Can too many cooks spoil the broth? Coordination costs, fatigue, and performance in high-intensity tasks

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Working Paper No. 1919

November 2019

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Can too many cooks spoil the broth? Coordination costs, fatigue, and performance in high-intensity tasks

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November 18, 2019

Workplace flexibility offers a wide range of opportunities but also carries risks within the context of collaborative tasks. While increasing the number of collaborators can reduce fatigue and therefore enhance performance, it also increases coordination costs. Our study investigates this trade-off in a complex team task with high effort costs in a natural setting. We use the instrumental variables method combined with an extensive sensitivity analysis to identify the causal effect of in-game substitutions on performance in professional basketball. Our findings suggest that increasing the number of collaborators, on balance negatively affects team performance. However, we also provide evidence that the most successful teams are able to optimally trade off both effects.

JEL-Code: D22, J4, J22, Z20

Keywords: coordination costs, fatigue, productivity, team performance, substitutions

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1. Introduction

The importance and prevalence of flexible work arrangements have been growing through the years. With improving information and communication technologies being a relevant driver, workplace flexibility in terms of time (e.g. flexible working hours), place (e.g. transportable teleworking), and task (e.g. job sharing/rotation) continues to spread and is accompanied by increasing demand on the employee side, with the provision of flexible scheduling policies representing a 'key decision for employers' to attract employees (Mas and Pallais, 2017, p. 3723). Moreover, research on the relationship between working hours and productivity shows that the reduction of working hours can increase output due to lower levels of work fatigue, work stress, and errors (e.g., Brachet et al., 2012; Pencavel, 2014; Collewet and Sauermann, 2017). We will call this the 'fatigue effect'.

However, despite further benefits such as positive effects on job satisfaction and overall employment, there are also concerns that this development comes at a cost, not only for workers, but also for companies. More specifically, if we think of workers engaged in a collaboration task, increasing the number of co-workers along with a reduction in working hours leads to coordination costs in a Becker and Murphy (1992) and Bolton and Dewatripont (1994) sense which may outweigh the positive effects of flexible work arrangements on productivity. Brooks (1975), for instance, suggests that this is the case in more complex tasks. Hence, the question is whether the trade-off between the 'fatigue effect' and the 'coordination costs effect' ultimately results in a positive or negative net effect from increasing flexible work arrangements in collaborative tasks.

In this paper we investigate this trade-off within the context of collaboration in a complex and high-intensity task. In particular, we use data from professional basketball–an industry where performance is very sensitive to fatigue and coordination–to investigate the causal effect of in-game substitutions on different outcome variables. To reduce the possibility of an omitted variable bias, we refer to an instrumental variables (IV) approach combined with an extensive sensitivity analysis. Our main result is that, on balance, increasing the number of collaborators negatively affects team productivity. The effect is non-linear and is more pronounced in situations related to higher coordination costs.

Furthermore, results suggest that teams differ in their ability to cope with the 'fatigue effect' and the 'coordination costs effect' such that the most successful teams are able to optimally trade-off both effects.

The remainder of the article is structured as follows: initially, Section 2 outlines our theoretical framework. Then Section 3 gives some background information on basketball and describes the data set. Section 4 presents the empirical strategy and the results. Finally, Section 5 concludes with a discussion.

2. Conceptual framework

A simple conceptual framework is to suppose that a task-related team performance Y is defined as net productivity, i.e. team productivity (P) minus coordination costs (C):

$$Y = P(A, S) - C(S). \tag{1}$$

Team productivity P is a function of the overall ability level of the team (A, $\frac{\partial P}{\partial A} > 0$) and the number of team members involved in the actual task (S). Following the literature on efficient working hours (e.g., Pencavel, 2014; Collewet and Sauermann, 2017), we assume positive, but declining marginal products ($\frac{\partial P}{\partial S} > 0$ and $\frac{\partial^2 P}{\partial S^2} < 0$) to account for the 'fatigue effect'. Furthermore, we propose increasing marginal (coordination) costs of S ($\frac{dC}{dS} > 0$ and $\frac{d^2 C}{dS^2} > 0$).[1] Hence, the optimal number of individuals involved in the task, S^*, is defined by the first order optimality condition $\frac{\partial P}{\partial S} = \frac{dC}{dS}$, see Figure 1.

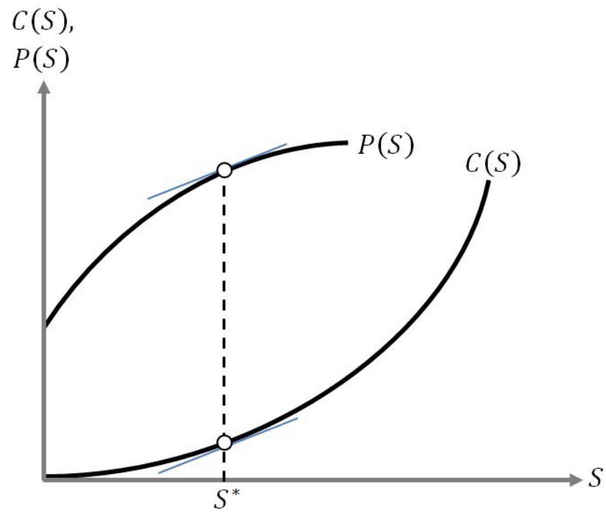
This simple model permits the following conclusions:

- If the team manager chooses the optimal task-specific number of collaborators $S = S^*$, the marginal effect of S on performance is zero: $\frac{\partial Y}{\partial S}|_{S=S^*} = 0$.

- If, however, coordination costs were systematically underestimated (overestimated), we have $\frac{\partial Y}{\partial S} < 0$ ($\frac{\partial Y}{\partial S} > 0$).

[1] Note that Lazear and Shaw (2007) instead refer to "communication costs" which decrease with personal knowledge.

Figure 1: Optimal number of team members involved in a task.



Since it is far easier to observe exhaustion than to exactly assess coordination costs, we expect underestimation to be the more likely scenario in our empirical analysis.

3. Institutional background and data

To better understand the institutional background of our study, we briefly explain why basketball (i.e. the National Basketball Association (NBA)) as a context and the set of rules regarding in-game substitutions seem to suit our research agenda.

Compared to other team sports such as association football, the NBA substitution rules allow both teams an unlimited number of substitutions during the course of every game providing plenty of flexibility and a plethora of in-game coaching tools. Substitutions require 'dead balls'–that is, a situation in which the ball is deemed to be temporarily not playable–and a stopped play clock. Substitutions can be attained through events such as full-timeouts, twenty-second timeouts, out-of-bounds turnovers, fouls, or for applying of the 'blood rule' (a player who is bleeding or who has blood on them or their clothes must immediately leave the playing area to receive medical attention). A player may not be substituted by a free-throw shooter or a jumper (i.e. a player participating in a jump ball) unless that player is injured. Every player is allowed to go out and come in again an unlimited number of times unless they are disqualified (e.g. after six personal fouls) or ejected (e.g. violation of the sports rules) by the referees. During an NBA game, every team has the chance to use six full timeouts and one twenty-second timeout per half.[2] Both types of timeouts have different implications regarding substitution opportunities for the two teams. On the one hand, during a full-timeout, all five players of each team may be substituted in/out. On the other hand, during a twenty-second timeout, just one player can be replaced by the team calling a timeout. Only then is the other team allowed to make a substitution as well. A noteworthy exception to this this rule is that all players of both teams may be removed if the twenty-second timeout is called in the last two minutes of the fourth quarter or the last two minutes of overtime.

Due to its formalised structure, richness (e.g. the amount of games every season and the multitude of performance indicators), and availability of comprehensive data, NBA data has already been used in previous studies on different topics such as behaviour in contests (e.g., Grund et al., 2013; Berger and Pope, 2011; Taylor and Trogdon, 2002), performance and compensation (e.g., Bodvarsson and Brastow, 1998; Berri and Krautmann, 2006; Simmons and Berri, 2011; Arcidiacono et al., 2017), discrimination (e.g., Kahn and Sherer, 1988; Price and Wolfers, 2010; Price et al., 2013), referee bias Price et al. (2009), employee selection (e.g., Ichniowski and Preston, 2017), and escalation effects (e.g., Staw and Hoang, 1995; Camerer and Weber, 1999).

Basketball as a sport seems to be particularly suitable for testing the contrary effects of fatigue and coordination on productivity for the following reasons. In the former's case, substitutions reduce the probability of injuries. Furthermore, they also preserve the health and energy of players, which has a positive effect on productivity.[3] In case of the latter, the fact that substituted players need to adjust to the specific pace of a game without having the opportunity to properly warm up indicates a dampening effect of substitutions on productivity. Additionally, basketball and the NBA, in particular, can be characterized as a fast sport with a wide spectrum of demands on every player (e.g. every player has to play in offence and defence equally), high levels of interdependence

[2] We refer to the official NBA rules during the relevant observation period comprising the seasons 2009/10 to 2016/17: https://www.nba.com/media/dleague/1314-nba-rule-book.pdf

[3] See that Baucells and Zhao (2018) also use data from professional sports to calibrate their fatigue disutility model.

between players (e.g. the guidelines on both ends of the floor involve all five players of a team), and a large number of substitutions in every game (e.g. players constantly come on and off the court and every team has an extensive rotation of players). Thus, we expect both types of effects to be more visible compared to other team sports (e.g. baseball or association football).

The data set used in this study comprises a total of 9,571 games in the 2009/10 to 2016/17 seasons.[4] A total of 664 of these games are observed in the play-offs. This amounts to 93.2% of all of the 10,267 NBA games played during all 8 seasons.

Our data provides detailed information on performance statistics, substitutions, and timeouts. Each substitution identifies the player leaving the court as well as the player entering.[5] All matches are split into sixteen 3-minute intervals and all play-by-play entries were summarized accordingly.

4. Empirical strategy and results

The aim of this section is to empirically examine whether the (task-specific) number of collaborators affects the (net) productivity of a team. We therefore operationalise the productivity of team i in game t and time period k, $Y_{i,t,k}$, by different basketball-specific performance measures, where the number of substitutions made by team i in game t and time period k, denoted by $S_{i,t,k}$, serves as our main explanatory variable.

Yet, 'naïve'OLS estimations face the prospect of an omitted variable bias.[6] That is, there is reason to believe that without detailed information on each substitution we cannot rule out the existence of confounders which impact $Y_{i,t,k}$ and $S_{i,t,k}$ simultaneously. Hence, $S_{i,t,k}$ and the error term would be correlated. To tackle this problem and to obtain conditionally exogenous variation in a team's number of substitutions in a given period k, we use the number of substitutions made by the opposing team in $k-1$, $SO_{i,t,(k-1)}$, as

[4] All data was scraped as play-by-play files from `ESPN.com/nba/scores`. We carefully checked all play-by-play data for completeness. Any games with incomplete information or miscoding (e.g. when the total score was not consistent with all the individual scoring entries) were omitted from the sample.

[5] For three cases in our data only one player was identified.

[6] This approach was followed by Gómez et al. (2017) who estimated a positive effect of substitutions on point differences.

an instrumental variable for $S_{i,t,k}$.

We estimate the following model of team i's (net) performance in game t and time period k:

$$Y_{i,t,k} = \beta_0 + \beta_1 \overline{S_{i,t,k}} + \xi' \mathbf{X}_{i,t,k} + \delta_{i,t} + \sigma_k + \varepsilon_{i,t,k}, \tag{2}$$

where the first stage is

$$S_{i,t,k} = \pi_0 + \pi_1 SO_{i,t,(k-1)} + \xi' \mathbf{X}_{i,t,k} + \delta_{i,t} + \sigma_k + \nu_{i,t,k}. \tag{3}$$

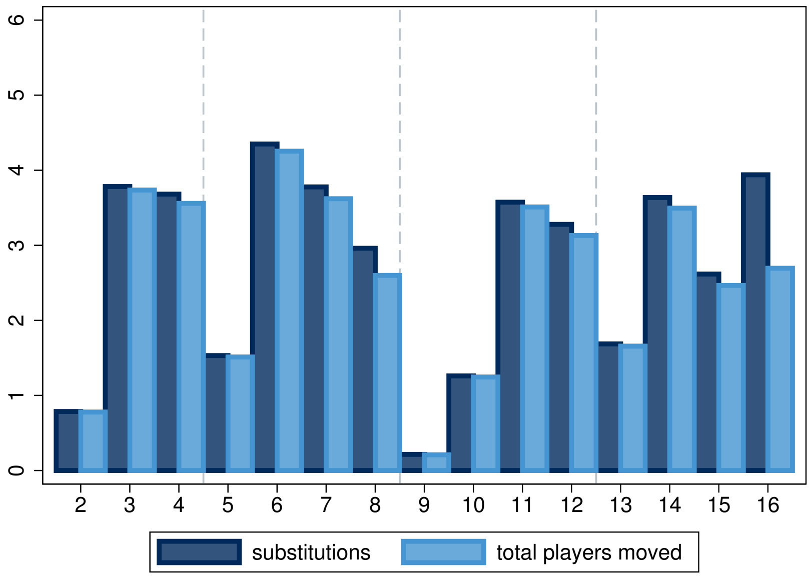
Here, $X_{i,t,k}$ is a vector of control variables including the field goals attempted (overall and at team level), the score difference at the beginning of periods k and the score difference measured over the whole period $k-1$, the total number of penalties for each team, and the number of team i's substitutions before period k as well as the number of substitutions made by the opposing team before period $k-1$. In addition, we include team-game fixed-effects ($\delta_{i,t}$) to control for unobserved team-game specific characteristics, and time-interval fixed-effects (σ_k) to account for dynamics over the course of a game. Finally, $\varepsilon_{i,t,k} \sim N(0, \sigma^2)$ is a mean-zero error term.

Figure 2 illustrates the means of substitutions by time periods $k = 2$ to 16. Note that each substitution is counted as 2, because $S_{i,t,k}$ is measured by the number of players substituted in and out. As an alternative measure, in Section 4.3 we use the number of *different* players substituted in period k (*total players moved*) as our causal variable of interest.

The Figure shows that teams rarely substitute in the initial periods of each quarter, and that the lowest average number of substitutions is measured after the half-time break. For most time periods, the number of substitutions and the number of total players moved is highly correlated. However, in the final period, the number of substitutions is significantly larger than the number of players moved. This can be explained by the fact that teams more frequently substitute players with certain strategic abilities, such as experts for rebounding or three-point shooting, in the game-deciding phase of a game.

The identifying assumption of our instrumental variable strategy is that the number of

Figure 2: Average number of substitutions and total players moved by time period k



Notes: Average number of substitutions and number of different players substituted for all 3-minute periods (2 to 16). Only periods of regulation play (48 minutes divided into four quarters) are used. Breaks between quarters are indicated by the dashed line.

substitutions made by the opponent in $k-1$ only affects the (relative) performance of team i in k only through $S_{i,t,k}$. However, there are clearly some potential determinants of relative performance in k which correlate with our instrumental variable. We therefore include a rich set of covariates to ensure that our instrument is conditionally valid.

Physical exhaustion. A potential concern for our identification strategy is that $SO_{i,t,(k-1)}$ may affect the (relative) performance of team i in period k through different team-specific levels of fatigue. That is, a higher value of $SO_{i,t,(k-1)}$ could mean that the opposing team benefits from a higher number of fresh players on the court in k. Consequently, our instrument is only valid (which means that the exclusion restriction only holds) if we control for fatigue.

Since our data set provides detailed information on all relevant actions observed on the court for all four quarters of a game, we chose shooting attempts as a proxy for the intensity of the game. Specifically, we used the total number of field goals attempted as well as the ratio of team i's attempts compared to attempts by the opposing team before k to control for the effort both teams exerted up to the observed time period. Additionally, we control for the total number of substitutions per team before k and the total number of substitutions made by the opponent before to the beginning of period $k-1$. Finally, team-game fixed effects are used to address the issue of differences in players' initial constitutions across teams. This approach also brings the benefit of being unaffected by in-season trading.

Penalties. Another thread to our causal estimation strategy is posed by the fact that substitutions are frequently triggered by teams recording personal fouls. It is crucial to note that players must leave the game after collecting a total of six personal fouls during a single game (see Section 3). As a reaction, coaches typically try to protect players by taking them off the court. This behaviour might have a direct effect on relative performance, because we would expect the most important (and hence best performing) players to be at a higher risk of being fouled out since they play for a greater number of minutes.

Our data provide detailed information about personal fouls during regulation time for all the games we observe. Consequently, we are able to control for the number of the observed team's personal fouls up to period k as well as for the opponent's fouls up to $k-1$.

Heterogeneity of players. Finally, it may also be the case that substitutions made by the opposing team in $k-1$ have a direct effect on team i's (relative) performance in period k. This is because even players filling the same position will likely differ in terms of specific abilities, experience or physical characteristics and therefore cannot be taken as perfect substitutes. Consequently, the opposing team could gain an advantage through strategic substitutions. As a consequence, it might be the case that rotations in $k-1$ cause a direct spillover into k. We account for this issue by controlling for the score difference before $k-1$ and the point difference in points scored by both teams in $k-1$.

Table 1 summarises the descriptive statistics for the substitutions and any control variables used in the regression framework.

Table 1: Descriptive statistics

Variable	*Mean*	*Std. dev.*	*Min.*	*Max.*
substitutions in k	2.58	2.73	0	50
total players moved in k	2.41	2.42	0	13
cumulative number of attempts before k	97.09	60.80	0	245
ratio of all attempts before k	1.01	0.18	0.1	10
score difference before *k-1*	0	9.92	-55	55
point difference both teams in *k-1*	0	4.02	-17	17
cumulative penalties before k	8.89	6.56	0	43
cumulative substitutions before k	8.72	6.54	0	42
number of timeouts called in *k-1*	0.30	0.49	0	3

Descriptive statistics for key variables used in model (2), N = 287,130.

First-stage estimation Table 2 presents the results from different specifications in our first stage (3). We estimate that the number of substitutions in k is positively associated with the opponent's substitutions in $k-1$. However, after including time-interval fixed-effects, the estimated coefficient for $SO_{i,t,(k-1)}$ turns negative and is significant at the 1% level (column (4)). It is essential to control for periods, because incentives for substitutions may vary over the course of a game. For instance, close to the end of a quarter teams typically use substitutions to compensate for the effort costs (fatigue) of the players on the court. In contrast, at the beginning of a period when the level of fatigue is low, a substitution is more likely to be caused either by an injury or the risk of a foul out. Figure 3 illustrates the estimated coefficient for our first stage ($\hat{\pi}_1$) split by time period $t \in 1, ..., 16$. It shows that the correlation between $SO_{i,t,(k-1)}$ and $S_{i,t,k}$ highly depends on the observed period.

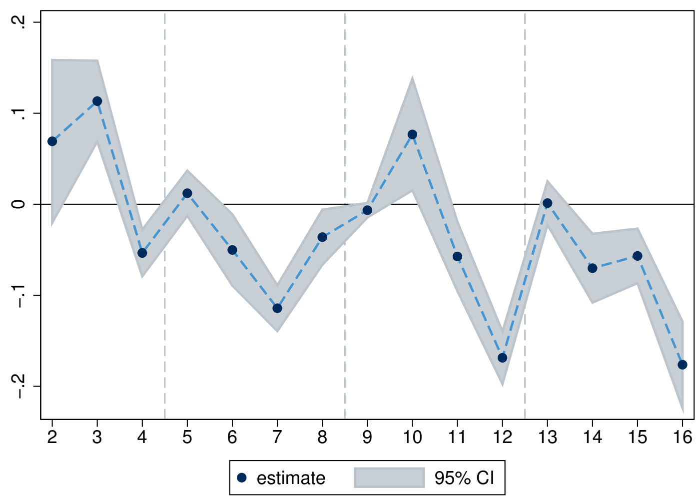
In the full specification of our first stage, we estimate that one additional substitution by the opposing team in $k-1$ decreases the number of substitutions by team i in the following period. We interpret this to mean that teams may take substitutions made by the opponent as positive feedback which lowers the incentive for own substitutions.

Table 2: First-stage results: different specifications

	(1)	(2)	(3)	(4)
opponent's substitutions	0.014***	0.019***	0.047***	-0.065***
in (k-1)	(0.004)	(0.004)	(0.005)	(0.005)
abs. no. throwing		0.006***	0.053***	-0.005***
attempts up to k		(0.000)	(0.001)	(0.001)
ration no. own atts		-0.202***	-0.238***	0.056*
over opponent's atts		(0.023)	(0.036)	(0.030)
score difference		0.011***	0.017***	0.015***
at the end of $(k-1)$		(0.001)	(0.001)	(0.001)
point difference		-0.005***	-0.011***	-0.007***
for period $(k-1)$		(0.001)	(0.001)	(0.001)
opponent's penalties		0.001	-0.006*	-0.012***
before k		(0.002)	(0.004)	(0.003)
own penalties		0.005**	-0.003	0.002
before k		(0.002)	(0.004)	(0.003)
own substitutions		-0.011***	-0.435***	-0.397***
before k		(0.003)	(0.004)	(0.004)
opponent substitutions		-0.032***	-0.058***	0.029***
before $k-1$		(0.002)	(0.004)	(0.004)
opponent timeouts		-0.120***	-0.066***	-0.012
in $(k-1)$		(0.012)	(0.011)	(0.010)
own timeouts		-0.211***	-0.128***	-0.112***
in $(k-1)$		(0.011)	(0.011)	(0.010)
Team*game FEs	*No*	*No*	*Yes*	*Yes*
Time interval FEs	*No*	*No*	*No*	*Yes*

Notes: N = 287,130. Robust standard errors clustered on the team-game level in round parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent level. The dependent variable is the number of substitutions in period k.

Figure 3: Estimated first stage for spit-samples in periods k



Notes: Each point illustrates the estimate for π_1 in equation 3 for a particular time period indicated on the y-axis. The shaded area illustrates the 95% confidence interval (CI)s.

4.1. Main results

Table 3 presents our main results derived from estimating a 2SLS. Firstly, our preferred variable for measuring the performance of team i in game t and period k is the difference in points scored, $ownpoints - opp.\ points$ (column (1)). Secondly, we examine the probability for team i of outperforming the opponent in a given period k (column (2)). Specifically, we use a binary variable equal to 1 if team i scores more points than the opponent in k. Thirdly, our setting (professional basketball) also includes situations in which the main objective of a team is to protect a lead for a certain period of time. Hence, a second binary variable is used which equals 1 if team i leads in the overall score after period k (column (3)).

We estimate that, on balance, one additional player substituted decreases the point difference in period k by 0.6 points. The probability of winning the period decreases by 6 percentage points if one player who has not yet participated is involved in a substitution. In terms of the overall score, the probability to still have the lead is negatively affected by substitutions and decreases by 2 percentage points.

Notice that the Kleibergen and Paap (2006) test statistic indicates that the instrumental variable is sufficiently strong ($F = 175.677$). Despite using team-game fixed effects and a rich set of controls, we cannot fully control for the time-specific ability or momentum of a team in a particular time period k. For example, a team with the momentum will have strong incentives to substitute and provide some resting time for their most productive players. As a consequence, since we expect teams with higher situational momentum or confidence to score more and to substitute more, we are unable to rule out a positive omitted variable bias.

A comparison of our IV results with OLS estimates reveals that the latter are qualitatively similar but positively biased towards 0. This is not surprising, since it is reasonable to assume that a substantial share of substitutions is observed for teams who experience peaks in situational momentum and productivity and intend to rest their key contributors. Consequently, we underestimate the negative effect of substitutions on team productivity using plain OLS.

In addition to the full sample of time periods 2-16, we also estimate model (2) for a restricted sample of time periods. NBA games consist of four quarters, with breaks in between quarters.[7] These breaks are used by coaches to interact with the team and make tactical adjustments. Consequently, coordination costs may differ between periods with and without play intermission beforehand. So we expect our instrument to have a stronger first stage as the substitutions by the opponent's team should have a greater impact in successive periods (which have no intermission).

The results for a restricted sample without periods 5, 9, and 13 are tabulated in Table 4. All the results for the full sample are confirmed. As expected, the instrument is tested to be stronger as the first-stage F-statistic (Kleibergen and Paap, 2006) increases. The estimated negative effect of substitutions on performance is comparable to the full-sample results at -0.456.[8] We conclude that including time intervals after intermissions does not affect our estimation results.

The analysis proceeds by identifying the relevant task-specific channels through which $S_{i,t,k}$ impacts on $Y_{i,t,k}$ (Section 4.2). After the introduction of an alternative measure of S in Section 4.3, we focus on the structural differences in coordination costs at match-level (Section 4.4). Finally, we account for potential non-linear effects in Section 4.5 and heterogeneity in the ability to trade-off coordination costs and fatigue across teams in Section 4.6.

4.2. A more detailed examination of how substitutions affect performance

In this section, we use a large set of team-specific performance indicators as additional dependent variables to gain a better understanding of how relative performance is affected by the task-specific channels (which we can refer to as subtasks) through which

[7] According to the rules of the game, there are play intervals of 120 seconds between the 1st and 2nd quarters, the 3rd and 4th quarters and the 4th quarter and overtime. Additionally, there is a 15-minute break at half-time.

[8] A bootstrap and permutation test confirms that the coefficients for the full sample (Table 3) are not statistically different at the 5% level.

Table 3: Estimated causal effect of total substitutions on productivity

Dep. var.:	**point difference**	**win period**	**lead after period**
substitutions[a]	-0.599***	-0.057***	-0.020**
	(0.120)	(0.015)	(0.009)
abs. no. throwing attempts up to k	-0.003	-0.000*	0.000
	(0.002)	(0.000)	(0.000)
ration no. own atts over opponent's atts	-0.537***	-0.054***	0.089***
	(0.065)	(0.008)	(0.006)
score difference at the end of $(k-1)$	-0.225***	-0.022***	0.020***
	(0.002)	(0.000)	(0.000)
point difference for period $(k-1)$	-0.200***	-0.020***	0.029***
	(0.003)	(0.000)	(0.000)
opponent's penalties before k	0.040***	0.004***	0.001
	(0.006)	(0.001)	(0.001)
own penalties before k	-0.046***	-0.004***	-0.002***
	(0.006)	(0.001)	(0.001)
own substitutions before k	-0.259***	-0.024***	-0.010***
	(0.049)	(0.006)	(0.004)
opponent substitutions before $k-1$	0.031***	0.003***	0.004***
	(0.008)	(0.001)	(0.001)
opponent timeouts in $(k-1)$	-0.022	-0.002	-0.003***
	(0.016)	(0.002)	(0.001)
own timeouts in $(k-1)$	-0.060***	-0.006**	0.004***
	(0.021)	(0.003)	(0.002)
team-game FEs	*yes*	*yes*	*yes*
time period FEs	*yes*	*yes*	*yes*
first stage coefficient		-0.065***	
		(0.005)	
F stat.[b]		175.677	
OLS estimate[c]	-0.253***	-0.024***	-0.010***
	(0.004)	(0.000)	(0.000)
N		287,130	

Notes: Robust standard errors clustered on the team-game level in round parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent level. All three specifications include team-game and time-period fixed-effects. [a] Variable 'substitutions' measures the number of players involved in substitutions during the game. Each substitution involves a minimum of two players. [b] Kleibergen–Paap F-statistic (Kleibergen and Paap, 2006); the null hypothesis is that the instrument is weak. [c] Estimated coefficient β_1 derived from estimating model 2 using OLS, including team-game as well as time period fixed-effects.

Table 4: Effect of substitutions on performance (sample without periods immediately following a break)

Dep. var.:	**point difference**	**win period**	**lead after period**
substitutions[a]	-0.456***	-0.045***	-0.027***
	(0.078)	(0.010)	(0.006)
additional controls	*yes*	*yes*	*yes*
team-game FEs	*yes*	*yes*	*yes*
time period FEs	*yes*	*yes*	*yes*
first stage coefficient		-0.130***	
		(0.007)	
F stat.[b]		332.171	
N		153,136	

Notes: Robust standard errors clustered on the team-game level in round parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent level. All three specifications include team-game and time-period fixed-effects. Coefficients for additional control variables are not reported due to space constraints. [a] The variable substitutions measures the number of players involved in substitutions during the game. Each substitution involves a minimum of two players. [b] Kleibergen–Paap F-statistic (Kleibergen and Paap, 2006); the null hypothesis is that the instrument is weak.

substitutions occur. The results are presented in Figure 4.

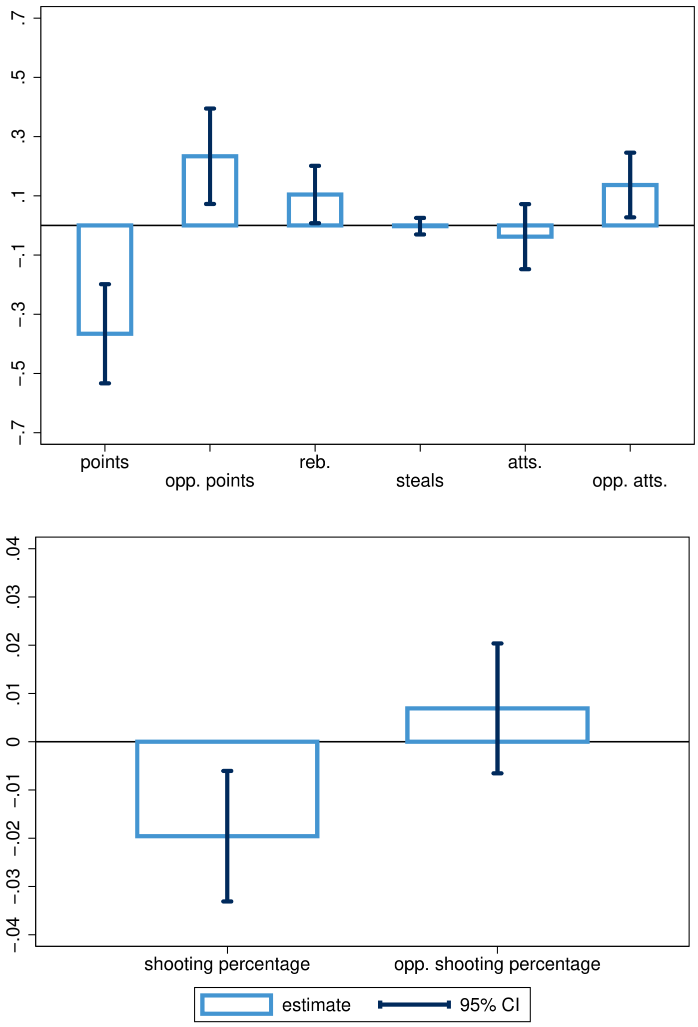
We find that the negative causal effect of substitutions on performance results mainly from the fact that team i scores fewer points whereas the opposing team scores more points. The same applies to the shooting percentage. Furthermore, the absolute number of rebounds increases in S, which can be explained by the fact that the opponent records a higher number of missed field goals.

Overall, we conclude that substitutions increase the coordination costs of a team which makes it harder to score and likewise to prevent the opponent from scoring. Since the preparation of a successful attack as well as the defence organisation is highly complex, it seems reasonable that the rise in coordination costs has its largest impact here.

4.3. Substitutions of different players

In addition to the number of substitutions, we use the total number of different players involved in a game ('*total players moved*') as an alternative measure. For example, say we observe three substitutions in a given period. The number of different players involved

Figure 4: Channels through which substitutions affect performance



Notes: N = 287,130.

could then range from one (if the same pair of players are multiple times) to the maximum number of available players on a team.

Since coordination costs in a collaborative task primarily arise from the integration of new co-workers, we expect the effect on performance to be stronger compared to the estimations in Section 4.1. Table 5 shows that this the case. Overall, we find that increasing the number of team members involved has a negative effect on performance. For instance, if one additional player enters the game in period k, the point difference (from team i's perspective) in k decreases by -0.782 points. This point estimate is slightly larger (in absolute values) than the $\hat{\beta}_1 = -0.599$ presented in Table 3 ('win period': $\hat{\beta}_1 = -0.074$ vs. -0.057, 'lead after period': $\hat{\beta}_1 = -0.027$ vs. -0.020.). However, the point estimates are not significantly different at the 5% level. Table A.1 in the Appendix presents the results for this alternative explanatory variable for the sample without the play intermission times. All results are qualitatively confirmed for this reduced sample.

4.4. Heterogeneous effects within a game

As explained above, there are four quarters of play with the 15-minute half-time break being the longest. Half-time breaks are typically used to adjust and coordinate team strategies so we expect teams to enter the second half with a clear and updated strategy. As a consequence, substitutions made in the second half of the game may trigger comparatively high coordination costs–especially in the beginning–since all of the strategic adjustments made during the break will be undermined.

To investigate whether the effect of substitutions on performance varies across halftimes, we split the sample accordingly. Table 6 shows the results. As expected, the effect is stronger in the second half.[9] This finding confirms that, on balance, changing the team after making strategic adjustments has greater detrimental effects. In addition, we can rule out that substitutions will predominantly be used to counter the negative effects of

[9]Note that the first stage for the second-half sample is comparably weak ($F = 9.219$). The coefficient of our instrument is significantly smaller than for the first-half sample (-0.024 vs. -0.050). As an explanation, see that strategic concerns like free-throw shooting ability, rebound potentials as well as three-point shooting are of increased relevance towards the end of games.

Table 5: The estimated causal effect on productivity of the total number of different players substituted

Dep. var.:	**point difference**	**win period**	**lead after period**
number of different players moved[a]	-0.782*** (0.157)	-0.074*** (0.020)	-0.027** (0.012)
abs. no. throwing attempts up to k	-0.001 (0.002)	-0.000 (0.000)	0.000 (0.000)
ration no. own atts over opponent's atts	-0.527*** (0.066)	-0.053*** (0.008)	0.090*** (0.006)
score difference at the end of $(k-1)$	-0.223*** (0.003)	-0.022*** (0.000)	0.020*** (0.000)
point difference for period $(k-1)$ $(k-1)$	-0.202*** (0.003)	-0.020*** (0.000)	0.029*** (0.000)
opponent's penalties before k	0.039*** (0.006)	0.004*** (0.001)	0.001 (0.001)
own penalties before k	-0.047*** (0.006)	-0.005*** (0.001)	-0.002*** (0.001)
own substitutions before k	-0.316*** (0.060)	-0.029*** (0.007)	-0.012** (0.005)
opponent substitutions before $k-1$	0.033*** (0.009)	0.003*** (0.001)	0.004*** (0.001)
opponent timeouts in $(k-1)$	-0.024 (0.017)	-0.002 (0.002)	-0.003*** (0.001)
own timeouts in $(k-1)$	-0.077*** (0.024)	-0.008*** (0.003)	0.004** (0.002)
team-game FEs	*yes*	*yes*	*yes*
time period FEs	*yes*	*yes*	*yes*
first stage coefficient		-0.050*** (0.004)	
F stat.[b]		141.833	
OLS estimate[c]	-0.317*** (0.004)	-0.030*** (0.000)	-0.012*** (0.000)
N		287,130	

Notes: Robust standard errors clustered on the team-game level in round parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent level. All three specifications include team-game and time-period fixed-effects. [a] The variable *total players moved* measures the number of different players involved in substitutions during the game. Each substitution involves a minimum of two players. [b] Kleibergen–Paap F-statistic (Kleibergen and Paap, 2006); the null hypothesis is that the instrument is weak. [c] Estimated coefficient β_1 derived from estimating model 2 using OLS, including team-game as well as time period fixed-effects.

physical exhaustion (see the beginning of this section). That is, if players were substituted out because they had become tired, we would estimate that there would be an even greater negative effect on team performance due to the number of substitutions. Further support for this argument is given in Table A.2 of the Appendix. Here again, the sample is restricted to periods which do *not* immediately follow a break, implying that there are fewer opportunities to give instructions and discuss tactics. It shows that the estimated β_1 and the 'second-half effect' qualitatively confirm our results from the non-restricted sample. However, the estimated effects (especially for the second half) are quantitatively smaller and more precisely estimated due to the substantially stronger F statistics on the exclusion restriction.

Table 6: Effect of absolute number of substitutions on performance - by games halves

	first half			*second half*		
Dep. var.:	**point diff.**	**win period**	**lead after period**	**point diff.**	**win period**	**lead after period**
subs.[a]	-0.861***	-0.110***	-0.039*	-3.281***	-0.229**	-0.162***
	(0.255)	(0.033)	(0.021)	(1.107)	(0.090)	(0.061)
additional controls	*yes*	*yes*	*yes*	*yes*	*yes*	*yes*
team-game FEs	*yes*	*yes*	*yes*	*yes*	*yes*	*yes*
time period FEs	*yes*	*yes*	*yes*	*yes*	*yes*	*yes*
first stage coeff.		-0.050***			-0.024***	
		(0.007)			(0.008)	
F stat.[b]		54.589			9.219	
N		133.994			153,136	

Notes: The dependent variable is the point difference for the observed team and the opposing team in the observed time period k. Robust standard errors clustered on the team-game level in round parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent level. All three specifications include team-game and time-period fixed-effects. [a] The variable *total players moved* measures the number of different players involved in substitutions during the game. Each substitution involves a minimum of two players. [b] Kleibergen–Paap F-statistic (Kleibergen and Paap, 2006); the null hypothesis is that the instrument is weak.

According to NBA rules, substitutions can take place when play has been officially stopped. Timeouts can be requested by the players and head coaches of both teams provided that the ball is 'dead' or is controlled by the team making the request. Hence, substitutions may differ systematically with regard to their strategic implications depending on the time and the team. For instance, substitutions made by team i during timeouts called by the other team are more likely to be an immediate reaction to the opponent's behaviour compared to substitutions made during their 'own' timeouts. Consequently, we estimate an alternative model using only substitutions during timeouts by the opposing team as the explanatory variable. The results are tabulated in 7. Again, we estimate a strong negative effect by substitutions on performance. The effects are almost twice as large as in our main results, as the score difference is estimated to deteriorate by about 1.2 points as one additional player is substituted. We conclude that the negative net effect of increased coordination costs is stronger if substitutions are not planned and reflecting a reaction to the opposing team's (timeout) behavior.

Table 7: Effect of substitutions on performance -
substitutions during timeouts called by the opposing team only

Dep. var.:	**point difference**	**win period**	**lead after period**
substitutions at opponent's timeout	-1.189*** (0.248)	-0.113*** (0.030)	-0.040** (0.019)
additional controls	*yes*	*yes*	*yes*
team-game FEs	*yes*	*yes*	*yes*
time period FEs	*yes*	*yes*	*yes*
first-stage coefficient		-0.033*** (0.002)	
F stat.		205.504	
N		287,130	

Notes: Robust standard errors clustered on the team-game level in round parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent level. All three specifications include team-game and time-period fixed-effects. [a] The variable substitutions measures the number of players involved in substitutions during the game. Only substitutions during timeouts initiated by the opposing team are counted. [b] Kleibergen–Paap F-statistic (Kleibergen and Paap, 2006); the null hypothesis is that the instrument is weak.

4.5. Non-linearities

It might be the case that the number of substitutions does not affect productivity in a linear way. To account for potential non-linear effects, we firstly construct two binary variables measuring different degrees of substitution intensity. Our baseline approach uses a variable which is equal to 1 if any substitutions can be observed and 0 if they cannot (columns (1) and (4) in Table 8). Secondly, we measure the extensive margin of substitutions by constructing a binary variable which equals 1 if the number of substitutions is in the interval [2,6] and 0 if no substitutions can be observed (columns (2) and (5)). In other words, we estimate the effect of a moderate compared to a zero level of substitutions on performance. Finally, we use a binary variable which is equal to 1 if more than 6 players are substituted in or out, and 0 if no substitution occurs (columns (3) and (6)). The results are presented in Table 8.

Table 8 shows a significant negative effect of any substitutions on the score difference (from team i's perspective) for the full and the restricted sample without periods immediately following a break. Note that we cannot trust the estimate in the 'none vs. moderate substitutions' case for the full sample (column (2)), because our instrument is weak (F-statistic < 10). However, in the restricted sample, our instrument is sufficiently strong and we estimate that the point difference in any period k will deteriorate by about 7 points (column (5)). Comparing extensive substitutions to none, we estimate that substitution extensively results in a negative performance effect of -5 in the point difference of the observed time interval (column (3), $\hat{\beta}_1 = -4$ in the restricted sample (column (6)).

From these results we conclude that performance is a concave function of substitutions.

Table 8: Non-linear effect of substitutions on performance[a]

	full sample			*without periods following a break*		
	(1)	(2)	(3)	(4)	(5)	(6)
none vs. any substitutions[a]	-11.992*** (3.506)			-6.140*** (1.163)		
none vs. moderate substitutions[b]		-20.494** (9.346)			-7.383*** (1.617)	
none vs. extensive substitutions[c]			-5.127*** (1.087)			-4.036*** (0.796)
additional controls	*yes*	*yes*	*yes*	*yes*	*yes*	*yes*
team-game FEs	*yes*	*yes*	*yes*	*yes*	*yes*	*yes*
time period FEs	*yes*	*yes*	*yes*	*yes*	*yes*	*yes*
F stat.[d]	16.785	5.269	116.953	90.835	51.058	156.943
N	287,130	266,663	116,723	153,136	138,579	45,426

Robust standard errors clustered on the team-game level in round parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent level. All three specifications include team-game and time-period fixed-effects. [d] Kleibergen–Paap F-statistic (Kleibergen and Paap, 2006) ; the null hypothesis is that the instrument is weak.

[a] Binary variable = 1 if observed team does substitute in observed period k, 0 else.

[b] Binary variable = 1 if team has 6 players involved in substitutions in observed period k, 0 else.

[c] Binary variable = 1 if team has more than 6 players involved in substitutions in observed period k, 0 else.

4.6. Heterogeneous effects across teams

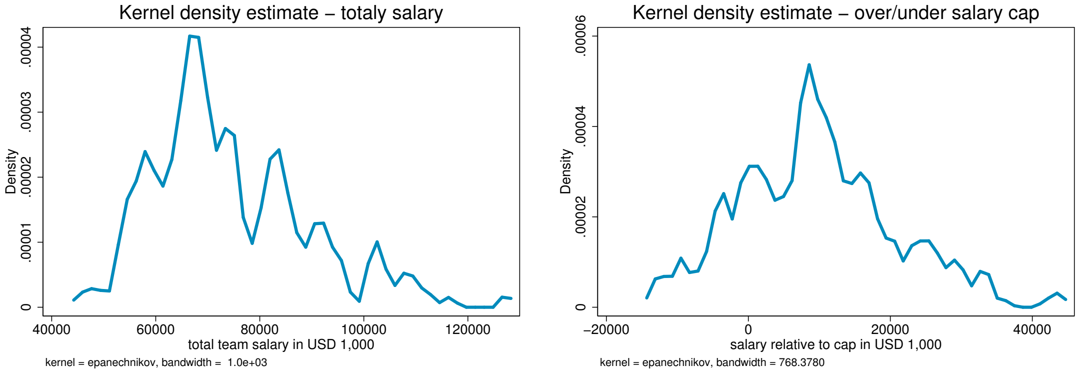
The analysis so far has provided evidence of a robust negative overall effect on performance by the number of team members and substitutions involved in the actual task. Hence, it appears that, on balance, the increase in coordination costs outweigh the reduction in fatigue. In response to our conceptual framework presented in Section 2 we ask: Does this mean that all teams systematically underestimate the coordination costs compared to the fatigue effects? Or do some teams adjust better than others, and if so, does it result in better long-term performances?

NBA players resemble standard employees in many aspects. They receive a salary, they sign employment contracts with teams and they can change employers and join other teams. Any team–just like a particular firm–has to decide how much to invest in costly human capital to maximise team productivity. A higher team salary will be positively correlated with higher overall potential productivity. It remains unclear, however, whether greater financial commitment mitigates or even erases the negative and dominant coordination cost effect proven in the preceding analysis. To address this issue, we collected salary data for all NBA teams in the 2009/10 to 2016/17 seasons.[10] Total salaries in the NBA are regulated by a soft salary cap, which resembles a non-strictly binding restriction on a team's salary. Figure 5 illustrates the distribution of annual team salaries as well as the difference for each team-season relative to the annual salary cap. On average, teams in our data spent USD 74.3 million, with an average of USD 9.6 million over the NBA salary cap.

Next, we split our pooled sample into the teams below and above the median total salary to assess whether the overall team salary or a team's positioning relative to the salary cap has an effect on how teams manage the trade-off between the fatigue effect and the coordination costs of substitutions. Columns (1) and (2) of Table 9 present these estimates. We estimate that teams with salaries above the median have a slightly lower negative effect of substitutions on productivity. Yet, the net effect of substitutions is still negative.

[10] Salary data is provided at at team-player-year level https://www.basketball-reference.com.

Figure 5: Team salary distributions



Notes: Total salaries and salary relative (over/under) the NBA salary cap for all teams and seasons in our data. Source: https://www.basketball-reference.com

Another important aspect is the salary (or ability) dispersion within teams. Consequently, we split the sample along the median of the team-season standard deviation of player salaries. The results are tabulated in columns (3) and (4) of Table 9. Although more even teams are estimated to have a smaller effect, we find a negative effect of team members contributing for both types of teams. Similarly, we estimate a negative effect of substitutions on productivity for teams below and above the median distance to the NBA salary cap (columns (5) and (6)).

While salaries are an important variable for explaining performance in professional sports, it is not a perfect predictor (e.g., Hinton and Sun, 2019). In basketball, teams play the regular season games with the clear intention of reaching the playoffs and consequently of having a chance to win the title. Therefore, intermediate standings later in the season work as a better predictor of final success. Figure 6 illustrates win-ratios per month in the regular season. The figure indicates that almost no team was able to reach the playoff tournament with a winning percentage below 0.4 in the months of December to April. On the contrary, every team with a winning percentage above 0.6 during the same period was almost certain to earn a playoff spot.

Next, we split the overall sample into three sub-samples to investigate how playoff chances affect the impact substitutions have on performance: (1) sure to get in, (2) uncertain and (3) out of contention. The results are presented in Table 10. Firstly, there is a very large and significant effect for those teams that are already left with no chance

Table 9: Effect of substitutions on performance - by financial commitment

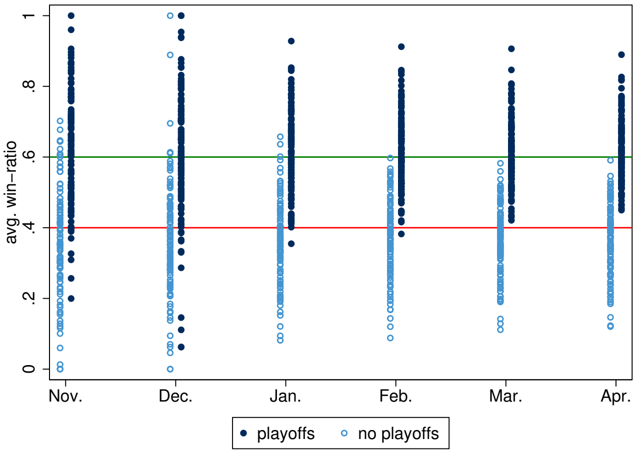
	total salary		*above/below cap*		*std. dev. total salary*	
	< median	**> median**	**< median**	**> median**	**< median**	**> median**
subs.[a]	-0.7217***	-0.4299**	-0.8077***	-0.3861*	-0.8181***	-0.3802**
	(0.1612)	(0.1775)	(0.1629)	(0.1828)	(0.1753)	(0.1656)
additional controls	*yes*	*yes*	*yes*	*yes*	*yes*	*yes*
team-game FEs	*yes*	*yes*	*yes*	*yes*	*yes*	*yes*
time period FEs	*yes*	*yes*	*yes*	*yes*	*yes*	*yes*
first stage coefficient	-0.0691***	-0.0608***	-0.0699***	-0.0584***	-0.0648***	-0.0646***
	(0.0070)	(0.0068)	(0.0069)	(0.0069)	(0.0069)	(0.0069)
F stat.[b]	96.2828	80.1817	101.9475	71.8371	87.5618	88.1440
mean subs.	2.7184	2.7700	2.7570	2.7313	2.7030	2.7857
N	143,610	143,520	143,940	143,190	144,165	142,965

Notes: The dependent variable is the score difference in the observed time interval k during the game (observed team - opposing team). Robust standard errors clustered on the team-game level in round parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent level. All three specifications include team-game and time-period fixed-effects. Coefficients for additional control variables are not reported due to space constraints. [a] The variable substitutions measures the number of players involved in substitutions during the game. Each substitution involves a minimum of two players. [b] Kleibergen–Paap F-statistic (Kleibergen and Paap, 2006); the null hypothesis is that the instrument is weak.

of getting into the play-offs. We estimate that an additional substitution decreases their point difference compared to the opposing team in period k by 0.6 points. Secondly, teams that are still in the hunt also suffer from a significant but smaller negative effect on performance by substitutions. Their score difference deteriorates by about 0.2 points as a result of substitution. Finally, for teams who have already as good as qualified, we do not measure a significant causal effect, however. All three estimations yield strong F-statistics on the exclusion restriction.

Note that we cannot rule out strategic behaviour like reactions to adverse incentives of the draft system (Taylor and Trogdon, 2002), which might explain the strong negative effect for the group of low performers. However, the fact that the group of high performers also faces incentives to conserve resources for the play-offs (e.g. Harbaugh and Klumpp, 2005) and that the first-stage estimators are of a similar size suggests that this argument is not very convincing. On the contrary, first-stage estimates help to resolve the chicken or egg causality dilemma. Better teams do not react less sensitively to opponent-induced changes, but are able to better cope with the resulting coordination costs. This is supported by the fact that better teams who are certain to qualify for the playoff tournament do not–on average–substitute less than teams that perform badly and are certain to miss the play-offs.

Figure 6: Win ratios per month in the regular season - 2009/10 to 2016/17



Notes: Number of wins over total games played by team and month for all 2009/10 to 2016/17 seasons. All solid markers represent teams who reached the playoff tournament in the observed season. All hollow markers denote teams who missed the play-offs. The solid green line indicates the threshold of winning 60% of all games. The solid red marks the lower threshold of 40% of all games won.

Table 10: Effect of substitutions on performance - by playoff outlook

	no chance	**in the hunt**	**qualified**
substitutions[a]	-1.1607***	-0.4115*	-0.0365
	(0.3862)	(0.2309)	(0.2863)
additional controls	*yes*	*yes*	*yes*
team-game FEs	*yes*	*yes*	*yes*
time period FEs	*yes*	*yes*	*yes*
first stage coefficient	-0.0528***	-0.0651***	-0.0770***
	(0.0114)	(0.0094)	(0.0140)
F stat.[b]	21.3617	47.6688	30.1484
mean subs	2.6393	2.7217	2.7456
N	52,110	74,595	34,650

Notes: Robust standard errors clustered on the team-game level in round parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent level. All three specifications include team-game and time-period fixed-effects. Coefficients for additional control variables are not reported due to space constraints. [a] The variable substitutions measures the number of players involved in substitutions during the game. Each substitution involves a minimum of two players. [b] Kleibergen–Paap F-statistic (Kleibergen and Paap, 2006); the null hypothesis is that the instrument is weak.

5. Robustness checks

In this section we provide a series of thorough robustness checks for our main results presented above. Particular emphasis was placed on the robustness of our causal identification strategy. As discussed, our identification strategy relied on estimating the LATE conditional on controlling for a set of control variables. To avoid strict assumptions about the functional form as well as the problem of dimensionality, we employ the nonparametric IV estimation method to obtain estimates for the LATE.

Following Frölich (2007), we estimated

$$\hat{\beta}_1^{np} = \frac{\sum_{p:Z_p^{bin}=1}(Y_p - \hat{m}_0(X_p)) - \sum_{p:Z_p^{bin}=0}(Y_p - \hat{m}_1(X_p))}{\sum_{p:Z_p^{bin}=1}(S_p - \hat{\mu}_0(X_p)) - \sum_{p:Z_p^{bin}=0}(S_p - \hat{\mu}_1(X_p))}, \tag{4}$$

where, for notational simplicity, subscript p indicates a combination of team-season i, game t, and time period k. Thus, Y_p measures the performance of a team i in game t and time period k. The variable S_p measures all substitutions in absolute terms by team i in game t and time period k. X_p is a vector of control variables. Z_p^{bin} is an alternative binary instrument and is equal to 1 if the opposing team made a substitution at least once in period $(k-1)$, but 0 otherwise. The $\hat{m}_z(x)$ and $\hat{\mu}_z(x)$ are nonparametric estimators of the conditional mean functions $m_z(x) = E[Y|X = x, Z = z]$ and $\mu_z(x) = E[P|X = x, Z = z]$.

The results from our non-parametric LATE estimations are presented in Table 11. The estimates for the pooled sample suggest a negative effect on performance of -0.672 points in the point difference for the observed period k of a substituted player. This confirms our main results presented above (-0.502, Table 3). The negative effect is again slightly smaller (-0.456) for a restricted sample without periods immediately following a break. In addition, nonparametric LATE estimates confirm a stronger negative effect for the second halves of games. However, the nonparametric estimation procedure provides a more precise estimate of -0.941 compared to the -3.281 derived from 2SLS.

In the empirical analysis of Section 4 we rely on team-game fixed effects to control for unobserved heterogeneity at team-game level. To test the robustness of this approach, we use an alternative specification including team- as well as opponent-season fixed-effects. The results are presented in Table 12. They qualitatively confirm all of our main prior findings shown in Table 3.

Figure 3 illustrated the first-stage coefficients for all 2 to 16 time periods for all games in our sample. Notably, the coefficients for periods 2, 3 and 10 are negative and are significant at the 5-percent level. This may raise concerns about the monotonicity assumption of our instrumental variable strategy. For the pooled sample, we estimate a consistently negative effect from the opposing team's substitutions in *k-1* on the observed team's substitutions in *k*. Next, periods 2, 3 and 10 were excluded from the sample. The new estimates confirm the main results qualitatively and quantitatively, see Table 13.

Overall, we conclude that our main results presented in Section 4 are robust to the use of different model specifications, alternative sample definitions and estimation methods.

Table 11: Nonparametric LATE estimates (1)

		nonparametric LATE			
	2SLS	**pooled**	**without intro periods**	**1st half**	**2nd half**
substitutions[a]	-0.502*** (0.132)	-0.672*** (0.119)	-0.370*** (0.068)	-0.548*** (0.202)	-0.941*** (0.209)
F stat.[b]	140.663	-	-	-	-
N	287,130	287,130	153,136	133.994	133.994

Notes: Estimated effect of substitutions on productivity using the non-parametric LATE estimator proposed by Frölich (2007). The dependent variable is the score difference in the observed time interval k during the game (observed team - opposing team). *, **, and *** indicate statistical significance at the 10, 5, and 1-percent level. All specifications include the full set of control variables, as well as team-game and time-period fixed-effects. Both $E[Y|X,Z]$ and $E[M|X,Z]$ are estimated by local logit regressions, with a bandwidth=∞ and $\lambda = 1$. [a] The variable substitutions measures the number of players involved in substitutions during the game. Each substitution involves a minimum of two players. [b] Kleibergen–Paap F-statistic (Kleibergen and Paap, 2006); the null hypothesis is that the instrument is weak.

Table 12: Effect of substitutions on performance - ALTERNATIVE FIXED-EFFECTS (TEAM-SEASON)

Dep. var.:	**point difference**	**win period**	**lead after period**
substitutions[a]	-0.224***	-0.023**	0.016**
	(0.084)	(0.010)	(0.007)
additional controls	*yes*	*yes*	*yes*
team season FEs	*yes*	*yes*	*yes*
opponent season FEs	*yes*	*yes*	*yes*
month FEs	*yes*	*yes*	*yes*
time period FEs	*yes*	*yes*	*yes*
first-stage coefficient		-0.087*** (0.005)	
F stat.[b]		328.106	
N		287,130	

Notes: Robust standard errors clustered on the team-game level in round parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent level. [a] The variable substitutions measures the number of players involved in substitutions during the game. [b] Kleibergen–Paap F-statistic (Kleibergen and Paap, 2006); the null hypothesis is that the instrument is weak.

Table 13: Effect of substitutions on performance - REDUCED SAMPLE

Dep. var.:	**point difference**	**win period**	**lead after period**
substitutions[a]	-0.224***	-0.023**	0.016**
	(0.084)	(0.010)	(0.007)
additional controls	*yes*	*yes*	*yes*
team-game FEs	*yes*	*yes*	*yes*
time period FEs	*yes*	*yes*	*yes*
first-stage coefficient		-0.064*** (0.005)	
F stat.[b]		146.004	
N		229,704	

Notes: Sample excludes time periods$k$ = 2, 3 and 10. Robust standard errors clustered on the team-game level in round parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent level. [a] The variable substitutions measures the number of players involved in substitutions during the game. [b] Kleibergen–Paap F-statistic (Kleibergen and Paap, 2006); the null hypothesis is that the instrument is weak.

6. Conclusion

Flexible work arrangements have risen sharply in popularity over the past decades. While working more or less intensely in varying teams inevitably yields benefits, such as more effective workload management, it may also increase the costs of coordinating experts who are engaged in performing complementary and complex tasks.

Using data from an industry where performance is very sensitive to fatigue and coordination (professional basketball), our findings indicate that, on balance, increasing the number of collaborators negatively affects team productivity. For instance, we find that a marginal increase in the number of collaborators per period decreases the point difference by 0.6 to 0.8 points.

While recent studies (e.g. Brachet et al., 2012; Pencavel, 2014; Collewet and Sauermann, 2017) highlight the deteriorating effect of fatigue on performance, our results can be taken as complementary advice to carefully consider the other side of the issue. While increasing the number of team members engaged in a task means a relief from fatigue as it reduces individual effort costs, it also caries the burden of increasing coordination costs. If performance is sufficiently sensitive to coordination costs, the net effect might be negative. This is especially true when team managers systematically underestimate coordination costs compared to fatigue. Furthermore, our analysis provides evidence for heterogeneity in the ability to deal with the 'fatigue effect' and the 'coordination costs effect'. That is, the most successful teams optimally trade off both effects. In this sense, our results stress the importance of being able to cope with coordination costs for overall performance and for inter-industrial comparison.

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A. Additional Tables

Table A.1: Effect of total players moved on performance (sample without periods immediately following a break)

Dep. var.:	**point difference**	**win period**	**lead after period**
number of different players moved[a]	-0.551***	-0.055***	-0.033***
	(0.094)	(0.012)	(0.007)
additional controls	*yes*	*yes*	*yes*
team-game FEs	*yes*	*yes*	*yes*
time period FEs	*yes*	*yes*	*yes*
first-stage coefficient		-0.108***	
		(0.006)	
F stat.		343.554	
N		153.136	

Notes: Sample restricted to periods which were not following an intermission (quarter or half breaks). Robust standard errors clustered on the team-game level in round parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent level. All three specifications include team-game and time-period fixed-effects. [a] The variable *total players moved* measures the number of different players involved in substitutions during the game. Each substitution involves a minimum of two players. [b] Kleibergen–Paap F-statistic (Kleibergen and Paap, 2006); the null hypothesis is that the instrument is weak.

Table A.2: Effect of absolute number of substitutions on performance - by halves of games (sample without periods immediately following a break)

	1st half			*2nd half*		
Dep. var.:	**point diff.**	**win period**	**lead after period**	**point diff.**	**win period**	**lead after period**
subs.[a]	-0.638***	-0.069***	-0.045***	-1.452***	-0.122***	-0.073***
	(0.118)	(0.015)	(0.010)	(0.196)	(0.021)	(0.012)
team-game FEs	*yes*	*yes*	*yes*	*yes*	*yes*	*yes*
time period FEs	*yes*	*yes*	*yes*	*yes*	*yes*	*yes*
first-stage coef.		-0.133***			-0.108***	
		(0.009)			(0.012)	
F stat.[b]		239.319			83.762	
N		76,568			76.568	

Notes: Sample restricted to periods which were not following an intermission (quarter or half breaks). Robust standard errors clustered on the team-game level in round parentheses. *, ** and *** indicate statistical significance at the 10-percent level, 5-percent level, and 1-percent level. All three specifications include team-game and time-period fixed-effects. [a] The variable substitutions measures the number of players involved in substitutions during the game. [b] Kleibergen–Paap F-statistic (Kleibergen and Paap, 2006); the null hypothesis is that the instrument is weak.

Table A.3: Nonparametric LATE estimates (2)

		nonparametric LATE			
	2SLS	**pooled**	**without intro periods**	**1st half**	**2n half**
number of different players moved[a]	-0.596***	-0.814***	-0.439***	-0.605***	-1.301***
	(0.157)	(0.152)	(0.088)	(0.238)	(0.307)
F stat.[b]	139.741	-	-	-	-
N	287,130	287,130	153,136	133.994	133.994

Notes: Estimated effect of number of different players on productivity using the non-parametric LATE estimator proposed by Frölich (2007). *, **, and *** indicate statistical significance at the 10, 5, and 1-percent level. All specifications include the full set of control variables, as well as team-game and time-period fixed-effects. Both $E[Y|X,Z]$ and $E[M|X,Z]$ are estimated by local logit regressions, with a bandwidth=∞ and $\lambda = 1$. [a] The variable *total players moved* measures the number of different players involved in substitutions during the game. Each substitution involves a minimum of two players. [b] Kleibergen–Paap F-statistic (Kleibergen and Paap, 2006); the null hypothesis is that the instrument is weak.