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Abstract

This paper investigates physiological responses to perceptions of unfair pay. We use an integrated approach exploiting complementarities between controlled lab and representative panel data. In a simple principal-agent experiment agents produce revenue by working on a tedious task. Principals decide how this revenue is allocated between themselves and their agents. Throughout the experiment we record agents' heart rate variability, which is an indicator of stress-related impaired cardiac autonomic control, and which has been shown to predict coronary heart disease in the long-run. Our findings establish a link between unfair payment and heart rate variability. Building on these findings, we further test for potential adverse health effects of unfair pay using observational data from a large representative panel data set. Complementary to our experimental findings we show a strong and significant negative association between unfair pay and health outcomes, in particular cardiovascular health.

Keywords: Fairness, social preferences, inequality, heart rate variability, health, experiments, SOEP.

JEL-Codes: C91, D03, D63, I14

1 Introduction

A large and growing body of evidence suggests that fairness perceptions play an important role in labor relations, affecting work morale, effort provision and market efficiency (see, e.g., Fehr et al., 1993, 1997; Abeler et al., 2010; Charness and Kuhn, 2011; Kube et al., 2012; Cohn et al., forthcoming)[1]. Fairness considerations have also been shown to help reconciling evidence on non-standard effects of minimum wages (Katz and Krueger, 1992; Card, 1995; Falk et al., 2006). While this work has studied behavioral effects, the present paper provides evidence on adverse effects of unfair pay at the physiological level. In particular, we investigate the potential impact of unfair pay on stress and adverse health outcomes.

To test for the potential link between wage related fairness perceptions, stress and health, we use an integrated approach, combining lab and field data to exploit complementarities of different data sources. We proceed in two steps. First, we report controlled lab evidence to test the hypothesis that unfairness perceptions have a negative effect on heart rate variability (HRV). HRV is the most important outcome measure in the analysis of stress at the workplace (for an overview see Jarczok et al. (2013))[2]. Among other functions, low HRV is a stress related early indicator of functional and structural impairments of the cardiovascular system, which increases the probability of future manifest coronary heart disease (see, e.g., Dekker et al., 2000; Steptoe and Marmot, 2002; Gianaros et al., 2005). Second, we analyze observational data from a large representative panel data set to study whether our findings from the lab extend to the general population and the labor market, in the sense that perception of unfair pay is related to (specific) health outcomes.

The lab experiment implements an employer-employee relation in form of a simple principal-agent framework. The agent produces revenue by working on a tedious task and the principal decides how to allocate it between the agent and himself. This set-up randomly implements various degrees of unfair pay, where the source of variation is the heterogeneity in generosity of the principals, who are randomly assigned to agents. The experimental set-up allows us to precisely measure physiological responses in terms of HRV. Low heart rate variability is observed during states of mental stress while enhanced heart rate variability occurs during states of

[1]For an overview and related studies, see Fehr and Gaechter (2000). The above-cited experimental work is complemented by interview studies with personnel managers (see, e.g., Agell and Lundborg, 1995; Bewley, 1999, 2005). Akerlof (1982) provides an early theoretical analysis of fairness and labor market efficiency.

[2]For a recent application in experimental economics see Dulleck et al. (2014).

mental relaxation.[3] Therefore, our hypothesis to be tested is an inverse relationship between the degree of unfair pay and agent's HRV. Our results confirm this hypothesis and suggest that unfair pay bears the potential to result in cardiovascular diseases in the long-run.

In a second step, we investigate whether the observed physiological reaction translates into impaired health in the field. Specifically, we test the hypothesis of an adverse health effect of unfair pay using data from the German Socio Economic Panel (SOEP), a large panel data set that is representative for the adult German population (Wagner et al., 2007). We apply an estimation strategy proposed by Angrist and Pischke (2009) consisting of fixed effects and lagged dependent variable estimation approaches as well as the bracketing property of these two approaches. We find a robust, strong and significant association between perceptions of unfair pay and lower subjective general health status.

In light of our lab findings we further hypothesized that adverse health effects should be specific to diseases related to the cardiovascular system, such as coronary heart disease (Steptoe and Kivimäki, 2012). Testing for an effect on specific health outcomes is possible as the SOEP not only elicits subjective responses to general health outcomes but also with respect to specific diseases. Confirming our hypothesis, we find that perceptions of unfair pay are in fact selectively related to heart disease. In contrast, and in line with the epidemiological literature, no such relation is observed for diseases which are mostly unrelated to the cardiovascular system as, e.g., cancer (Heikkilä et al., 2013). These results are also confirmed in a so-called dose-response analysis that takes the frequency of unfairness perceptions into account.

Our findings establish a link between unfair pay and coronary heart disease suggesting that on top of behavioral consequences reported in previous work, perceptions of unfair pay can have important negative physiological consequences with possible welfare implications: The global public health and economic burden of cardiovascular disease is immense. Coronary heart disease, along with major depression, is estimated to be the leading cause of life years lost to premature death and years lived with disability worldwide (Lopez et al., 2006). Moreover, among adult populations of high income countries, coronary heart disease is the leading cause of death, and cost of illness studies estimate that almost one percent of the gross national product is attributable to the direct and indirect costs of coronary heart disease (Liu et al., 2002). On an organizational level our findings suggest that fair pay does not only contribute to higher work moral and motivation, but also to a

[3] For details and references, see Section 2.2.

better health status of employees. In this sense our findings suggest important efficiency consequences of fair wages, additional to efficiency wage arguments (Akerlof, 1982).

The remainder of the paper is organized as follows. In the next section we present our experimental design and results. Section 3 reports results regarding the representative panel data. Section 4 concludes.

2 An experiment to study physiological responses to unfair pay

Unfairness in employer-employee relations can occur if effort of an employee is not adequately rewarded by the employer. We take this idea to our experiment and measure employees' physiological reactions in response to unfair pay. Given the heterogeneity in employer's generosity and the fact that employers and employees are randomly matched, fairness of pay varies, and is randomly assigned.

2.1 Design and procedure

In the experiment we implemented a simple principal-agent framework which means that participants were situated in an employer-employee relationship. Upon arrival to the lab, subjects were randomly assigned to the role of agent (i.e., employee) or principal (i.e., employer) and randomly matched into pairs consisting of one agent and one principal. The interaction was completely anonymous, i.e., at no point subjects learned about the identity of their partner. Subjects received all instructions via computer screen.[4]

Before the experiment started HRV recording devices were attached to the agents' arms. Agents then received a pile of numbered sheets. On each sheet there was a table containing a large number of zeros and ones. The work task was to count the correct number of zeros on a given sheet and to enter this number on a computer screen. Total working time was 25 minutes. Each correctly entered number of zeros per sheet created revenue of three Euros. If the entered number was "almost" correct (deviation of plus/minus 1 with respect to the correct number) revenue was one Euro. The accumulated revenue was continuously shown to agents on the screen. Agents were explicitly told that they could complete as many sheets as they wanted to, including completing no sheet at all. Principals were informed that agents cre-

[4]We used z-Tree as computer software (Fischbacher, 2007). Instructions are shown in the Appendix.

ated revenue by working on a task. They were not aware of the specific task and the payment structure, nor did they have any information concerning the relative performance of their agent. Principals did not work and were told that they were free to do things like reading newspapers or completing class-work.

After completion of the 25 minute working time, each principal was informed about the accumulated revenue, and was asked to allocate it between himself and the agent. Starting with the revelation of the allocation, the agent was given a time window of 15 minutes to cope with this information which enables us to analyze medium-run lasting physiological effects.

Subjects were male students from the University of Bonn studying various majors except economics. They gave their informed consent to participate in the experiment. Exclusion criteria for the agents were the use of medication with potential interference with cardiovascular function or the presence of a chronic disease condition, such as hypertension, cardiac arrhythmias, coronary heart disease, or diabetes. In total 80 subjects participated in the experiment (five sessions of 16 subjects, 40 principals and 40 agents). Due to incorrectly attached measurement devices we could not record HRV for six subjects. Four further subjects showed abnormal values or indicated a cardiovascular disease after participation. The main analysis is thus based on 30 subjects in the role of agents with complete and valid data. Importantly, the 10 subjects who were excluded were not different from the other subjects, neither in terms of working behavior nor treatment by their principals (see Footnote 9). Further, we show that our results do not change much if we include all available observations.

2.2 Measures

HRV measures. As physiological measure of agents' autonomic nervous system activity we use heart rate variability (HRV)[5]. HRV is an established marker of stress-

[5] At the beginning of the experiment a polar F810i device (polar electro OY, Kempele, Finland) was attached to record and store time intervals between consecutive heart beats (inter-beat-interval, IBI). Agents were instructed to remain seated during the whole experiment and try to restrict all movements, with the exception of their dominant arm operating the computer. The target time window for physiological recordings lasted five minutes. Data were transmitted to a PC, stored, and analyzed offline by a researcher who was blind to the psychological outcome measures. After visualizing and manually correcting data for artefacts a smoothness priors method was used to remove trends of the IBI time series. Then, a HR time series was derived and the following time-domain based HRV indices were calculated: SD-IBI (standard deviation of the IBI series), SD-HR (standard deviation of the HR series), and RMSSD-IBI (root mean square of successive differences of the IBI series) (Niskanen et al., 2004). The RMSSD-IBI represents a sensitive index of parasympathetically-dominated, respiratory related, fast fluctuations of HR, and can be calculated with milliseconds precision. It is considered to accurately index resting vagal tone directed

related activation of the autonomic nervous system (Task Force, 1996; Steptoe and Marmot, 2002). HRV reflects the continuous interaction of sympathetic and vagal influence on heart rate, indicating an individual's capacity to generate regulated physiological responses to demanding situations (Appelhans and Luecken, 2006). Low HRV mirrors a decreased vagal tone with sympathetic predominance and is observed, among others, during states of mental stress (von Borell et al., 2007). Conversely, enhanced HRV occurs during states of mental relaxation (Vermunt and Steensma, 2003). Regarding emotions there is a consistent association of negative emotions such as anger and anxiety with reduced HRV whereas positive emotions such as amusement and joy are associated with increased HRV (Kreibig, 2010). Low HRV is an early indicator of functional and structural impairments of the cardiovascular system, which increases the probability of future manifest coronary heart disease (Dekker et al., 2000; Steptoe and Marmot, 2002; Gianaros et al., 2005).

In the analysis we use two measures of HRV elicited at two different points in time. The first one serves as a baseline measure (HRV_baseline) and was measured towards the end of the working period but prior to the revelation of the allocation decision. The second one was taken 15 minutes after exposure to the stimulus, i.e., the revelation of the principal's allocation decision. It records the medium-run response of the autonomic nervous system to the stimulus, and is our outcome of interest (HRV_response).[6] In the analysis, we use the difference HRV_response - HRV_baseline as dependent variable. In the presence of a relatively small sample and an outcome variable with high between-subject and low within-subject variation, using the difference instead of only the post treatment measure (HRV_response) serves two purposes: It corrects for potential baseline level imbalances and enhances the power of the statistical test.[7]

Degree of unfairness measure. Any model of fairness has at least two components, the outcome of an action, such as a wage payment, and a reference standard against which the outcome is evaluated (compare, e.g., Fehr and Schmidt (1999), Charness and Rabin (2002) or Falk and Fischbacher (2006)). In our experiment

to the heart and was documented to be rather resistant to the biasing effects of breathing (Penttilae et al., 2001). As SD-IBI and SD-HR are highly correlated with RMSSD-IBI we restrict the presentation of findings to RMSSD-IBI, as a robust and well validated time-domain based indicator of parasympathetic cardiac control. All calculations were done with a computer program for advanced HRV analysis (Niskanen et al., 2004).

[6]This procedure is in line with Brosschot and Thayer (2003) who show that especially negative emotions are related to a relatively long lasting heart rate response.

[7]For a comparison of difference-in-differences and mean comparison approaches see McKenzie (2012). Given a pre- and post-treatment correlation of $r > 0.5$, the diff-in-diff approach has more statistical power.

the outcome is simply the principal's payment to the agent. In order to determine the fairness of a particular payment, this payment needs to be compared with a reference standard, i.e., a payment that is considered fair. A natural reference standard, often assumed in interpreting experimental results and modeled, e.g., in Fehr and Schmidt (1999) or Falk and Fischbacher (2006), is equality in payoffs. Note, however, that using equal payoffs would neglect the agents' effort costs necessary to produce revenue. Applying an equal share as reference standard would therefore require an assessment of effort costs, which is notoriously difficult in real-effort tasks such as ours. Instead of using equal payoffs, arbitrarily adjusted for effort costs, we construct a measure called "objectively fair pay" to determine the relevant reference standard and the resulting degree unfairness.

The "objectively fair pay" was obtained from a survey study with 45 additional male students from the University of Bonn who did not take part in the experiment before. These subjects received a detailed description of the experimental setting including information about the payment structure and an example of the counting-zero-task. After being fully aware of the decision context they were asked: "Imagine the employee produced revenue of X Euro. In your opinion, what would be a fair and appropriate allocation of the money?" Subjects rated respectively five randomly chosen amounts of actually produced revenues, which were presented in random order. Thus, for every amount of revenue produced in the experiment we have on average more than 10 assessments of uninvolved third parties about what is considered a "fair and appropriate" pay. For each produced revenue we take the mean amount as an objective measure of fair pay, i.e., the reference standard.

Most fairness models determine the degree of fairness as the difference between outcome and reference standard (e.g., Fehr and Schmidt (1999)). Accordingly, our "degree of unfairness" measure is the difference between an agent's actual pay and the objective reference standard.[8] Importantly, due to the random matching of principals to agents, and the natural heterogeneity in generosity among principals, our experiment implements a random assignment of the degree of unfairness. Figure A1 indicates that the degree of unfairness is unrelated to the revenue produced by the agent (Pearson's $r = 0.033, p = 0.861, N = 30$).

[8]Our degree of unfairness measure correlates well with agents' own assessment of unfair pay: After the revelation of the principal's payment decision, agents answered a short survey on perceived fairness of the received payment. We asked them: "In your view, how fair was the return you received from your principal?". This question uses a similar wording as the item that we use in the panel data analysis. Answers were given on a 5-point Likert scale. The correlation between the assigned degree of unfairness and the subjectively perceived unfairness is sizable and highly significant (Pearson's $r = 0.552, p < 0.01, N = 30$).

2.3 Results from the experiment

Table 1 reports means and standard deviations of our main variables.[9] On average agents produced a revenue of 20.93 Euro and received a pay of 9.53 Euro. The actual pay sharply contrasts with the pay considered as objectively fair: The amounts differ on average by 4.10 Euro and no agent received more than the objectively fair amount. Moreover, there is a substantial variation in fairness violations, a prerequisite for the analysis of the effect of fairness perceptions on HRV.

Variable	**Mean**	**Std. Dev.**
Revenue produced by agents (in Euro)	20.93	8.57
Objectively fair pay (in Euro)	13.64	5.32
Actual pay (in Euro)	9.53	5.58
Objectively fair - actual pay (in Euro)	4.10	2.28

Table 1: Descriptive statistics. $N = 30$; the difference between objectively fair and agent's actual pay is our measure of the degree of unfairness.

As discussed above, the dependent variable in the analysis is the difference between HRV_response (measured 15 minutes after exposure to the unfairness stimuli) and HRV_baseline (measured before the allocation was revealed). Since the variation in the degree of fairness violation stems from the heterogeneity in generosity among randomly matched principals, the analysis of the results is straightforward. In column 1 of Table 1, we regress the standardized difference HRV_response - HRV_baseline on the standardized degree of unfairness. The results indicate a significant negative effect of the degree of unfairness on HRV ($p < 0.05$). In column 2 we confirm the result by controlling for generated revenue by the agent. In Table A1 we show results regarding the same specifications but include all available observations, including those with potentially defective HRV measures. The results are virtually unchanged. The analysis indicates that HRV reacts negatively towards being treated in a more unfair way, i.e., fairness systematically affects the autonomic nervous system.

[9] Table 1 reports data for the 30 subjects with complete and valid heart rate measures. Subjects with incomplete or invalid measures were not different in any systematic way. Kruskal-Wallis rank tests do not reject the null hypotheses that both groups are drawn from the same population for all variables reported in Table 1 (p-values are between 0.522 and 0.938).

	Standardized (HRV_response - HRV_baseline)	
	(1)	(2)
Standardized degree of unfairness	-0.317**	-0.310**
	[0.149]	[0.150]
Generated revenue		-0.025
		[0.021]
Constant	0.000	0.526
	[0.176]	[0.465]
Observations	30	30
Adjusted R-squared	0.068	0.084

Table 2: Regression analysis on the effect of fairness violation on HRV. OLS estimates with robust standard errors in brackets. The dependent variables is the difference between HRV_response (measured 15 min after exposure to the unfairness stimuli) and HRV_baseline (measured before the allocation was revealed). The degree of unfairness measure is the difference between the objectively fair pay, rated by uninvolved third parties, and the actual pay assigned by the principal. ***, **, * indicate significance at 1-, 5-, and 10-percent level, respectively.

3 Unfair pay and health: representative field data

Our experimental data show medium-run (15 min) reduced HRV, a marker of stress-related activation of the autonomic nervous system, in response to unfair pay. In the long-run, reduced HRV has been shown to be a risk factor of coronary heart disease (Tsuji et al., 1996; Xhyheri et al., 2012; Hillebrand et al., 2013). In combination, these findings suggest that perception of unfair wages might lead to actual diseases in the long-run. Hence, we would expect that if perceptions of unfair pay constitute a chronic source of stress, unfair pay should be negatively related to employees' general health status and in particular to cardiovascular diseases. For an overview on the potential physiological channels see Steptoe and Kivimäki (2012).

In the following we investigate this issue in the context of the German labor market using data from the German Socio-Economic Panel (SOEP). In this data we cannot exploit a randomized treatment variation. Instead, we use two different panel data estimation techniques.

3.1 Sample and data description

The SOEP is a representative panel survey of the adult population living in Germany. All household members above age 17 are interviewed on a wide range of individual and household information and their attitudes on assorted topics.[10] Interviews are conducted on a yearly basis, but not all items we use have been elicited in each wave. Information on individuals' labor market status, including wages are recorded in every wave, and in the years 2005, 2007, 2009, 2011 and 2013, respectively, employed participants were additionally asked if they perceive their income as fair. The question reads as follows: "Do you consider the income that you get at your current job as fair?", with the possible answers "yes" or "no". This constitutes our "unfair wage" measure in the analyses of the SOEP data. About 37% of the employees in the pooled sample stated that they consider their wage as unfair.

The data set also contains items about health status, in particular about subjective health status in general and whether various diseases have been diagnosed in the past. The question about subjective health status is included in each wave and reads as: "How would you describe your current health status?" Responses are given on a 5-point scale ranging from "very good" to "bad". For the analysis, the variable "subjective health status" was coded in a way that higher values indicate better health. For the pooled sample the mean is 3.53 (standard deviation is 0.84). While subjective health indicators have their limitations, previous research in health economics suggests that responses to subjective health status questions predict health impairments and mortality.[11]

For the years 2009, 2011 and 2013, respectively, more objective and specific measures can be constructed from answers to the question whether a physician has "ever diagnosed" a particular disease, mentioned in a list presented to participants. Analyzing responses to this question is particularly informative as it allows a more precise test of our hypothesis: Since impaired cardiac autonomic control, as indicated by low HRV, is of particular significance for cardiovascular health (Steptoe and Kivimäki, 2012) we hypothesized that perceptions of unfair pay predict heart disease, rather than diseases such as cancer or asthma which are mostly unrelated to the cardiovascular system (Heikkilä et al., 2013). Finding selective associations would suggest that unfair pay affect health through stress-related mechanisms akin to what we find in our lab data.[12]

Our hypothesis of an adverse relation between the perception of unfair pay and health draws on the premise that the individual cannot choose his compensation

[10]For more details on the SOEP, see www.diw.de/gsoep/ and Wagner et al. (2007), SOEP v30 was used.

[11]For a comprehensive discussion of the literature, measurement issues, reporting biases and effects on labor market outcomes, see Currie and Madrian (1999). They discuss potential limitations of subjective health measures but also point out that self-reported measures are good indicators of health as they are highly correlated with medically determined health status.

[12]We thank Janet Currie for suggesting testing for selective associations.

himself and that the employment is of certain relevance for the individual. Therefore, we restrict our sample to full- and part-time dependent employees with positive income.

3.2 Estimation strategy

In the absence of randomized treatment variation, the two major concerns regarding the causal interpretation of the potential empirical relation between health status and unfair pay are (time-invariant) omitted variables and reverse causality in the sense that the perception of unfair pay might be influenced by past health status. For instance, unobserved dispositional stress might drive the perception of unfair pay and health outcomes simultaneously, or wages might be perceived as unfair when one is in bad health and has to pay for medical expenditures.[13]

As suggested by Angrist and Pischke (2009) we tackle both concerns separately by using two different panel data approaches. We will use the bracketing property of the two approaches to interpret the results. To estimate the effect of unfair pay on health in the presence of unobserved individual heterogeneities, we implement the following fixed effects model:

$$H_{it} = \alpha_i + \lambda_t d_t + \rho U_{it} + X'_{it}\beta + u_{it} \qquad (1)$$

where H_{it} is the health status of individual i in period t ($i = 1, \ldots, N; t = 1, \ldots T$), α_i is the individual fixed effect, d_t are year dummies and U_{it} is a dummy indicating if an individual perceives his wage as unfair. X_{it} is a vector of time-varying covariates as, e.g., income and age. u_{it} is the idiosyncratic error. This model can also be interpreted as a differences-in-differences (DD) model. Just consider U_{it} as the interaction of a time dummy and a treatment group identifier.

To tackle the reverse causality issue and to estimate the effect of unfair pay on health conditional on time-varying past health status, we implement the following lagged dependent variable model:

$$H_{it} = \alpha + \theta H_{it-1} + \lambda_t d_t + \rho U_{it} + X'_{it}\beta + u_{it} \qquad (2)$$

As demonstrated by Angrist and Pischke (2009), these fixed effects and lagged dependent variable approaches have a useful bracketing property.[14] If one of the two

[13] We thank an anonymous referee for pointing us to these examples.

[14] Form a theoretical point of view it might be useful to combine the fixed effects and the lagged dependent variable approaches. However, the conditions for consistently estimating the effect of interest in such a combined model are much more demanding than those required for separately

models, no matter which one, captures the true data generating process, then the true treatment effect lies in between the two estimated treatment coefficients. One can therefore interpret fixed effects and lagged dependent variables as "bounding the causal effect of interest" (Angrist and Pischke, 2009: 246).

3.3 Panel data results

In the following, we present estimation results based on the models described in equations (1) and (2). We use subjective health status as well as specific diagnosed diseases as dependent variable. Coefficients regarding (1) are fixed effects estimates, coefficients regarding (2) are OLS estimates. We cluster standard errors on the individual level. As described above, we respectively control for income and age (time-varying controls) and include dummies indicating the year of data collection.

In a first step we explore the effects of the perception of unfair pay on subjective health status. The data structure of the SOEP allows us to estimate the models for five waves (2005, 2007, 2009, 2011 and 2013). Column (1) displays the results regarding the individual fixed effects model and column (2) shows the results of the lagged dependent variable model. Both models indicate highly significantly negative effects of unfair wage on subjective health status. Applying the bracketing property of the two models, we estimate a negative effect of unfair wage on subjective health status of between 0.051 and 0.097 points. The effect is sizable: It is equivalent to an increase in age between 2.5 and 10 years and exceeds the effects of a 1000-Euro-decrease in monthly net wage.

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estimating fixed effects and lagged dependent variable models, see Nickell (1981).

Dependent variable: subjective health status (higher values indicate better health)		
Estimation approach:	Fixed effects	Lagged dependent variable
	(1)	(2)
Unfair wage	-0.051***	-0.097***
	[0.011]	[0.008]
Lagged health status		0.541***
		[0.005]
Net wage/1000	0.037***	0.028***
	[0.010]	[0.004]
Age	-0.019***	-0.010***
	[0.005]	[0.0004]
Individual fixed effects	yes	no
Year dummies	yes	yes
Observations	39,314	39,314
Individuals	15,247	15,247
(Overall) R-squared	0.072	0.348

Table 3: Relation between subjective health status and unfairness perception (SOEP). Column (1) shows FE estimates, column (2) shows OLS estimates, respectively with standard errors clustered at the individual level in brackets. The dependent variable measures subjective health status on a 5-point scale ("bad" to "very good"). "Unfair wage" is a dummy being one if the respondent answered the question "Do you consider the income that you get at your current job as fair?" with "no" and zero otherwise. The sample includes full- and part-time dependent employees. For comparison the sample in column (1) is restricted to cover the same sample as column (2). ***, **, * indicate significance at the 1-, 5-, and 10-percent level, respectively.

We now move on to the analysis of specific diseases. Table 4 summarizes estimation results for eight specific diseases listed in the SOEP survey in 2009, 2011 and 2013.[15] As in Table 3 we estimate the effect of unfair wage within the framework of the two panel data models. The dependent variables are binary and indicate whether or not a physician has "ever diagnosed" the particular disease. The displayed coefficients refer to linear probability models. Column (1) refers to the model described in equation (1) and shows fixed effect estimates, column (2) is based on the model described in equation (2) and shows OLS estimates.

As shown in column (2) the coefficients resulting from lagged dependent variable models indicate significant effects of unfair wage on depression ($p < 0.1$), migraine ($p < 0.01$) and heart disease ($p < 0.01$). Heart disease, however, is the only disease

[15] The indication of dementia was also asked for but dementia was excluded from the analysis since less than 0.0002% of the analyzed sample indicated this disease. All regressions are available on request.

where the fixed effects model (column (1)) indicates a significant effect ($p < 0.01$) as well. Applying the bracketing property of the two estimation approaches shows that the effect of unfair wage on the probability of suffering from heart disease is substantial: Relative to a baseline probability of 3%, the probability increases by 0.8 to 1.1 percentage points if an individual perceives his wage as unfair.

The relatively low power resulting from the combination of binary independent and binary dependent variables does not allow us to completely rule out effects of unfair wage on the other specific diseases even in the absence of significance. However, finding a selective adverse effect on heart disease is in line with our hypothesis that unfairness driven health effects operate through stress-related mechanisms (Steptoe and Kivimäki, 2012) akin to what we find in our lab data.

	Coefficients of "unfair wage"	
	Estimation approach:	
	Fixed effects	Lagged dep. variable
Dependent variable:	(1)	(2)
Apoplectic stroke (0.3%)	-0.000	0.001
Asthma (4.4%)	0.005	0.003
Cancer (2.4%)	-0.003	-0.001
Depression (4.5%)	0.000	0.006*
Diabetes (3.4%)	-0.000	0.000
Heart disease (3.0%)	0.011***	0.008***
High blood pressure (16.9%)	0.005	0.007
Migraine (5.6%)	0.005	0.011***
Time varying controls	yes	yes
Individual fixed effects	yes	no

Table 4: Relation between specific diseases and unfairness perception (SOEP). Linear probability models, where column (1) refers to the model described in equation (1) and shows FE estimates, and column (2) refers to the model described in equation (2) and shows OLS estimates. The models in column (1) were estimated for the years 2013, 2011 and 2009 with 26,307 observations of 14,016 individuals. Due to using a lagged dependent variable in column (2), these models could only be estimated for the years 2013 and 2011 with 13,812 observations of 8,991 individuals. The samples include full- or part-time dependent employees. The regression models refer to the same specifications as in columns (1) and (2) in Table 3. Percentages displayed next to the specific disease are baseline probabilities of suffering from the respective diseases in the sample of employees who do not perceive their wage as unfair. To calculate significance levels, standard errors were clustered at the individual level. ***, **, * indicate significance of the "unfair wage" coefficient at the 1-, 5-, and 10-percent level, respectively.

3.4 Robustness: Dose-response analysis

In epidemiology it is often argued that the demonstration of a so called "dose-response relation" strengthens the argument for cause and effect. In the context of this study, a dose response-analysis means to relate, conditional on the fact that wage was ever perceived as unfair, the frequency of waves in which wage was perceived as unfair to health status and diseases.[16] To consider the longest possible time span, we use health outcomes in the year 2013 and relate them to the frequency of perceiving wage as unfair in the years 2013, 2011, 2009, 2007 and 2005. For comparability, we restrict the sample to individuals who participated in the survey in all five relevant waves.

Figure 1 shows the dose-response relation of the frequency of perceiving wage as unfair and subjective health status. The bars indicate the mean subjective health status of subgroups of employees who perceived their wage as unfair in either one, two, three, four or five periods, respectively. The pattern shows a significant downward trend (Spearman's $\rho = -0.148, p < 0.01, N =$ 1,869), i.e., a negative dose-response relation. In other words, health status decreases in the frequency (and duration) of experiencing wages as unfair. Regressing subjective health status on the dose (frequency) of perceiving wage as unfair and controlling for income and age (in 2013) yields a β_{dose} of -0.065 ($p < 0.01$).

Table A2 shows the results of the corresponding analysis regarding specific diagnosed diseases. The results confirm the effects shown in the previous section (Table 4). Heart disease is the only category of diseases that shows a significant dose-response relation ($p < 0.05$). In sum, the dose-response analysis further strengthens the causal interpretation of adverse health effect of unfairly low wage.

[16] We thank an anonymous referee for this suggestion.

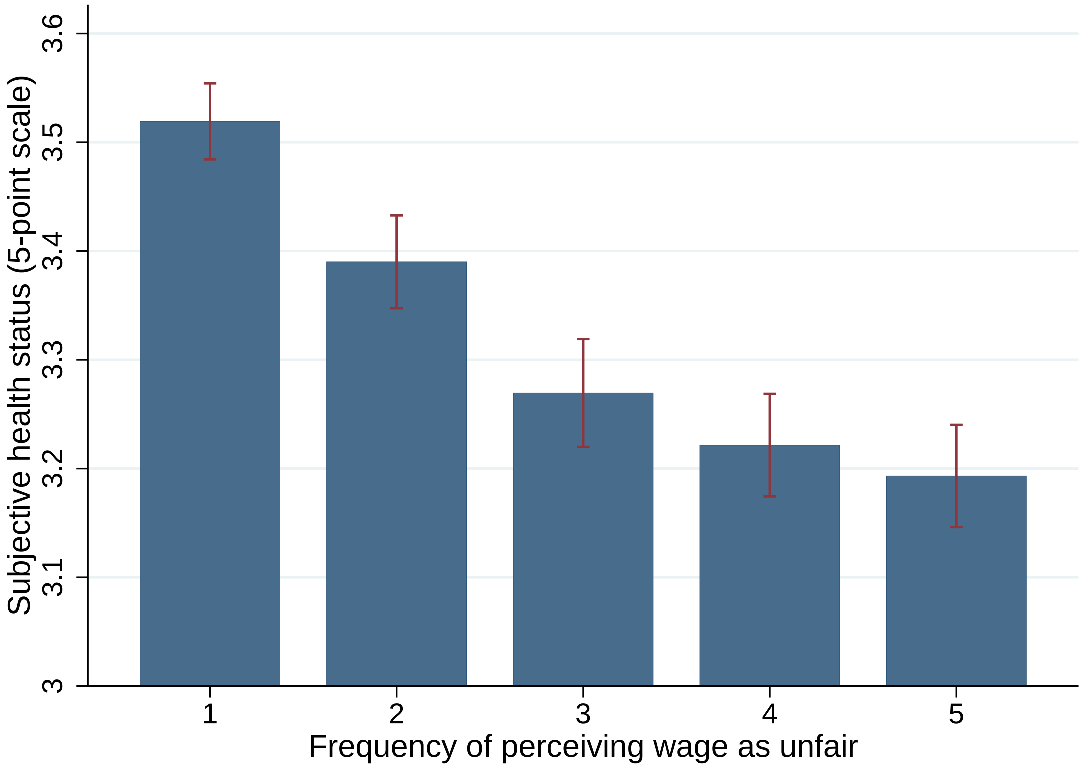

Figure 1: Dose-response relation between the frequency of perceiving wage as unfair and subjective health status. The y-axis indicates subjective health status in 2013. The categories on the x-axis indicate how often within the years 2013, 2011, 2009, 2007 and 2005, the subject reported perception of unfair pay. N = 1,869. Error bars refer to standard errors of the mean (SEM).

4 Concluding remarks

In this paper we establish a link between the experience of unfair pay and heart rate variability: Higher levels of unfairness go along with lower heart rate variability. Low heart rate variability reflects stress and an impaired balance between the sympathetic and the vagal nervous system, and has been shown to predict coronary heart disease in the long-run. Using a large representative panel data set (SOEP) we therefore test whether perceptions of unfair pay predict adverse health outcomes in the general population. Combining lab and field data is useful in terms of cross validating findings and simultaneously providing evidence that is both, controlled and based on representative data.[17] Our findings suggest that health status is in fact negatively affected by unfair pay. Moreover, we find selective associations for specific health outcomes that are predicted if the effect operates through stress-related mechanisms (Steptoe and Kivimäki, 2012).

[17]For a discussion of lab and field data, see Falk and Heckman (2009).

Our findings are related to a literature that points out behavioral effects of fairness in labor relations. We show that perceptions of unfair pay do not only affect the efficiency of labor relations in reducing work morale (e.g., Fehr et al., 1997), but also by potentially affecting the health status of the workforce. This finding is in line with the epidemiological literature on the general relation between inequality and health. There is observational evidence suggesting a link between income inequality or low income and bad health status or even death (Kennedy et al., 1996; McDonough et al., 1997; Lynch et al., 1997). More specifically, there is epidemiological evidence that people who are confined to demanding jobs that fail to adequately compensate efforts are at increased risk of suffering or dying from coronary heart disease (Bosma et al., 1998; Kivimäki et al., 2002; Kuper et al., 2002). An overview on the epidemiological and medical sociological literature in this context can be found in Table A3 and Siegrist (2005).[18] Our study complements and connects the epidemiological and economic literature by using a comprehensive approach which combines the use of biomarkers in the laboratory and panel data analyses of representative field data.

On a general level our findings provide evidence that the human body registers and systematically processes social and contextual information. This is related, e.g., to findings in Fliessbach et al. (2007) who show that the human brain encodes social comparison. Using fMRI they report that for a given own wage, receiving a wage that is lower than that of another subject is associated with a significantly lower activation in reward-related brain areas, in particular the ventral striatum. In our representative panel data analysis we show that on top of actual life circumstances and outcomes, such as net wages, perceptions of unfair treatment induce adverse physiological responses. Given that health affects labor market outcomes (see, e.g., Currie and Madrian, 1999), this suggests an important potential feedback mechanism: Labor market experience can induce perceptions of unfairness with consequences for health, which in turn affects labor market outcomes. The feedback mechanism between social environment, perceptions and body responses suggests complementary effects: We may have to think about some aspects of labor markets differently, with the fairness-health link potentially leading to a vicious circle involving poor pay and poor health. We believe this question deserves attention in future work.

[18]This discussion is also connected to the recent epidemiological literature on the relation between discrimination and health. For a recent overview see Lewis et al. (2015).

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Appendix

Additional Tables and Figures

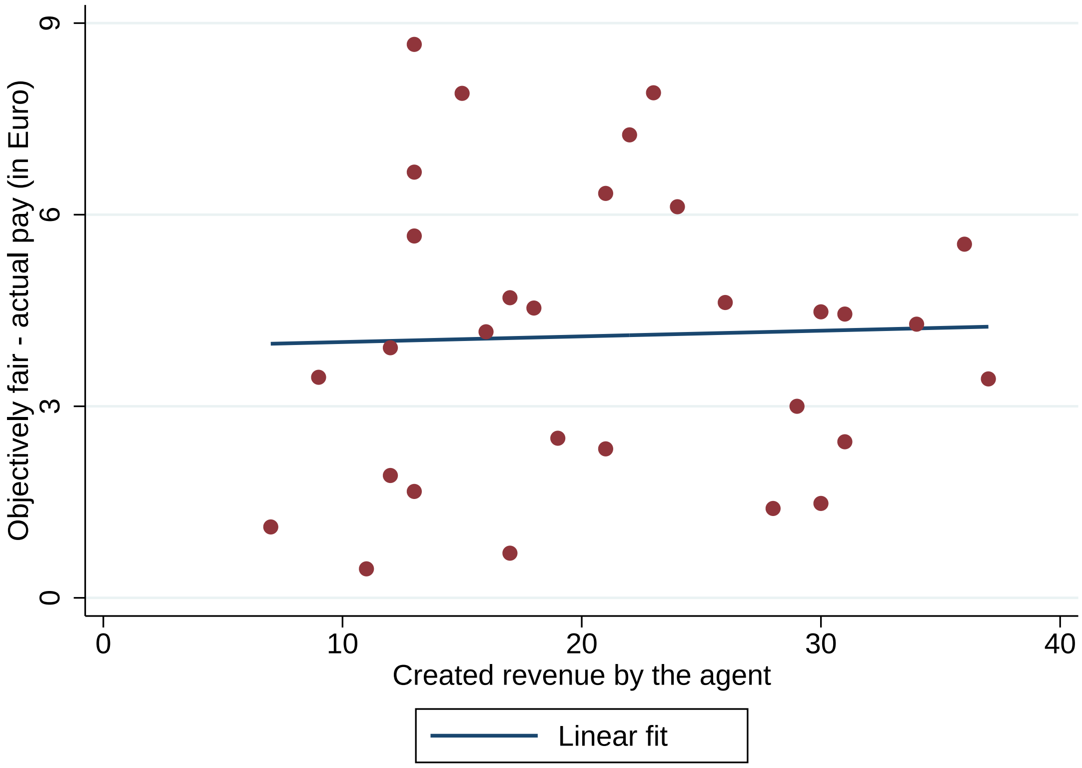

Figure A1: Degree of unfairness and created revenue. The difference between the objectively fair and the agent's actual pay ("degree of unfairness") is not related to created revenue by the agent (Pearson's $r = 0.033, p = 0.861, N = 30$.

	Standardized (HRV_response - HRV_baseline)	
	(1)	(2)
Standardized degree of unfairness	-0.360**	-0.353**
	[0.133]	[0.135]
Generated revenue		-0.026
		[0.021]
Constant	0.000	0.547
	[0.162]	[0.443]
Observations	34	34
Adjusted R-squared	0.103	0.125

Table A1: Regression analysis on the effect of fairness violation on HRV including individuals with potentially defective HRV measures. OLS estimates with robust standard errors in brackets. The dependent variables is the difference between HRV_response (measured 15 min after exposure to the unfairness stimuli) and HRV_baseline (measured before the allocation was revealed). The degree of unfairness measure is the difference between the objectively fair pay, rated by uninvolved third parties, and the actual pay assigned by the principal. ***, **, * indicate significance at 1-, 5-, and 10-percent level, respectively.

Dose-response relation	Dose: frequency of perceiving wage as unfair	
Dependent variable:	Marginal effects (probit)	Standard errors
Apoplectic stroke	0.002	0.001
Asthma	0.003	0.003
Cancer	0.003	0.003
Depression	0.003	0.004
Diabetes	0.004	0.003
Heart disease	0.006**	0.003
High blood pressure	0.007	0.007
Migraine	0.006	0.004
Controls: income & age		

Table A2: Dose-response relation between the frequency of perceiving wage as unfair and diagnosed diseases. The specific diagnosed diseases are regressed on the dose (frequency) of perceiving wage as unfair, income and age. Displayed coefficients are marginal effects after probit. Diagnosed diseases refer to the year 2013. Dose is the frequency of perceiving wage as unfair in the years 2013, 2011, 2009, 2007 and 2005. N = 1,872. ***, **, * indicate significance at the 1-, 5-, and 10-percent level, respectively.

Table A3: Overview over epidemiological studies on the relation of economic inequality and health.

Authors and Year	**Method**	**Data**	**Indicator**	**Health Measure**	**Results**
Kennedy et al. (1996)	State-level comparison, cross-sectional multivariate OLS analysis	United States census population (1990); Compressed mortality files from the National Center for Health Statistics	Income inequality at state-level (Robin Hood index and Gini coefficient)	Mortality	Income inequality measured by the Robin Hood Index is positively correlated with almost all mortality measures. The Gini coefficient shows small correlations.
McDonough et al. (1997)	Pooled logistic regression	Panel Study of Income Dynamics (PSID) for the years 1968 through 1989	Low income	Mortality	Low income is a strong predictor for higher mortality, especially in case of persistent low income.
Lynch et al. (1997)	Cross-sectional logistic regression, proportional hazards regressions	Alameda County Study, representative sample of adults in Alameda County, California	Low income	Physical, psychological and cognitive functioning	Sustained low income leads to poorer physical, psychological, and cognitive functioning.

Bosma et al. (1998)	Logistic regression (individual-level)	Whitehall II prospective cohort study of British civil servants (aged 35 to 55 years)	Imbalance between personal effort (competitiveness, overcommitment) and rewards (promotion prospects, blocked career)	Coronary heart disease	Effort-reward imbalance predicts coronary heart disease.
Kivimäki et al. (2002)	Cox proportional hazards model to relate baseline characteristics and outcomes	Employees of a company in the metal industry in Finland with baseline examination in 1973 and mean follow up of 25.6 years; National mortality register 1973-2001	Work stress questionnaire (job strain and effort-reward imbalance models)	Cardiovascular mortality	Work stress is related to a higher cardiovascular mortality risk.
Kuper et al. (2002)	Cox proportional hazards and logistic regression	Whitehall II prospective cohort study of British civil servants (aged 35 to 55 years)	Effort–reward imbalance at the job	Coronary heart disease and physical and mental functioning	A ratio of high efforts to rewards predicts higher risk of coronary heart disease as well as poor physical and mental functioning.

Instructions of the experiment

In the following we present translations of the original German instructions.

Instructions for Employees

You are now taking part in an economic experiment. Please read the following instructions carefully. Everything that you need to know to participate in this experiment is explained below. Should you have any difficulties in understanding these instructions please notify us. We will answer your questions at your cubicle.
During the course of the experiment you can earn money. The amount of money that you earn during the experiment depends on your decisions and the decisions of another participant. At the end of the experiment you will receive the sum of money that you earned during the experiment in cash.
Please note that communication between participants is strictly prohibited during the experiment. In addition we would like to point out that you may only use the computer functions, which are required for the experiment. Communication between participants and unnecessary interference with computers will lead to exclusion from the experiment. In case you have any questions we are glad to assist you.
The participants of this experiment were randomly assigned the roles of employers and employees. You are an employee for the entire course of the experiment.
In the following you can earn money by working on a task. The money you earn will be received by your employer, who decides on how to divide the money between him and you. The interaction is completely anonymous, i.e., at no point you will learn the identity of the employer and the employer will not learn your identity.

Your work task

The work task is to count the correct number of zeros on prepared sheets containing zeros and ones. At your cubicle you find an example of such a sheet. At the top you see the sheet number. Below that you find a table with zeros and ones. To earn money, you have to count the correct number of zeros and enter it into the computer. To do that you will receive a new computer screen for each sheet.
The first input screen is for the first sheet. Under the heading: "How many zeros are on sheet 1?" you find a box where you can enter a number. Type the correct number into that box and click on "OK". As soon as you have clicked on the "OK"-button, the screen for the next sheet appears etc.

As long as you have not clicked on the OK-button, you can change your entry. As soon as you have clicked on OK, however, the next screen appears.
For each correctly solved sheet you create revenue of 3 Euro. For example, if there are 29 zeros on a particular sheet and you type 29, you create revenue of 3 Euro. If your entry deviates by plus/minus 1 from the correct number of zeros, you receive 1 Euro. If your entry deviates by more than plus/minus 1, you create no revenue for that particular sheet.

Example:
Suppose, the correct number of zeros on a particular sheet is 15.
If you type 15, you create revenue of 3 Euro.
If you type in either 14 or 16, you create revenue of 1 Euro.
If you type in a number smaller than 14 or larger than 16, you create revenue of zero Euro.

Please note: As soon you have clicked OK, you cannot revise your entry anymore. The next screen for the next sheet appears immediately.

On each input screen you are informed about the number of correctly solved sheets, the number of almost correctly solved sheets (deviation plus/minus 1) as well as the resulting amount of revenue you have produced. In addition you see on the screen the remaining time in seconds.
You have 25 minutes to solve sheets and create revenue (25 minutes = 1500 seconds). You can work on as many sheets as you like: None, one, two etc. up to a maximum of 20. The sheets will be allocated as soon as you have read the instructions.

The decision of the employer

Your employer will receive the amount of money you have produced. He divides the amount of money between himself and you. Any feasible allocation is possible. For example, the employer can keep the whole amount for himself, give the whole amount to you, he can keep 10 percent of the amount and give you 90 percent, he can divide exactly equally etc.

The employer does not work and does not create any revenue. He knows, however, that the amount of money that he can divide depends on your work effort.

Following your working time and the allocation decision of the employer, you will have to complete a short questionnaire. Then, the experiment is over and you will receive your payments in cash, depending on the amount of money and the allocation decision.

If you have any questions, please let us know.

If you have read these instructions, please click “Start”.

Instructions for Employers

You are now taking part in an economic experiment. Please read the following instructions carefully. Everything that you need to know to participate in this experiment is explained below. Should you have any difficulties in understanding these instructions please notify us. We will answer your questions at your cubicle.
During the course of the experiment you can earn money. The amount of money that you earn during the experiment depends on your decisions and the decisions of another participant. At the end of the experiment you will receive the sum of money that you earned during the experiment in cash.
Please note that communication between participants is strictly prohibited during the experiment. In addition we would like to point out that you may only use the computer functions, which are required for the experiment. Communication between participants and unnecessary interference with computers will lead to exclusion from the experiment. In case you have any questions we are glad to assist you.
The participants of this experiment were randomly assigned the roles of employers and employees. You are an employer for the entire course of the experiment. The interaction is completely anonymous, i.e., at no point you will learn the identity of the employee and the employee will not learn your identity.

Your are matched with one employee. This employee can earn money by working on a simple task. The amount of money depends on the employee's work effort.
You receive the produced amount of money. Then, you decide which amount you keep for yourself and which amount you want to give to the employee. Any feasible allocation is possible.
For example, you can keep the whole amount for yourself, give the whole amount to the employee, keep 10 percent of the amount and give 90 percent to the employee, divide exactly equally etc.

You do not work and do not create any revenue.
The working time during the employee can - but is not obliged to - work spans 25 minutes. During that time you can read, work on something for yourself etc. As soon as the produced amount of money is fixed, you get a notice on your computer screen. At that point you are asked to provide an allocation decision.
Following your allocation decision, you will have to complete a short questionnaire. Then, the experiment is over and you will receive your payments in cash, depending on the amount of money and the allocation decision.
If you have any questions, please let us know.
If you have read these instructions, please click "Start".