's interest in doping.

Although doping is illegal, the cyclist can use drugs to boost his performance; therefore the performance function is additive as before. Additionally, the wage function and team manager's utility are unchanged.

The cyclist's utility function changes due to the fact that the doping fight gives rise to an additional term in his cost function. The doping-test cost depends on a random variable which is represented by $\varepsilon_2$. The term $\varepsilon_2$ describes the drug tests' uncertainty because a doped cyclist does not know if his drug abuse will be detected. This uncertainty reflects the imperfect instruments in the fight against doping. The new cost function is

$$C\left(a, d\right) = \frac{1}{2}c_1 a^2 + \frac{1}{2}c_2 d^2 + \frac{1}{2}c_3 d\varepsilon_2, \tag{10}$$

where $\varepsilon_2 \sim N(d, \sigma_2^2)$ and $c_3 > 0$. The drug test influences the overall cost in different ways. First of all, if the cyclist starts without doping $d = 0$ the test will never be positive (no false positive). In this situation, there are no additional costs, and a clean cyclist will not fear a false positive. If

[2]Berry (2008) and Pitsch (2009) discuss the the fallacies of the current fight against doping in more detail.

the cyclist uses forbidden drugs to boost his performance, there exists the probability that the doping-test cost will occur because the anti-doping fight takes place. The expected value of $\varepsilon_2$ is $d$. Thus, the structure of the expected doping-test cost is comparable to the structure of training and doping costs: doping-test costs are convex in doping. The doping-test cost reflects the ex-ante perspective of a cyclist. An increase in his doping level will increase the detection probability. Therefore, the doping-test cost is continuous in doping.

The detection method in this model is powerful. On average, the fight against doping can predict the real level of doping. Moreover, I assume that $\sigma_2^2$ is very small, and such a small variance improves the detection method in this setting even more. Another nice property of a small variance is that negative doping-test costs are unlikely.

The characterisation of this last setting allows for the application of the maximisation process again. The next chapter will come back to this in detail and develop the equilibria in all three settings.

# 5 Equilibrium analysis

In the different institutional settings, the signed contract, the chosen effort levels and the resolved uncertainty determine the outcome of the game. The underlying moral hazard problem is solvable by backward induction, and the steps are the same in all settings.

All settings are either single- or multi-task principal-agent models. The linear compensation scheme, the cyclist's exponential utility function and the normally distributed uncertainty allows for deriving a closed-form solution in all settings. A nice property of the LEN model is the fact that it is possible to formulate the rider's utility in terms of the certainty equivalent. This transformation simplifies the team manager's maximisation problem by reformulating the participation and incentive constraint with the help of the certainty equivalent. The new participation constraint is binding and leads to the fixed compensation level $t$. The first-order condition of the certainty equivalent represents the cyclist's incentive constraint and specifies the optimal effort levels. By substituting these values – fixed compensation level and effort level – into the team manager's expected utility function, the resulting maximisation process is solvable and the optimal contract and effort level are derived; the cyclist's and team manager's second order conditions are negative.

The two benchmark settings are standard problems in the principal-agent literature (see, e.g. Wagenhofer (1996)), and the solutions are well documented. Therefore, in this chapter the equilibrium analysis concentrates on the last setting *Inclusion-of-Doping*, and the two benchmark settings are discussed briefly.

## 5.1 Benchmark setting: ***No-Doping*** $(ND)$

This setting describes a cyclist who is hired by a team manager. The rider competes in races and prepares himself by choosing a training level. Doping is not available; therefore, a single-task principal-agent model describes the resulting team structure. In this framework, the certainty equivalent is a representation of the cyclist's utility function. The athlete's certainty equivalent is influenced by the wage, the effort costs from training and the costs from uncertainty:

$$CE(a,t,s)_{ND} = t + sv_1 a - \frac{1}{2}c_1 a^2 - \frac{\eta s^2 \sigma_1^2}{2}. \tag{11}$$

The certainty equivalent (11) is used to formulate the participation and incentive constraints. The fixed compensation level $t$ and the first-order condition of the certainty equivalent are used to simplify the team manager's maximisation problem. The optimal contract and the optimal training level are

$$s^*_{ND} = \frac{v_1^2}{v_1^2 + c_1 \eta \sigma_1^2}, \tag{12}$$

$$t_{ND}^{*} = \frac{1}{2}\left(\eta\sigma_1^2 - \frac{v_1^2}{c_1}\right)(s_{ND}^{*})^2 + \underline{w} \text{ and} \tag{13}$$

$$a_{ND}^{*} = \frac{v_1}{c_1}(s_{ND}^{*}). \tag{14}$$

The optimal value for $s_{ND}^{*}$ is between zero and one $0 < s_{ND}^{*} < 1$ which means that the team manager and the athlete share the benefits from success in competition. The performance-related wage component $s_{ND}^{*}$ is associated with the optimal training level $a_{ND}^{*}$ which is always bigger than zero. Higher training costs $c_1$ will decrease the optimal training level, and higher marginal benefits $v_1$ from training will increase the training level. A more risk-averse cyclist, measured by $\eta$, will choose a lower training intensity, and a higher variance of the uncertain event $\sigma_1^2$ decreases training efforts as well.

The values $s_{ND}^{*}$, $t_{ND}^{*}$, and $a_{ND}^{*}$ allow the calculation of expected utilities. The team manager's expected utility is

$$E(q-w)_{ND}^{*} = \frac{v_1^2}{c_1}(s_{ND}^{*}) - \frac{1}{2}\left(\frac{v_1^2}{c_1} + \eta\sigma_1^2\right)(s_{ND}^{*})^2 - \underline{w}, \tag{15}$$

and the cyclist's expected income is equal to his outside option.

In this basic setting, the team manager generates an expected utility by hiring a cyclist. The optimal contract defined in equation (12) and (13) asks for a positive training level that is chosen by the rider.

In the next section, the results of the second benchmark setting are presented in which doping is a legal means to boost performance.

## 5.2 Benchmark setting: *Inclusion-of-Doping* $(D)$

In this setting the cyclist can choose a training and doping level. Thus, a multi-task principal-agent model is used. As before, the compensation scheme is linear, the athlete's utility function is exponential and the uncertainty is described by a random variable which is normally distributed. In addition, I assume that the following constants which are used in both settings are identical: variance $\sigma_1$, marginal utility of training $v_1$, marginal costs of training $c_1$, and the coefficient of absolute risk aversion $\eta$. These assumptions allow for comparing the two benchmark settings.

The closed-form solution is calculated by repeating the steps of the underlying maximisation process. First of all, the introduction of doping changes the athlete's certainty equivalent to

$$CE(a,d,t,s)_D = t + sv_1a + sv_2d - \frac{1}{2}c_1a^2 - \frac{1}{2}c_2d^2 - \frac{\eta s^2\sigma_1^2}{2}. \tag{16}$$

The positive terms of equation (16) are the earnings from the contract. The first two negative terms represent the effort costs – from training and doping – and the last term represents the uncertainty cost of his compensation. The closed form solution is characterised by using the certainty equivalent in the team manager's maximisation problem. The optimal contract is

$$s_D^* = \frac{c_2v_1^2 + c_1v_2^2}{c_2v_1^2 + c_1v_2^2 + c_1c_2\eta\sigma_1^2} \text{ and} \tag{17}$$

$$t_D^* = \frac{1}{2}\left(s_{ND}^*\right)^2\left(\eta\sigma_1^2 - \frac{v_1^2}{c_1} - \frac{v_2^2}{c_2}\right) + \underline{w}, \tag{18}$$

where $0 < s_D^* < 1$; thus, the team manager and the cyclist share the benefits again. The optimal values for $a_D^*$ and $d_D^*$ are

$$a_D^* = \frac{v_1}{c_1}\left(s_D^*\right) \text{ and} \tag{19}$$

$$d_D^* = \frac{v_2}{c_2}\left(s_D^*\right). \tag{20}$$

In the *Inclusion-of-Doping* setting, the values $a_D^*$ and $d_D^*$ are positive and they depend on the costs of training and doping, on the benefits from training and doping, on the coefficient of absolute risk aversion and on the variance. The values of $a_D^*$ and $d_D^*$ depend in an intuitive way on the independent variable. The training level will decrease if doping costs $c_2$ or training costs $c_1$

increase. The doping level will also decrease in training costs $c_1$ and doping costs $c_2$. Moreover, an increase in marginal benefits from doping $v_2$ and training $v_1$ leads to a higher training and doping level. In summary, higher costs will lead to a reduction in performance, and higher benefits increase training and doping intensity and boost the athlete's performance. Another interesting property is the fact that higher uncertainty in competitions $\sigma_1^2$ and a higher level of risk aversion $\eta$ leads to a decrease in training and doping levels. Thus, higher uncertainty diminishes the effects from training and doping which leads to a reduction in effort investments.

The last step is to calculate the expected utility for both players. As before, the cyclist's expected income equals his outside option. The team manager's expected utility is given by

$$E(q-w)_D^* = \left(\frac{v_1^2}{c_1} + \frac{v_2^2}{c_2}\right)(s_D^*) - \frac{1}{2}\left(\frac{v_1^2}{c_1} + \frac{v_2^2}{c_2} + \eta\sigma_1^2\right)(s_D^*)^2 - \underline{w}. \tag{21}$$

This setting describes the team manager's and rider's behaviour in an environment in which doping is available and legal. The team manager's incentive contract implements positive training and doping levels, and the next setting includes the fight against doping.

## 5.3 Anti-Doping setting: ***Imperfect-Monitoring*** $(AD)$

The last setting represents professional cycling in a realistic way. The cyclist can choose training and doping levels in order to improve his good performance in competitions. The extension, in comparison to the benchmark setting *Inclusion-of-Doping*, is the introduction of the fight against doping. The WADA tests athletes, and convicted cyclists are punished. Therefore, the cyclist's costs are enlarged by the doping-test costs that are caused by the existence of the anti-doping agency. In summary, this section presents a multi-task principal-agent model in an institutional environment that punishes forbidden behaviour.[3]

As before, I assume that the constants that are used in all three settings are identical: variance $\sigma_1$, marginal utility of training $v_1$ and doping $v_2$, marginal costs of training $c_1$ and doping $c_2$, and the coefficient of absolute risk aversion $\eta$.

Once again, the optimal contract is found by backward induction using the linear contract and the participation and incentive constraints. The certainty equivalent in this setting is

$$CE(a,d,t,s)_{AD} = t + sv_1 a + sv_2 d - \frac{c_1 a^2}{2} - \frac{c_2 d^2}{2} - \frac{\eta s^2 \sigma_1^2}{2} - \frac{c_3 d^2}{2} - \frac{\eta d^2 c_3^2 \sigma_2^2}{8}. \quad (22)$$

The first part of the cyclist's certainty equivalent has not changed. The positive terms describe the earnings, and there are the negative terms correspond to the effort costs for training and doping. In comparison to the setting *Inclusion-of-Doping*, two new terms appear due to the fight against doping. The last two terms in equation (22) represent the doping-test costs. The first expression is the expected doping-test cost and the second expression represents the cost of the testing uncertainty.

The solution of the team manager's maximisation problem is deduced with the help of the certainty equivalent, the participation constraint, and the incentive constraint. The participation constraint and the first-order conditions of the incentive constraint define the optimal values for $t^*$, $a^*$ and $d^*$ which create the new maximisation problem:

$$max_s \, \frac{sv_1^2}{c_1} + \frac{sv_2^2}{c_2 + c_3 + \frac{1}{4}\eta c_3^2 \sigma_2^2}$$

[3] The underlying structure of this setting can be found in different fields of application. One example is industrial organisation because the sanctioning of cartels has a similar structure. The principal-agent situation is reflected in a company in which the shareholders hire a manager. The manager can create benefits for the shareholders by using legal or illegal means (e.g. price agreements between competitors). If such a price agreement is detected a public authority will punish the firm for illegal behaviour.

$$-\frac{s^2v_1^2}{2c_1}-\frac{s^2v_2^2\left(c_2+c_3+\frac{1}{4}c_3^2\eta\sigma_2^2\right)}{2(c_2+c_3+\frac{1}{4}\eta c_3^2\sigma_2^2)^2}-\frac{\eta s^2\sigma_1^2}{2}-\underline{w}. \tag{23}$$

The first order derivative leads to the following value for $s^*_{AD}$:

$$s^*_{AD}=\frac{(c_2+c_3+\frac{1}{4}\eta c_3^2\sigma_2^2)v_1^2+c_1v_2^2}{(c_2+c_3+\frac{1}{4}\eta c_3^2\sigma_2^2)v_1^2+c_1v_2^2+c_1(c_2+c_3+\frac{1}{4}\eta c_3^2\sigma_2^2)\eta\sigma_1^2}, \tag{24}$$

where $0<s^*_{AD}<1$. The second order condition is always negative and $s^*_{AD}$ maximises the team manger's expected utility. The values for $a^*_{AD}$ and $d^*_{AD}$ are

$$a^*_{AD}=\frac{v_1}{c_1}\left(s^*_{AD}\right) \text{ and} \tag{25}$$

$$d^*_{AD}=\frac{v_2}{(c_2+c_3+\frac{1}{4}\eta c_3^2\sigma_2^2)}\left(s^*_{AD}\right). \tag{26}$$

The result is that in the setting *Imperfect-Monitoring*, $a^*_{AD}$ and $d^*_{AD}$ are positive. The values depend, in an intuitive way, on training, doping and doping-test costs. The training and doping level will decrease if training cost $c_1$, doping cost $c_2$, or doping-test cost $c_3$ increases. Moreover, an increase in marginal benefits $v_1$ or $v_2$ leads to a higher training level and doping level. Overall, higher costs reduce training and doping intensity, and higher benefits will boost the athlete's performance. An additional property is the fact that higher uncertainty in competitions $\sigma_1$ leads to a decrease in training and doping levels because the importance of training and doping on the outcome of the competition is reduced.

A further insight considers the anti-doping fight. A higher uncertainty in doping tests $\sigma_2$ will decrease the optimal training and doping levels. Inaccurate doping tests reduce the incentive to abuse forbidden drugs because the team manager must compensate the risk-averse cyclist for this increase in uncertainty. This result holds true due to the fact that I assumed clean athletes will never test positive. If it is possible that clean athletes test positive, then the result may change because this can create an incentive for clean athletes to use drugs.

Given these values, the fixed compensation level is

$$t_{AD}^{*} = \frac{1}{2}\left(s_{AD}^{*}\right)^{2}\left(\eta\sigma_1^2 + \frac{v_2^2 c_3\left(4 + c_3\eta\sigma_2^2\right)}{4(c_2 + c_3 + \frac{1}{4}\eta c_3^2\sigma_2^2)^2} - \frac{v_1^2}{c_1} - \frac{v_2^2}{c_2}\right) + \underline{w}. \tag{27}$$

Here, $t_{AD}^{*}$ depends on the wage of the minimum acceptable certain monetary equivalent, on the doping, training and doping-test costs, on the benefits of doping and training, the coefficient of absolute risk aversion and the variances of competition and doping-tests.

The team manager's expected utility can be calculated with the values for $t_{AD}^{*}$, $a_{AD}^{*}$ and $d_{AD}^{*}$:

$$\begin{aligned} E(q-w)_{AD}^{*} = & \left(\frac{v_1^2}{c_1} + \frac{v_2^2}{(c_2 + c_3 + \frac{1}{4}\eta c_3^2\sigma_2^2)}\right)\left(s_{AD}^{*}\right) \\ & -\frac{1}{2}\left(\frac{v_1^2}{c_1} + \frac{v_2^2}{(c_2 + c_3 + \frac{1}{4}\eta c_3^2\sigma_2^2)} + \eta\sigma_1^2\right)\left(s_{AD}^{*}\right)^2 - \underline{w}. \end{aligned} \tag{28}$$

Thus, the optimal contract and the outcome in the setting *Imperfect-Monitoring* are determined. The binding participation constraint leads to the fact that the athlete's expected income equals his outside option's utility. The next chapter evaluates and compares the results of all three settings. An overview of the results is presented in Appendix A.

# 6 Results

This chapter answers the research question, is doping well organised in professional cycling. I will show that the team manager has an incentive to provide a doping-friendly infrastructure, that the fight against doping cannot stop drug abuse and that the team manager cannot implement a doping-free sport on her own.

These results are developed by a comparison of the institutional settings. The first step in answering the research question is to specify the benchmark setting *No-Doping*.

## 6.1 Benchmark setting: ***No-Doping*** $(ND)$

This setting is characterised by the absence of doping. In this setting professional cycling is described with the help of two inequalities. These inequalities are introduced as additional assumptions that hold true in all three settings in order to make them comparable.

First of all, cyclists will become professionals if their benefits from training are higher than their costs from training. Otherwise they will end their career and stop competing in professional sports. In addition, the influence of training on the athlete's success is bigger than pure luck or other variables. This guarantees that it is worthwhile to train, at least in the long run. Therefore, in professional sports, training has a positive influence on success, and this connection is stronger than the effect of uncertainty in the form of pure luck. This consideration is represented by the following assumption:

$$\frac{v_1^2}{c_1} \geqslant \eta\sigma_1^2. \tag{29}$$

Secondly, professional cyclists must begin their training early in life. Thus, they spend many hours in engaging in intensive training because without this investment it is not possible to compete in professional sports. As a consequence, it is difficult for athletes to finish a vocational training which decreases the value of their outside option. Overall, training is more important than pure luck in competition, and the difference between these values is higher than the outside option. This assumption is represented in the following equation:

$$\frac{1}{2}\left(\frac{v_1^2}{v_1^2 + c_1\eta\sigma_1^2}\right)\left(\frac{v_1^2}{c_1} - \eta\sigma_1^2\right) \geqslant \underline{w}. \tag{30}$$

I assume that equations (29) and (30) are true in all settings.

The two assumptions lead to another property that helps to characterise professional cycling: cycling teams will exist if their profits are not negative. This result is achieved by an approximation which uses a property of the performance-related component of the wage. In all settings the performance related component of the wage is between zero and one $0 < s^* < 1$; thus,

$$s^* > (s^*)^2 \tag{31}$$

holds true. This property allows the following approximation of the team manager's utility which is given in equation (15):

$$\begin{aligned}
E(q-w)^*_{ND} &= \frac{v_1^2}{c_1}(s^*_{ND}) - \frac{1}{2}\left(\frac{v_1^2}{c_1} + \eta\sigma_1^2\right)(s^*_{ND})^2 - \underline{w} \\
&> \frac{v_1^2}{c_1}(s^*_{ND}) - \frac{1}{2}\left(\frac{v_1^2}{c_1} + \eta\sigma_1^2\right)(s^*_{ND}) - \underline{w} \\
&= \frac{1}{2}\left(\frac{v_1^2}{c_1} - \eta\sigma_1^2\right)(s^*_{ND}) - \underline{w} \\
&= \frac{1}{2}\left(\frac{v_1^2}{c_1} - \eta\sigma_1^2\right)\left(\frac{v_1^2}{c_1} - \eta\sigma_1^2\right) - \underline{w} \geqslant 0.
\end{aligned} \tag{32}$$

Condition (30) implies that the team manager's expected utility is bigger than zero, and therefore, the team will generate profits in the benchmark setting without drugs. These profits justify the existence of teams in professional cycling.

The specification of the setting *No-Doping* is finished. Conditions (29) and (30) represent actual properties in professional cycling, and as a consequence, the team is profitable. The next step is the analysis of the second benchmark setting in which doping is possible. The comparison of both benchmark settings provides the answer to the first research question: Does the team manager support drug abuse?

## 6.2 Benchmark setting: ***Inclusion-of-Doping*** $(D)$

The possibility of doping in this setting changes the principal-agent problem to a multi-task moral-hazard problem. The equilibrium analysis shows that the optimal contract changes in comparison to the first benchmark setting. The performance related component of the wage $s^*$ differs in both settings, and the introduction of doping increases the performance related payment $s_D^* > s_{ND}^*$:

$$s_D^* = \frac{c_2 v_1^2 + c_1 v_2^2}{c_2 v_1^2 + c_1 v_2^2 + c_1 c_2 \eta \sigma_1^2} > \frac{v_1^2}{v_1^2 + c_1 \eta \sigma_1^2} = s_{ND}^*$$

$$\Leftrightarrow c_1^2 v_2^2 \eta \sigma_1^2 > 0. \tag{33}$$

Thus, the incentives for effort are higher in the situation in which doping is available. The difference in the pay for performance, between both settings, leads to an increase in doping $d_D^* > d_{ND}^* = 0$. Additionally, the training level increases

$$a_D^* = \frac{v_1}{c_1} s_D^* > \frac{v_1}{c_1} s_{ND}^* = a_{ND}^*, \tag{34}$$

and overall performance increases as well $q_D^* > q_{ND}^*$:

$$q_D^* = v_1 a_D^* + v_2 d_D^* + \varepsilon_1 > v_1 a_{ND}^* + \varepsilon_1 = q_{ND}^*$$

$$\Leftrightarrow \frac{(v_1)^2}{c_1} \left( s_D^* - s_{ND}^* \right) + \frac{(v_2)^2}{c_2} s_D^* > 0. \tag{35}$$

Condition (35) is fulfilled due to the difference in the payment for performance $s_D^* > s_{ND}^*$. This result is responsible for two consequences. First, doping increases the cyclist's performance in competition, and therefore, clean athletes will rank lower in competition. In addition, a clean cyclist can hardly win a race if the competitors use forbidden drugs. Although a doped athlete performs better, he will not benefit from this performance improvement. Given the principal-agent structure, the athlete cannot increase his expected utility by using drugs. In principal-agent models, the agent always gets the equivalent of his outside option; this is true in all settings of this paper. Therefore, in the benchmark setting *Inclusion-of-Doping* the abuse of performance-enhancing drugs is the one and only way for the cyclist to earn the equivalent of his outside option. If he is not willing to use drugs he will not sign the offered contract; thus, ending his career in professional cycling.

The first research question analyses the team manager's interest in drug abuse. The interesting question is whether the team manager benefits from the better performance induced by doping, or not. If doping increases the expected profit of the team, the consequence will be that the team manager has an interest in doping. Under the assumption that drug abuse is available, the team manager's expected profit is given in equation (21). The equations (31) and (33), which guarantee the existence of teams in cycling in the setting *No-Doping*, ensure that the team manager's expected profit in the setting *Inclusion-of-Doping* is always bigger than zero:

$$\begin{aligned}
E(q-w)^*_D &= \left(\frac{v_1^2}{c_1}+\frac{v_2^2}{c_2}\right)(s^*_D) - \frac{1}{2}\left(\frac{v_1^2}{c_1}+\frac{v_2^2}{c_2}+\eta\sigma_1^2\right)(s^*_D)^2 - \underline{w} \\
&> \left(\frac{v_1^2}{c_1}+\frac{v_2^2}{c_2}\right)(s^*_D) - \frac{1}{2}\left(\frac{v_1^2}{c_1}+\frac{v_2^2}{c_2}+\eta\sigma_1^2\right)(s^*_D) - \underline{w} \\
&= \frac{1}{2}\left(\frac{v_1^2}{c_1}-\eta\sigma_1^2\right)(s^*_D) + \frac{1}{2}\frac{v_2^2}{c_2}(s^*_D) - \underline{w} \\
&> \frac{1}{2}\left(\frac{v_1^2}{c_1}-\eta\sigma_1^2\right)(s^*_D) - \underline{w} > \frac{1}{2}\left(\frac{v_1^2}{c_1}-\eta\sigma_1^2\right)(s^*_{ND}) - \underline{w} \geq 0. \qquad (36)
\end{aligned}$$

Equation (36) shows that the team manager's expected profit is positive. Comparing the expected profits in both benchmark settings allows for answering the question of whether the team manager is interested in doping, or not. It turns out that the team manager's expected profit when using drugs is always higher than the team manager's expected profit without drug abuse:

$$E(q^*_D - w^*_D)^*_D - E(q^*_{ND} - w^*_{ND})^*_{ND} > 0. \tag{37}$$

The detailed proof is presented in Appendix B. Equation (37) shows the team manager's interest in drug abuse. It is profitable for a team manager to engage in doping, and organized doping will occur in a situation where there is not a fight against doping. The team manager designs the incentive contract which implements the cyclist's drug abuse. The rider must compete with drugs to receive his outside option in expectation.

So far, I have described and analysed the benchmark settings. The last two research questions will be answered in the next section with the help of the setting *Imperfect-Monitoring*.

## 6.3 Anti-Doping setting: *Imperfect-Monitoring* $(AD)$

In the third setting the anti-doping fight is implemented, and the institutional framework describes the fight against doping in reality. In my model, this fight is quite effective in comparison to reality. First of all clean athletes will never test positive. In addition, a doping cyclist has little chance of testing negative, and cost of detection increases in the doping level.

The fight against doping influences the optimal contract, and the cyclist's doping-test costs are responsible for a decrease in the performance related payment $s^*_{AD} < s^*_D$:

$$\begin{aligned} s^*_{AD} &= \frac{(c_2 + c_3 + \frac{1}{4}\eta c_3^2\sigma_2^2)v_1^2 + c_1 v_2^2}{(c_2 + c_3 + \frac{1}{4}\eta c_3^2\sigma_2^2)v_1^2 + c_1 v_2^2 + c_1(c_2 + c_3 + \frac{1}{4}\eta c_3^2\sigma_2^2)\eta\sigma_1^2} \\ &< \frac{c_2 v_1^2 + c_1 v_2^2}{c_2 v_1^2 + c_1 v_2^2 + c_1 c_2 \eta\sigma_1^2} = s^*_D \\ &\Leftrightarrow 0 < v_2^2 c_1^2 c_3 \eta\sigma_1^2 + \frac{1}{4} v_2^2 c_1^2 c_3^2 \eta\sigma_1^2\sigma_2^2. \end{aligned} \tag{38}$$

This change in $s^*$ decreases the cyclist's optimal training effort:

$$a^*_{AD} = \frac{v_1}{c_1} s^*_{AD} < \frac{v_1}{c_1} s^*_D = a^*_D. \tag{39}$$

The same effect is observable at the doping level. The optimal doping level in the setting *Imperfect-Monitoring* decreases by the reduction of $s^*$. A comparison of the drug levels reveals that $d^*_D$ is higher than $d^*_{AD}$:

$$d^*_{AD} < d^*_D \Leftrightarrow \frac{v_2}{c_2 + c_3 + \frac{1}{4} c_3^2 \eta \sigma_2^2} s^*_{AD} < \frac{v_2}{c_2} s^*_D. \tag{40}$$

The doping-test cost increases the denominator of the drug level in the setting *Imperfect-Monitoring* and reduces the doping level. Moreover, the reduced performance related wage component $s^*$ creates an additional reduction in the drug level. Thus, the fight against doping reduces the doping level in professional sports, although it is not possible to implement a drug-free sport. Drug abuse will occur because $d^*_{AD}$ is still positive. At least the reduction of the doping level leads to a protection of the cyclist's health.

In summary, the fight against doping decreases the training intensity and the level of drug abuse. Therefore, the cyclist's performance decreases in races by the introduction of the fight against doping. A comparison of the performance levels in the settings *Inclusion-of-doping* and *Imperfect-Monitoring* reveals that the fight against doping reduces the athlete's performance:

$$q^*_D > q^*_{AD} \Leftrightarrow \left( \frac{v_1^2}{c_1} + \frac{v_2^2}{c_2} \right) s^*_D - \left( \frac{v_1^2}{c_1} + \frac{v_2^2}{c_2 + c_3 + \frac{1}{4} c_3^2 \eta \sigma_2^2} \right) s^*_{AD} > 0. \tag{41}$$

As before, the doping test cost and the lower performance related wage component decreases the overall performance. Therefore, the audience will consume competitions with lower performance in comparison to the situation without a doping fight.

The insights from the optimal contract, the training level and the doping level allows for concentrating on the actors and their doping incentives in a situation in which a doping fight takes place.

The principal-agent model generates the result that the cyclist, as agent, always gets the expected utility of his outside option. Therefore, the cyclist is indifferent between the settings. If he uses drugs, he will get paid for his effort by the team. As a consequence, the team manager's interest in drug abuse must be considered. The anti-doping fight influences the team manager's expected profit which is presented in equation (28). The use of three properties ($s^*_{AD}$ is between zero and one, $s^*_{AD} > s^*_D > s_{ND}$, and equation (30) holds true) leads to a positive expected profit for the team manager:

$$E(q-w)^*_{AD} = \left(\frac{v_1^2}{c_1} + \frac{v_2^2}{(c_2+c_3+\frac{1}{4}\eta c_3^2\sigma_2^2)}\right)(s^*_{AD})$$

$$-\frac{1}{2}\left(\frac{v_1^2}{c_1} + \frac{v_2^2}{(c_2+c_3+\frac{1}{4}\eta c_3^2\sigma_2^2)} + \eta\sigma_1^2\right)(s^*_{AD})^2 - \underline{w}$$

$$> \frac{1}{2}\left(\frac{v_1^2}{c_1} + \frac{v_2^2}{(c_2+c_3+\frac{1}{4}\eta c_3^2\sigma_2^2)} - \eta\sigma_1^2\right)(s^*_{AD}) - \underline{w}$$

$$> \frac{1}{2}\left(\frac{v_1^2}{c_1} - \eta\sigma_1^2\right)(s^*_{AD}) - \underline{w} > \frac{1}{2}\left(\frac{v_1^2}{c_1} - \eta\sigma_1^2\right)(s^*_{ND}) - \underline{w} > 0. \tag{42}$$

As a consequence, the team exists in the setting *Imperfect-Monitoring* due to the positive profits. The team manager's interest in doping depends on the profits that are available in situations with and without doping. It is not possible to return to the setting *Inclusion-of-Doping* because there is a fight against doping. There are no false positives, thus, I compare the team manager's profits in the settings *No-Doping* and *Imperfect-Monitoring*. By looking at the team manager's profits I can find out whether the team manager is interested in a clean sport, or not. If the expected utility with doping is higher, although the anti-doping fight takes place, there will be an incentive for the team to support the cyclist's drug abuse. The proof that the following equation holds true is in Appendix C:

$$E(q^*_{AD} - w^*_{AD})^*_{AD} - E(q^*_{ND} - w^*_{ND})^*_{ND} > 0. \tag{43}$$

The team manager's expected utility is higher in the anti-doping setting. Thus, the team manager is interested in an abuse of forbidden substances and she is willing to compensate the cyclist for the forbidden doping activity. This willingness to pay is reflected in the contract; therefore, the rider will use drugs. The result achieved explains the rise of organized doping in cycling teams. Moreover, it becomes clear that the anti-doping fight can only reduce the extent of drug abuse; it is not possible to create a drug-free sport with such anti-doping instruments.

The last research question is whether the team manager can offer a drug-free sport on her own, or not. In order to answer this question, I assume that the team manager is willing to abstain from doping although this behaviour would lead to a reduction in profits. Under this assumption, the team manager wants to design a contract that provides for a drug-free sport. It turns out that, although the team manger wants to implement a clean sport, the cyclist is interested in using drugs. To show this, I assume that doping and training are available and the fight against doping is implemented. The team manager wants to set the doping level to zero, and offers the *No-Doping* contract in which doping is not considered. Therefore, the offered contract is the following:

$$s^*_{ND} = \frac{v_1^2}{v_1^2 + c_1\eta\sigma_1^2}, \text{ and} \tag{44}$$

$$t^*_{ND} = \underline{w} - \frac{1}{2}\frac{v_1^2}{c_1}\left(\frac{v_1^2}{v_1^2 + c_1\eta\sigma_1^2}\right)^2 + \frac{\eta\sigma_1^2}{2}\left(\frac{v_1^2}{v_1^2 + c_1\eta\sigma_1^2}\right)^2. \tag{45}$$

Given this contract offer, the cyclist must decide on his doping and training level. The cyclist is willing to use drugs if this choice leads to a higher expected utility. Thus, I consider the certainty equivalent of the anti-doping setting in which doping is possible and the fight against doping takes place. The substitution of $s^*_{ND}$ and $t^*_{ND}$ in $CE(a, d, t, s)$ simplifies the equation. The certainty equivalent only depends on the doping level $d$:

$$CE(d) = \underline{w} + \frac{v_1^2 v_2}{v_1^2 + c_1 \eta \sigma_1^2} d - \frac{c_2 d^2}{2} - \frac{c_3 d^2}{2} - \frac{\eta d^2 c_3^2 \sigma_2^2}{8}. \tag{46}$$

An increase in training will not lead to a higher certainty equivalent; so it is sufficient to analyse the doping choice. In order to calculate the cyclist's optimal doping level, it is necessary to build the derivative with respect to $d$. Rearranging the derivative leads to the optimal doping level because the second order condition is always negative. So, the cyclist maximises his profit by choosing

$$d^* = \frac{v_1^2 v_2}{(v_1^2 + c_1 \eta \sigma_1^2)(c_2 + c_3 + \frac{1}{4} \eta c_3^2 \sigma_2^2)} > 0. \tag{47}$$

The consequence is that the cyclist chooses a positive doping level to maximise his expected utility, although the team manager wants to implement a clean sport. Given the optimal doping and training level, the cyclist's certainty equivalent is

$$CE = \frac{\frac{1}{2} c_2 v_1^4 v_2^2 + \frac{1}{2} c_3 v_1^4 v_2^2 + \frac{1}{8} \eta \sigma_2^2 c_3^2 v_1^4 v_2^2}{(v_1^2 + c_1 \eta \sigma_1^2)^2 (c_2 + c_3 + \frac{1}{4} \eta c_3^2 \sigma_2^2)^2} + \underline{w} > 0. \tag{48}$$

The certainty equivalent is always positive. If we compare this certainty equivalent with the cyclist's outside option it turns out that $CE > \underline{w}$. The athlete can increase his utility by using drugs, and this increase explains the athlete's interest in using drugs even though the team manager wants to hire a clean cyclist. Thus, the outcome of the team manager's anti-doping attitude is that the cyclist will choose a positive doping level to increase his own expected utility. In the end, the team manager cannot design a contract that provides a drug-free sport if training and doping are not observable for her.

# 7 Conclusion

In professional cycling many doping scandals occur, although there is a stakeholders' consensus for a clean sport. This raises the research question that is addressed in this paper: Are all these doping cases only exceptions in the otherwise clean cycling community, or is doping well organised and incentivised by the system?

The question is answered by modelling the interaction between a team manager and a cyclist. A multi-task principal-agent model illustrates the information asymmetry and conflicting objectives between both actors. The comparison of three institutional settings reveals the influence of the fight against doping on the team members' behaviour.

The analysis shows that team managers have an incentive to implement organized doping. Team managers offer contracts to cyclists that implement the abuse of drugs. In my model, the rider adopts to these contracts and he cannot gain anything by using drugs.

In addition, my model demonstrates that the fight against doping mitigates the doping problem by decreasing the extent of doping. The cyclist will use fewer forbidden drugs, but drug abuse will still exist. Thus, it is not possible to offer a drug-free sport with the help of the current anti-doping policies. Moreover, this doping fight will not change the teams' interest in doping. Organised doping offers higher profits to the team manager than relying on clean cyclist.

Another insight is that the team manager cannot ensure a drug-free sport through contracts designed for this purpose. In such a situation, the cyclist will use forbidden drugs as long as his effort is not observable. Therefore, doping seems to be well organised in professional cycling, and the image of a clean cycling community is misleading.

The results are relevant for discussing the doping problem. If it is the aim of the fight against doping to establish a drug-free sport, it is necessary to consider the doping incentives for other actors as well. This paper demonstrates the team manager's incentive to support doping. The same might be true for other actors as well. Sport physicians, sponsors, media and regulating bodies like governments or sport associations may benefit from doping, too. Thus, future research should identify doping incentives for all these actors. If there are additional incentives for doping by other actors, the fight against doping must concentrate on these actors in order to have a clean sport. Economics can help to evaluate new ideas in the fight against doping.

Another insight is that the current fight against doping is imperfect. Thus, the ineffective anti-doping instruments support a distorted image of professional cycling. As a consequence, it might be better to invest the resources being used in the fight against doping toward the health protection of the respective athletes.

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# Appendix A

Table 1: Setting equilibria

| | No-Doping ($ND$) | Inclusion-of-Doping ($D$) | Imperfect-monitoring ($AD$) |
|---|---|---|---|
| $CE$ | $t + sv_1a - \frac{1}{2}c_1a^2 - \frac{\eta s^2\sigma_1^2}{2}$ | $t + sv_1a + sv_2d - \frac{1}{2}c_1a^2 - \frac{1}{2}c_2d^2 - \frac{\eta s^2\sigma_1^2}{2}$ | $t + sv_1a + sv_2d - \frac{c_1a^2}{2} - \frac{c_2d^2}{2} - \frac{\eta s^2\sigma_1^2}{2} - \frac{c_3d^2}{2} - \frac{\eta d^2c_3^2\sigma_2^2}{8}$ |
| $s^*$ | $\frac{v_1^2}{v_1^2+c_1\eta\sigma_1^2}$ | $\frac{c_2v_1^2+c_1v_2^2}{c_2v_1^2+c_1v_2^2+c_1c_2\eta\sigma_1^2}$ | $\frac{(c_2+c_3+\frac{1}{4}\eta c_3^2\sigma_2^2)v_1^2+c_1v_2^2}{(c_2+c_3+\frac{1}{4}\eta c_3^2\sigma_2^2)v_1^2+c_1v_2^2+c_1(c_2+c_3+\frac{1}{4}\eta c_3^2\sigma_2^2)\eta\sigma_1^2}$ |
| $a^*$ | $\frac{v_1}{c_1}\left(s_{ND}^*\right)$ | $\frac{v_1}{c_1}\left(s_D^*\right)$ | $\frac{v_1}{c_1}\left(s_{AD}^*\right)$ |
| $d^*$ | $0$ | $\frac{v_2}{c_2}\left(s_D^*\right)$ | $\frac{v_2}{(c_2+c_3+\frac{1}{4}\eta c_3^2\sigma_2^2)}\left(s_{AD}^*\right)$ |
| $E(q-w)^*$ | $\frac{v_1^2}{c_1}\left(s_{ND}^*\right) - \frac{1}{2}\left(\frac{v_1^2}{c_1}+\eta\sigma_1^2\right)\left(s_{ND}^*\right)^2 - \underline{w}$ | $\left(\frac{v_1^2}{c_1}+\frac{v_2^2}{c_2}\right)\left(s_D^*\right) - \frac{1}{2}\left(\frac{v_1^2}{c_1}+\frac{v_2^2}{c_2}+\eta\sigma_1^2\right)\left(s_D^*\right)^2 - \underline{w}$ | $\left(\frac{v_1^2}{c_1}+\frac{v_2^2}{(c_2+c_3+\frac{1}{4}\eta c_3^2\sigma_2^2)}\right)\left(s_{AD}^*\right) - \frac{1}{2}\left(\frac{v_1^2}{c_1}+\frac{v_2^2}{(c_2+c_3+\frac{1}{4}\eta c_3^2\sigma_2^2)}+\eta\sigma_1^2\right)\left(s_{AD}^*\right)^2 - \underline{w}$ |

# Appendix B

I want to show that

$$E(q_D^* - w_D^*)_D^* - E(q_{ND}^* - w_{ND}^*)_{ND}^* > 0. \tag{49}$$

The first step is to simplify the equation and bring it down to a common denominator. After that, the equation can be simplified and the result is developed:

$$\frac{v_1^2}{c_1}\frac{v_2 c_1^2 \eta\sigma_1^2 \left(v_1^2 c_2 + v_2 c_1^2 + c_1 c_2 \eta\sigma_1^2\right)\left(v_1^2 + c_1\eta\sigma_1^2\right)}{\left(v_1^2 c_2 + v_2 c_1^2 + c_1 c_2 \eta\sigma_1^2\right)^2 \left(v_1^2 + c_1\eta\sigma_1^2\right)^2}$$

$$+\frac{v_2^2}{c_2}\frac{\left(v_1^2 c_2 + v_2 c_1^2\right)\left(v_1^2 c_2 + v_2 c_1^2 + c_1 c_2 \eta\sigma_1^2\right)\left(v_1^2 + c_1\eta\sigma_1^2\right)^2}{\left(v_1^2 c_2 + v_2 c_1^2 + c_1 c_2 \eta\sigma_1^2\right)^2 \left(v_1^2 + c_1\eta\sigma_1^2\right)^2}$$

$$-\frac{v_2^2}{2c_2}\frac{\left(v_1^2 c_2 + v_2 c_1^2\right)^2\left(v_1^2 + c_1\eta\sigma_1^2\right)^2}{\left(v_1^2 c_2 + v_2 c_1^2 + c_1 c_2 \eta\sigma_1^2\right)^2 \left(v_1^2 + c_1\eta\sigma_1^2\right)^2}$$

$$+\frac{1}{2}\left(\frac{v_1^2}{2c_1} + \eta\sigma_1^2\right)\frac{v_1^4\left(v_1^2 c_2 + v_2 c_1^2 + c_1 c_2 \eta\sigma_1^2\right)^2 - \left(v_1^2 c_2 + v_2 c_1^2\right)^2\left(v_1^2 + c_1\eta\sigma_1^2\right)^2}{\left(v_1^2 c_2 + v_2 c_1^2 + c_1 c_2 \eta\sigma_1^2\right)^2 \left(v_1^2 + c_1\eta\sigma_1^2\right)^2}$$

$$\Leftrightarrow \frac{\frac{5}{2}v_1^2 v_2^4 c_1^3 \eta^2\sigma_1^4 + \frac{1}{2}v_1^8 v_2^2 c_2 + 2v_1^6 v_2^2 c_1 c_2 \eta\sigma_1^2 + \frac{1}{2}v_1^4 v_2^2 c_1^2 c_2 \eta^2\sigma_1^4 + v_1^6 v_2^4 c_1}{\left(v_1^2 c_2 + v_2 c_1^2 + c_1 c_2 \eta\sigma_1^2\right)^2 \left(v_1^2 + c_1\eta\sigma_1^2\right)^2}$$

$$+\frac{2v_1^4 v_2^4 c_1^2 \eta\sigma_1^2 + 2v_1^4 v_2^2 c_1 c_2 \eta^2\sigma_1^4 + v_1^2 v_2^2 c_1^3 c_2 \eta^3\sigma_1^6}{\left(v_1^2 c_2 + v_2 c_1^2 + c_1 c_2 \eta\sigma_1^2\right)^2 \left(v_1^2 + c_1\eta\sigma_1^2\right)^2}$$

$$+\frac{v_1^4 v_2^6 \frac{c_1^2}{2c_2} + v_1^2 v_2^6 \eta\sigma_1^2 \frac{c_1^3}{c_2} + v_2^6 \eta^2\sigma_1^4 \frac{c_1^4}{2c_2} + v_1^4 v_2^2 \eta\sigma_1^2 + \frac{1}{2}v_1^2 c_1^4 \eta^3\sigma_1^6}{\left(v_1^2 c_2 + v_2 c_1^2 + c_1 c_2 \eta\sigma_1^2\right)^2 \left(v_1^2 + c_1\eta\sigma_1^2\right)^2} > 0. \tag{50}$$

The last equation has only positive terms. Thus, the result must be bigger than zero, and the consequence is that $E(q-w)_D^* > E(q-w)_{ND}^*$.

# Appendix C

I compare the team manager's profit in the first and third setting and find out which profit is higher. To do so, I solve the following equation:

$$E(q^*_{AD} - w^*_{AD})^*_{AD} > E(q^*_{ND} - w^*_{ND})^*_{ND}. \tag{51}$$

The first step is to bring both sides of the equation down to a common denominator. Afterwards, it is possible to simplify the equation by bringing all parts to one side of the equation. This leads to the following result:[4]

$$\frac{\frac{1}{2}v_1^4A^2\left(v_1^2 + c_1\eta\sigma_1^2\right) + v_1^2v_2^2c_1A\left(\frac{3}{2}v_1^2 + c_1\eta\sigma_1^2\right) + v_2^4c_1^2\left(\frac{3}{2}v_1^2 + \frac{1}{2}c_1\eta\sigma_1^2\right) + \frac{1}{2A}v_2^6c_1^3}{c_1\left(v_1^2A + v_2^2c_1 + c_1A\eta\sigma_1^2\right)^2}$$

$$> \frac{v_1^6 + v_1^4c_1\eta\sigma_1^2}{2c_1\left(v_1^2 + c_1\eta\sigma_1^2\right)^2}$$

$$\Leftrightarrow \frac{1}{2}v_1^8v_2^2c_1A^2 + 2v_1^6v_2^2c_1^2A^2\eta\sigma_1^2 + \frac{5}{2}v_1^4v_2^2c_1^3A^2\eta^2\sigma_1^4 + v_1^6v_2^2c_1^2A$$

$$+3v_1^4v_2^4c_1^3A\eta\sigma_1^2 + \frac{5}{2}v_1^2v_2^4c_1^4A\eta^2\sigma_1^4 + v_1^2v_2^2c_1^4A^2\eta^3\sigma_1^6 + \frac{1}{2}v_1^4v_2^6c_1^3 + v_1^2v_2^6c_1^4\eta\sigma_1^2$$

$$+\frac{1}{2}v_2^6c_1^5\eta^2\sigma_1^4 + \frac{1}{2}v_2^4c_1^5A\eta^3\sigma_1^6 > 0. \tag{52}$$

The left hand side of equation (52) is always bigger than zero and thus PED will be used, although a fight against doping takes place.

[4] I define $A = \left(c_2 + c_3 + \frac{1}{4}c_3^2\eta\sigma_2^2\right)$