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Privacy Concerns, Voluntary Disclosure of Information, and Unraveling: An Experiment

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Privacy Concerns, Voluntary Disclosure of Information, and Unraveling: An Experiment*

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Abstract

We study the voluntary revelation of private, personal information in a labor-market experiment with a lemons structure where workers can reveal their productivity at a cost. While rational revelation improves a worker's payoff, it imposes a negative externality on others and may trigger further unraveling. Our data suggest that subjects reveal their productivity less frequently than predicted in equilibrium. A loaded frame emphasizing personal information about workers' health leads to even less revelation. We show that three canonical behavioral models all predict too little rather than too much revelation: level-k reasoning, quantal-response equilibrium, and to a lesser extent inequality aversion.

JEL Classification numbers: C72, C90, C91

Keywords: information revelation, privacy, lemons market, level-k reasoning, quantal response equilibrium, inequality aversion.

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1 Introduction

Privacy concerns and the treatment of personal data and are at the center of current policy debates.[1] With the rise of digital data processing and the increased communication of information via the Internet, a wealth of personal data can be accumulated and distributed at low cost. As a result, private enterprises and governmental institutions alike face new challenges of how to adequately handle the private data of their citizens and clients.

Cases where individuals *voluntarily* disclose private information are regarded as increasingly important. For example, prospective tenants or job applicants often voluntarily disclose verified personal information. In the US, online services such as MyBackground-Check.com provide verified information on, for example, drug tests, criminal records and previous rental addresses to prospective landladies or employers.[2] New-generation passports and identity cards often contain biometric data, and the policy debate seems to regard whether people can freely agree to include the sensitive information as relevant.[3] Another example are health or pregnancy tests voluntarily provided to existing or future employers.[4, 5]

The main reason why the voluntary disclosure of personal information can raise privacy concerns is due to unraveling effects. In a world where credible signals can easily be obtained and distributed, these signals will be used by those with the best medical records, credit scores, etc. This may put pressure on others to disclose similar information about themselves because not disclosing will be interpreted as a signal of low quality. Thus, granting people the right to decide whether to disclose can be less of a voluntary choice than it seems at first sight. Or, as Posner (1998, p. 103) succinctly puts it "*As for privacy in general, it is difficult to see how a pooling equilibrium is avoided in which privacy is 'voluntarily' surrendered, making the legal protection of privacy futile.*"

The importance of the unraveling argument is also reflected in the current legal debate. Peppet (2011) summarizes the legal perspective and argues that the voluntary disclosure of private information is crucial because of unraveling effects. The challenge to regulating voluntary disclosure is that there are always some agents in whose interest it is to disclose their information. Limits to inquiry that forbid an uninformed party from seeking information from an informed counterpart may not be sufficient as the informed party might

[1]To quantify this statement, we conducted a Google Books Ngram Viewer comparison of several keywords and compared them to the term "privacy concerns". We found that the use of the term "privacy concerns" in the English literature has been increasing steadily since the Seventies. This is in contrast to other topics like "nuclear threat" (in decline and nowadays occurring less frequently than "privacy concerns") or "racial discrimination" (more frequent than "privacy concerns", but also in decline).

[2]Connolly (2008) explicitly advises applicants in the job market to use such online services (pp. 59-60).

[3]See Curtis (2006) for the debate in Australia, Acharya and Kasprzycki (2010) for Canada, Probst (2011) for Germany, Grijpink (2001) for the Netherlands.

[4]Some of Apple Inc. suppliers screened their workers with health and pregnancy test (Apple 2012). See also New-York Times, January 26, 2012. The unraveling argument suggests that whether workers voluntarily agreed to take the tests is immaterial.

[5]Further examples, discussed in Peppet (2011), include car insurance policies or rental car contracts where drivers can voluntarily agree to have the car monitored with GPS-based systems.

feel that it is in her interest to disclose the information. A means to avoid unraveling may be to completely forbid the use of certain information, as for example in the *Genetic Information Nondiscrimination Act* (GINA) passed in 2008 in the US to prohibit the use of genetic information by insurers.

Our goal is to contribute to the debate of whether voluntary information disclosure is problematic because of unraveling effects. Will there be complete unraveling in the markets? Will there be too much or too little disclosure of information? Will participants anticipate the behavior of others and the externalities imposed by their choices? Does the decision to reveal information depend on the context such as the perceived sensitivity of the information?

We study the voluntary disclosure of information in a laboratory experiment with the help of a setting that we call *revelation game*. In a labor market with a lemons structure (Akerlof 1970), workers can truthfully reveal their productivity to employers at a cost. Revelation correctly uncovers the worker's productivity, and it imposes an externality on others. Equilibrium play involves information revelation by the workers with the highest productivity, where the share of workers who reveal in equilibrium depends on the revelation cost and the distribution of productivities. When revelation costs are negligible, there is complete unraveling: only the workers with the lowest productivity will choose not to reveal, but the very act of concealing makes it possible to identify their productivity in equilibrium.

In the experiments we consider three different labor markets. Depending on the experimental parameters, either complete unraveling, partial unraveling or no unraveling (except for the player with the highest productivity) should occur. We conduct the experiments with a loaded frame (where "workers" can purchase a fictitious "health certificate") and with a neutral frame as a control treatment.

We find that revelation rates are systematically lower compared to the equilibrium prediction. Workers who are supposed to reveal in equilibrium fail to take the equilibrium choice significantly more often than workers who should conceal their productivity in equilibrium. Strengthening these findings, we observe only moderate learning effects toward equilibrium over several rounds of play. Moreover, we find a statistically and economically significant framing effect: there is more revelation and equilibrium consistency in neutrally framed sessions. Furthermore, it appears that the labor-market-health frame triggers privacy concerns.

We then explore the reasons for incomplete unraveling. Our aim is to uncover systematic reasons for concealing one's productivity. We show that three canonical behavioral models consistently predict too little rather than too much revelation: level-k reasoning, quantal-response equilibrium, and inequality aversion. Our interest is not in comparing the performance of the three different models but rather in employing the models to uncover the mechanisms that can stop or mitigate unraveling.

A central prerequisite of the unraveling argument is that players are capable of several steps of reasoning. Typically, only the most productive workers will find it in their interest to reveal information when others conceal. However, given the most productive players reveal, more players will reveal, and so on. Such iterated steps of reasoning are captured by the level-k model.[6] We show for our game that revelation may require a large number of such steps of reasoning whereas concealing always requires only one step of reasoning. Since experiments show that participants exhibit limited depth of reasoning, the level-k model suggests an asymmetry in our game: workers who should reveal in equilibrium will be more likely to fail to do so (that is, they conceal) than workers who should conceal. Hence, the level-k model implies incomplete unraveling.

Following McKelvey and Palfrey (1995), we analyze the quantal response equilibrium (QRE) of the revelation game. The QRE suggests that the payoff from concealing, all else being equal, will become more attractive than the payoff from revealing for workers with a low productivity. The reason is that, for low productivity workers, the (expected) payoff differences between concealing and revealing are small. This difference is larger for high productivity workers who therefore reveal more often in QRE. If the equilibrium calls for revelation, QRE suggests (at least for the parameter we estimate) that a sizeable share of decisions by low productivity workers will be mistaken. Moreover, QRE may even suggest that workers who reveal in equilibrium exhibit non-monotonic behavior: the probability of revelation initially decreases in the rationality parameter before it increases and approaches one asymptotically. Such non-monotonicities do not occur for workers who conceal in equilibrium. As a result, QRE players will frequently fail to reveal but will less often fail to conceal.

We also investigate the role of inequality aversion (Fehr and Schmidt 1999) for the results. Sufficiently inequality-averse players will be reluctant to disclose information because of the externality this imposes on the other players. Thus, there can be less revelation than with standard preferences. More revelation is, by contrast, difficult to reconcile with inequality aversion: choosing to reveal when (standard) equilibrium calls for concealment will often reduce payoffs and increase payoff inequalities. It follows that inequality aversion is also consistent with our under-revelation result.[7]

To sum up, models of bounded rationality (level-k, QRE) and models of other-regarding preferences all suggest incomplete unraveling. Given the strong interest in unraveling in

[6] The level-k model was introduced by Stahl and Wilson (1995) and Nagel (1995). Its original application was to explain subjects' behavior in p-beauty-contest games (compare, for example, Bosch-Domenech, Montalvo, Nagel and Satorra (2002), Kocher and Sutter (2005) or Brañas-Garza, Garcia-Muñoz and González (2012) for some other studies of this kind). Further applications include private-value auctions (Crawford and Iriberri 2007) or centipede games (Kawagoe and Takizawa 2012, Ho and Su 2013). Some games such as the "20-11 money request game" have specifically been designed for the elicitation of k-levels (Arad and Rubinstein 2012, Lindnera and Sutter 2013). There are also extensions of the model such as Camerer, Ho and Chong (2004) or Goeree and Holt (2004).

[7] Nevertheless, below, we do not consider inequality aversion to be a prime explanation for our experiments. The reason is that the model has multiple equilibria, and the patterns we observe in the data only occur with a low frequency in the simulations of a calibrated version of the inequality model of Fehr and Schmidt (1999).

the theoretical literature, we believe that these behavioral aspects should receive more attention. If under certain conditions unraveling is less severe than predicted by the theory, this can affect the optimal policy choice with respect to privacy protection.

Taken together, our results do not lead to unambiguous policy conclusions. On the one hand, the unraveling of private information due to voluntarily disclosure may be less problematic than economic theory suggests. Players fail to reveal personal information because of bounded rationality or other-regarding preferences. Further, some players have a non-standard preference against revealing their personal data in connection with privacy-sensitive issues like health, as suggested by the comparison of the neutral and the loaded framing of the experiment. On the other hand, we observe a substantial amount of revelation in the experiment. This suggests that unraveling effects in voluntary disclosure regimes can force players to reveal more information. Such effects should be considered in the context of privacy policies involving free choice.

In the next section, we review the relevant literature. Section 3 introduces the revelation game and Section 4 the experimental implementation and the different treatments. Section 5 reports on the results. Section 6 investigates reasons for the behavioral patterns we observe and Section 7 concludes.

2 Related Literature

Following the introduction of the lemons problem by Akerlof (1970), the costly but truthful revelation of private information—the certificate solution to the lemons problem—was suggested by Viscusi (1978). Subsequently, it was shown by Milgrom (1981), Grossman and Hart (1980) and Grossman (1981) that taking no action (not acquiring a certificate) may reveal an agent's type when other agents have an incentive to disclose information. They pointed out that complete unraveling may result (see also Jovanovic (1982)).[8]

More recently, Hermalin and Katz (2006) investigated the impact of privacy regimes on consumer and producer rents in markets with price discrimination, taking into account unraveling effects. They argue that markets may be ex post efficient due to unraveling. However, laws banning unraveling can improve welfare ex ante because the socially wasteful revelation costs can be avoided.

While information disclosure has received much attention in the theoretical literature, only Forsythe, Isaac and Palfrey (1989) have studied unraveling in an experiment.[9] They

[8]Just as in our markets where unraveling implies disclosure of information, Ostrovsky and Schwarz (2010) show that unraveling occurs when information is fully disclosed in the context of matching markets. Either, for example, schools do not disclose information about grades fully or - with full disclosure - unraveling to earlier contract dates with less information available occurs.

[9]There is also an empirical literature on the topic based on field data. Jin (2005) reports evidence on incomplete unraveling among Health Maintenance Organizations which may disclose information on the quality of their services on a voluntary basis. As for mandatory disclosure Jin and Leslie (2003) find that the introduction of hygiene quality grade cards for restaurants increases the consumers' sensitivity for

study a game where sellers have superior information about the good compared to the buyers and can decide whether to reveal this information. The game has multiple Nash equilibria. Full unraveling in the sense of sellers disclosing their private information about the good takes place in the unique sequential equilibrium, which experimental subjects learn to play in the course of several rounds of play. Our game differs from the one in Forsythe et al. (1989) in that it has a unique equilibrium with partial unraveling. Moreover, the cost of revelation is negligible in Forsythe et al. (1989) but not in our setup.

Our experiments have some bearing on the question of how people make choices regarding their personal data. To our knowledge, we are the first to study the unraveling of privacy experimentally.[10] However, there is a study on the framing effects of defaults used in electronic commerce for various privacy settings, see Johnson, Bellman and Lohse (2002). Experiments have also been used to investigate decisions regarding personal data. When making purchasing decisions, consumers have been found to provide personal data freely, even when it is relatively easy and costless to avoid it (see Acquisti and Grossklags (2005) and Beresford, Kübler and Preibusch (2012)). This behavior in combination with a strong concern for privacy protection voiced in surveys has been called the "privacy paradox".

In an experiment on information acquisition and revelation by Schudy and Utikal (2012), the impact of different data security schemes on information acquisition is investigated. The paper employs a loaded frame where subjects can acquire the results of a binary test (for example, an HIV test). The data security regimes are perfect privacy (no one but the testee gets to know the test result), imperfect privacy (there is a 50% chance that the results of the test will be leaked to a player interacting with the testee), and automatic dissemination where the test results are automatically disclosed to both players in a group. The authors find that information acquisition, that is, taking a test, is almost complete whenever there is some data security. The only treatment with incomplete data acquisition is the one with the automatic dissemination of the test results.

3 The Revelation Game

Our design is based on a labor market with a lemons structure. There are $n \geq 2$ workers with $n \in N$. Worker i has productivity θ_i. Let $\Theta = \{\theta_1, \theta_2, ..., \theta_n\}$ and assume w.l.o.g.

hygiene issues in restaurants. More recently, Lewis (2011) pointed out that a lack of (voluntarily provided) ex-post verifiable information on used cars (photos, text hinting at rust, scratches, etc.) has a negative influence on the selling price in internet auctions. When such information is not easily verifiable (e.g., baseball trading cards), Jin and Kato (2008) show that cards of alleged high quality trade at substantially higher prices although their actual quality is not distinguishable compared to other cards.

[10] The issue of the signaling of private information is broadly related. The experimental literature on this includes early contributions like Miller and Plott (1985), Brandts and Holt (1992), Potters and van Winden (1996), and Cooper, Garvin and Kagel (1997), and more recent papers like Kübler, Müller and Normann (2008), Cooper and Kagel (2009) and de Haan, Offerman and Sloof (2011).

that $\theta_1 \leq \theta_2 \leq ... \leq \theta_n$.

All n workers simultaneously choose between two actions, to *reveal* or to *conceal* their productivity. Revelation causes a cost of $c > 0$ and correctly reveals the worker's productivity. Let $I_i \in \{0, 1\}$ be a function indicating whether worker i has chosen to reveal her productivity, with $I_i = 1$ denoting revelation and $I_i = 0$ concealment.

Workers' payoffs are determined as follows. If worker i chooses to reveal, i earns her productivity minus the revelation cost. If not, she receives the average productivity of all workers who have chosen not to reveal. Formally, i's payoff is

$$\Pi_i = \begin{cases} \theta_i - c & \text{if } I_i = 1 \quad (\textit{reveal}) \\ \sum_{j=1}^{n}(1 - I_j)\theta_j / \sum_{j=1}^{n}(1 - I_j) & \text{if } I_i = 0 \quad (\textit{conceal}). \end{cases}$$

These payoffs can be thought to arise in a competitive labor market where two or more employers bid for workers and earn the workers' (expected) productivity. The employers in this labor market would know the set Θ, that is, they would know the n payoff functions of the n workers, but do not know which worker has which payoff function. Employers would earn an expected payoff of zero.

This is a static game with complete information. The equilibrium concept is Nash equilibrium.

Proposition 1. *In any pure strategy Nash equilibrium of the revelation game, we have* $I_n^* \geq I_{n-1}^* \geq ... \geq I_2^* \geq I_1^* = 0$.

The proof can be found in the Appendix. The proposition formally suggests the pattern $I_1 = I_2 = ... = 0 < I_m = ... = I_n = 1$, $1 < m < n$, of equilibrium actions. The exception is the trivial case where no player reveals, $I_1 = I_2 = ... = I_n = 0$. The trivial case can be excluded whenever $\theta_n - c \geq \sum_j \theta_j / n$. That is, the highly productive workers reveal, and low-productivity workers conceal. See Jovanovic's (1982) Theorem 1 for a similar result in a different context.

Definition 1. *Let* $\bar{\theta}(s) = \frac{1}{s}\sum_{i=1}^{s}\theta_i$. *Further, define* $C = \left\{i | \theta_i - c \leq \bar{\theta}(i)\right\}$ *and* $R = \left\{i | \theta_i - c \geq \bar{\theta}(i)\right\}$.

In words, $\bar{\theta}(s)$ is the average of the productivities of all workers $1, 2, ..., s$. The set C contains all workers whose best-response is to conceal given that all workers with lower (higher) productivity conceal (reveal). And R is the set of all workers whose best-response is to reveal given that all workers with lower (higher) productivity conceal (reveal).

Proposition 2. *The revelation game has unique pure strategy equilibrium if and only if* $\max(C) < \min(R)$*,* See the Appendix for a proof. Note that while the games we use in our experiment all have a unique pure strategy equilibrium, it is easy to construct cases with multiple equilibria with the help of the proposition. Suppose $n = 3$, $c = 100$, $\theta_1 = 200$, $\theta_2 = 402$ and $\theta_3 = 403$. We have $\bar{\theta}(1) = 200, \bar{\theta}(2) = 301$ and $\bar{\theta}(3) = 335$. Therefore, $C = \{1, 3\}$ and $R = \{2\}$. There are multiple equilibria: in one pure strategy Nash equilibrium, all workers conceal and we have $\theta_i - c < 335$ for $i = 1, 2, 3$; in a second pure strategy Nash equilibrium, workers 2 and 3 reveal and we have $\theta_1 - c < 200$, $\theta_{2,3} - c > \frac{200+\theta_{2,3}}{2}$.

4 Experimental Design and Procedures

In our experimental markets, there are $n = 6$ different workers in a market. We design three different markets, A, B, and C, with different realizations of Θ. The cost of revelation, c, always equals 100 experimental currency units; it does not vary across workers, markets or treatments. The different productivities in each market are reported in Table 1. The entries in bold type indicate that the corresponding subject reveals her productivity in equilibrium.

The three markets are played on a rotating basis. In period 1 subjects play Market A, in period 2 they play Market B, and in period 3 Market C is played before they start all over again with Market A. Each market is played five times, totaling 15 periods altogether.

At the beginning of the experiment, subjects were randomly allocated into groups of six, and they stayed in their group for the whole experiment (fixed matching). The productivities θ_i, expressed in experimental currency units, were randomly assigned to the workers in each period. The instructions emphasized that this allocation of productivities is without replacement such that each productivity value occurs exactly once in each group and in each period.

Productivity	Market A	Market B	Market C
θ_1	200	200	200
θ_2	210	**448**	280
θ_3	230	**510**	360
θ_4	260	**551**	**440**
θ_5	300	**582**	**520**
θ_6	**600**	**607**	**600**

Table 1: Workers' productivities in the three different markets. Entries in bold face indicate that the player reveals in equilibrium ($I_i = 1$).

The Nash equilibrium for the three markets is as follows. In Market A, only worker 6 reveals her productivity. That is, we have $I_6 = 1 > I_5 = I_4 = I_3 = I_2 = I_1 = 0$ in equilibrium. In Market B, all workers except for worker 1 reveal: $I_6 = I_5 = I_4 = I_3 = I_2 = 1 > I_1 = 0$. Finally, in Market C, we have $I_6 = I_5 = I_4 = 1 > I_3 = I_2 = I_1 = 0$. The motivation for employing Markets A to C is that we need qualitatively different equilibrium outcomes to be able to infer whether there is too much or too little revelation. For example, Market B may show that subjects reveal too little, but given that almost all workers should reveal in equilibrium, we need to contrast this with Market A where only one of six workers reveal in Nash equilibrium.

We consider two treatments, one baseline treatment and one control. The control treatment is identical to the baseline treatment except in one dimension.

1. The baseline treatment, called LOADED, is based on the revelation game described in the previous section with one peculiarity. It employs a loaded labor-market frame. Subjects are told that they are acting as *workers* in a *labor market*. Their productivity is referred to as their *health status*, and subjects are told that they need to decide whether or not to *buy a health certificate*.

2. In our second treatment, NEUTRAL, we remove the labor market frame. The productivity is called *number* and the decision is merely between *yes* and *no*. The neutral treatment is implemented in order to control for the possibility of subjects' privacy concerns elicited by the framing. If the subjects care for privacy, there should be more revelation in this treatment compared to the baseline treatment with the loaded frame.

The feedback given to the participants at the end of a period was as follows. In all sessions, subjects were informed of their own profits and the market wage of that period. In 11 groups of the LOADED treatment, we deviated from this and gave additional information about the choices of all six workers in the group. Our hypothesis was that the additional feedback supports learning. We do, however, find no impact of the additional feedback whatsoever (see Section 5.3 for an analysis of learning effects). For most of the paper, we therefore ignore the differences in feedback in the LOADED treatment and pool the data.

	LOADED_BASE	LOADED_FEED	NEUTRAL	Σ
detailed feedback	no	yes	no	
number of participants	72	66	66	204
number of independent groups	12	11	11	34
number of sessions	3	3	3	9
groups per session	4	3-4	3-4	

Table 2: Treatments.

The experiment was conducted at the experimental lab at the Technical University Berlin using the z-Tree software package by Fischbacher (2007) and Greiner's (2004) online recruitment system. In total, 204 subjects participated in the experiment, a session lasted around 60 minutes, and subjects earned between € 8.19 and € 12.51. The average payment was € 10.70. More details on the number of participants or the independent observations gathered in this experiment can be found in Table 2.

5 Results

5.1 Main Findings

This section summarizes the experimental results of the treatments Loaded and Neutral. We will give an overview of the participants' decisions and show how these decisions relate to the equilibrium predictions. We will also explore the differences between the treatments Loaded and Neutral. We mainly use non-parametric tests where we conservatively count each group of six players as one independent observation.

Our main research question is whether and to what extent subjects reveal their productivity. Table 3 displays the relevant revelation rates per market, averaged across the six workers. It turns out that subjects reveal significantly too little compared to the Nash prediction, except for Market A where observed and predicted behavior are quite similar. For example, in the Market B of treatment Loaded, subjects reveal in 53.0% of the cases whereas the prediction is 83.3%. Similar findings result for Market C. In Neutral, revelation rates are somewhat closer to the prediction but still differ markedly. Using a sign test, revelation rates are significantly below the prediction in Markets B and C of both Loaded and Neutral (two-sided tests, all $p < 0.05$). We refer to this finding as *under-revelation*. (We will come back to the higher revelation rates in Neutral and the apparent exception of Market A.)

	Market A		
	equilibrium	Loaded	Neutral
reveal	0.167	0.188	0.176
(std. dev.)		(0.068)	(0.037)
	Market B		
	equilibrium	Loaded	Neutral
reveal	0.833	0.530	0.618
(std. dev.)		(0.155)	(0.108)
	Market C		
	equilibrium	Loaded	Neutral
reveal	0.500	0.361	0.448
(std. dev.)		(0.094)	(0.062)

Table 3: Revelation rates (market average across all six workers). Standard deviations (in parenthesis) are calculated using group averages.

Table 4 reports the results of probit regressions (clustered at the group level)[11] providing further statistical support for these observations. The dependent variable, *Consistency*, indicates whether a subject behaves in line with the Nash prediction. The dummy

[11] See Martin, Normann and Snyder (2001) for a formal definition of the standard errors in this case.

variable *Reveal* indicates the equilibrium action of the corresponding subject (*Reveal* = 1). The dummy for the treatment with the loaded frame is *Loaded* and *Period* captures possible time trends. The dummy variables *Market A* and *Market B* represent departures from the (baseline) Market C in the regression. Considering the different markets, the regressions confirm that there are more equilibrium choices in Market A and fewer equilibrium choices in Market B compared to Market C.

	(1)	(2)	(3)
Reveal	-0.911***	-0.786***	-0.786***
	(0.0962)	(0.149)	(0.149)
Loaded	-0.370***	-0.248	-0.196
	(0.130)	(0.194)	(0.215)
Reveal×Loaded		-0.167	-0.167
		(0.205)	(0.205)
Market A	0.226***	0.224***	0.224***
	(0.0760)	(0.0762)	(0.0762)
Market B	-0.210***	-0.212***	-0.212***
	(0.0504)	(0.0507)	(0.0507)
Period	0.0647***	0.0651***	0.0781**
	(0.0177)	(0.0180)	(0.0373)
Period×Loaded			-0.0179
			(0.0425)
Constant	1.606***	1.513***	1.475***
	(0.128)	(0.159)	(0.182)
Observations	3,060	3,060	3,060
Pseudo R^2	0.145	0.145	0.145

Robust standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 4: Probit regression results on the equilibrium consistency of choices.

Observation 1. *In Markets B and C of treatments* LOADED *and* NEUTRAL*, we observe significantly fewer revelation decisions than predicted.*

There is a striking difference between the frequency of out-of-equilibrium revelation and concealment decisions. In the LOADED treatment, workers conceal when the equilibrium calls for revelation in 16%, 38%, and 33% of all decisions in Markets A, B and C, respectively; the corresponding frequencies for workers who reveal when the equilibrium predicts concealment are only 6%, 10%, and 6%. This difference is highly significant for all three markets (two-sided Wilcoxon signed-rank test, $p < 0.001$). In NEUTRAL these figures read 11%, 26%, and 16% (if the prediction is to reveal) and 3%, 0%, and 5% (for workers with a prediction to conceal) and the difference is also significant (two-sided Wilcoxon signed-rank test, $p = 0.003$). The regressions in Table 4 confirm that

Reveal has a highly significant negative influence on the likelihood of subjects choosing the equilibrium action.

Observation 2. *In both* LOADED *and* NEUTRAL*, workers who reveal in equilibrium violate the prediction significantly more often than workers who conceal in equilibrium.*

Note that this second observation qualifies the finding that revelation rates in Market A are equal to the prediction at the market level. Indeed, the revelation rates of Market A in Table 3 mask the fact that the single worker who is supposed to reveal in equilibrium fails to take the equilibrium decision about three times as often as the five workers who should not reveal in equilibrium on average. That is, we have far more out-of-equilibrium concealment compared to out-of-equilibrium revelation also in Market A.

We further break down behavior for the different productivities. Table 5 summarizes the equilibrium prediction and actual play for all workers in the three markets. Consider workers who are expected to reveal in equilibrium, denoted by the entry of 1 in the "Nash" row. The differences between actual revelation rates and predictions are major, ranging from from 15% up to 68% in LOADED. The table shows that these inconsistencies with equilibrium play are positively correlated with worker productivity for those workers who should reveal in equilibrium.[12] In contrast, inconsistencies with equilibrium play are not correlated with productivity when workers should conceal in equilibrium, and they are also generally small.[13] In NEUTRAL, the under-revelation result is less pronounced, and again the same correlation for out-of-equilibrium conceal decisions can be found but there is no correlation for out-of-equilibrium reveal decisions.

Worker	1	2	3	4	5	6
			Market A			
Nash	0	0	0	0	0	1
LOADED	0.02	0.07	0.04	0.06	0.10	0.84
NEUTRAL	0.04	0.02	0.02	0.02	0.07	0.89
			Market B			
Nash	0	1	1	1	1	1
LOADED	0.10	0.32	0.44	0.65	0.81	0.85
NEUTRAL	0	0.35	0.71	0.78	0.91	0.96
			Market C			
Nash	0	0	0	1	1	1
LOADED	0.04	0.03	0.09	0.41	0.77	0.83
NEUTRAL	0.04	0.04	0.09	0.62	0.93	0.98

Table 5: Average revelation rates across markets and treatments. An entry of 0 denotes that the worker is predicted to conceal while 1 denotes that the worker is predicted to reveal.

[12] A sign test (two-sided) on the sign of Spearman's ρ calculated for each group yields $p \leq 0.001$ for both, LOADED and NEUTRAL.

[13] A sign test (two-sided) on the sign of Spearman's ρ calculated for each group yields $p = 0.455$ for LOADED and $p = 0.508$ for NEUTRAL.

Observation 3. *In both* LOADED *and* NEUTRAL*, choices inconsistent with the equilibrium prediction are correlated with productivity when workers should reveal but not when they should conceal.*

5.2 Framing Effect

As is apparent from the results reported above, subjects in the NEUTRAL treatment reveal more often than in LOADED. We observe differences in three dimensions:

- When averaging across workers (Table 3), revelation rates are higher in NEUTRAL than in LOADED for Markets B and C, although this is only significant in Market C (two-sided Mann-Whitney U-Tests, Market C: $p = 0.008$; Market B: $p = 0.132$).
- We find that more decisions are in line with the equilibrium prediction in NEUTRAL than with the loaded frame. In LOADED, 79.8% of the decisions are consistent compared to 87.8% in NEUTRAL. This difference is significant (two-sided Mann-Whitney U-Test, $p = 0.027$).
- The higher level of equilibrium play in NEUTRAL has a distinct pattern: there are more equilibrium revelation choices, but not more equilibrium conceal decisions in NEUTRAL compared to LOADED. Averaging across the three markets in LOADED, we observe 34.2% conceal decisions of workers who should reveal in equilibrium and 6.2% reveal decisions for workers who should conceal in equilibrium. For NEUTRAL, the corresponding numbers are 20.8% and 3.6%. The decrease from 34.2% to 20.8% is significant (two-sided Mann-Whitney U-Test, $p = 0.024$) but the decrease from 6.2% to 3.6% is not (two-sided Mann-Whitney U-Test, $p = 0.356$).

The regression analysis in Table 4 supports these findings. *Loaded* leads to less equilibrium choices than the baseline treatment NEUTRAL, as expected. Adding the interaction *Reveal*×*Loaded* suggests that decisions in LOADED are less likely to be consistent with the equilibrium only when they concern reveal decisions, as argued above: in regressions (2) and (3) of in Table 4, *Loaded* is insignificant but *Loaded* together with the interaction term *Reveal*×*Loaded* is significant at the 5% level (Wald tests, in regression (2) $p = 0.012$, and $p = 0.022$ in (3)).

Observation 4. *In* NEUTRAL*, subjects reveal their productivity more often than in* LOADED*. While there are significantly more choices consistent with equilibrium in* NEUTRAL*, this effect is quantitatively and statistically significant only for workers who should reveal in equilibrium.*

These findings suggest that the labor market frame in combination with the health certificate affects choices. It gives rise to preferences not restricted to the monetary incentives of the game. A share of subjects were more reluctant to disclose their productivity in the loaded treatment where private information concerned the subject's health status. Hence, revelation of private information increases or decreases depending on the contextual frame, without any real privacy issues at stake in the experiment.

5.3 Learning and Feedback

We now check whether subjects learn to play the equilibrium over time and whether detailed feedback accelerates learning. As mentioned, we have employed two different feedback formats in the Loaded, Loaded_Base and Loaded_Feed treatments. In Loaded_Base subjects were only informed about their own profits and about the market wage of that period. In Loaded_Feed subjects received additional information about the revelation decisions of all six workers in the group.

Figure 1 shows the frequency of choices consistent with equilibrium over time. (We aggregate across markets because their time trends are virtually identical.) There is an increase in equilibrium decisions in all three treatments, Loaded_Base, Loaded_Feed and Neutral. Overall, however, learning effects appear to be only modest in this game. Equilibrium consistency increases by about 5 to 8 percentage points. In contrast, choices observed in beauty contest games with similar group sizes quickly converge to the Nash equilibrium (see Nagel (1995)).[14]

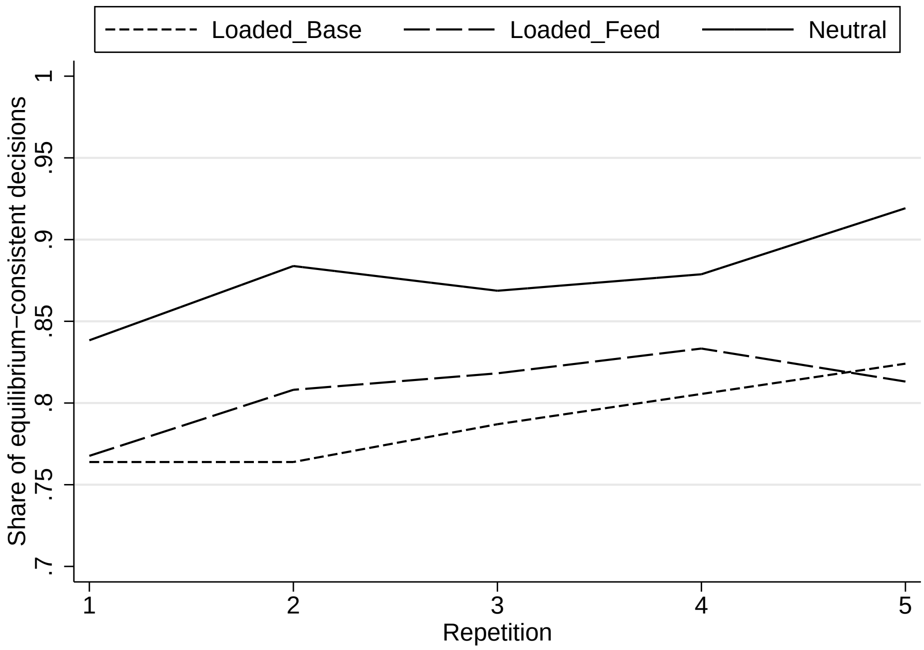

Figure 1: Fraction of equilibrium-consistent decisions across treatments over time.

[14]It may appear that, in Neutral, the overall rate of equilibrium consistent choices is reasonably high toward the end. Note, however, that this average includes all markets and all workers, and in Market A only one worker is supposed to reveal. As seen above, the rate of equilibrium inconsistency can be rather high for some markets and some workers. So the average error rate reported here suggests a substantial share of non-equilibrium decisions for some workers.

The results from the two variants LOADED_BASE and LOADED_FEED are very similar. Regarding the consistency of choices with the equilibrium predictions, we find that 78.9% and 80.9% of the decisions are consistent in LOADED_BASE and LOADED_FEED, respectively. The difference is not statistically significant ($p = 0.558$). The measures for under- and over-revelation with respect to the equilibrium predictions are also hardly distinguishable. About one-third of the decisions, 35.3% in LOADED_BASE and 32.9% in LOADED_FEED, are classified as under-revelation while the numbers for over-revelation are 6.9% and 5.5% in LOADED_BASE and LOADED_FEED, respectively. Neither under- nor over-revelation varies significantly across these two treatments, with corresponding p-values of 0.758 and 0.685. We also compared decisions between the two different feedback formats per market and per period but did not find any significant differences.

Finally, in the regressions reported in Table 4 the positive coefficient of *Period* shows that time positively influences the equilibrium play of the subjects. The effect is moderate and does not vary across treatments as the interaction term between *Period* and *Loaded* incorporated in regression (3) is insignificant. A test for joint significance between *Period* and this interaction is also insignificant ($p = 0.429$). Hence, we infer that there are no differences concerning learning between *Loaded* and in *Neutral*.

The findings in this section suggest that learning is difficult in the revelation game. From this we take that under-revelation is a robust phenomenon, not simply a mistake that subjects commit only once in a while. Nevertheless, let us note that while our focus has been on deviations from the equilibrium predictions, this is not to say that subjects' behavior is grotesquely inconsistent with the predictions. However, we believe it is important to investigate systematic deviations from equilibrium in order to better understand behavior in the context of voluntary information revelation and privacy.

6 Explaining under-revelation

In this section, we discuss explanations for the under-revelation results of Observations 1 to 3. We consider (i) level-k reasoning, (ii) quantal response equilibrium, and (iii) inequality aversion in the next subsections.[15] As none of the models can explain the observed framing effect, we focus on the treatment NEUTRAL, keeping in mind that the data in LOADED reveal even less disclosure of private information.

6.1 Level-k reasoning

To analyze our game with level-k reasoning, we assume that level-0 players randomize with probability 0.5 between their two actions, although the exact level-0 assumption

[15] We can dismiss risk aversion as a possible explanation for the under-revelation results. Risk aversion would predict the opposite behavior because revealing one's productivity guarantees a certain payoff whereas not revealing it causes a payoff that is uncertain.

does not matter much qualitatively for our game.[16] We then calculate the best replies for $k > 1$ where level-k', $k' > 0$ players believe that all other players reason at level $k = k' - 1$.

Table 6 displays the required levels of reasoning for players to pick their equilibrium action in the various markets for different productivities. The fewest iterations are required in Market A. The highest level-k requirement occurs in Market B for player 2 who has to perform five steps of reasoning. We note that level-k reasoning yields Nash equilibrium choices for a finite number of steps.

Productivity	Market A	Market B	Market C
θ_1	$200^{k\geq1}$	$200^{k\geq1}$	$200^{k\geq1}$
θ_2	$210^{k\geq1}$	$\mathbf{448}^{k\geq5}$	$280^{k\geq1}$
θ_3	$230^{k\geq1}$	$\mathbf{510}^{k\geq4}$	$360^{k\geq1}$
θ_4	$260^{k\geq1}$	$\mathbf{551}^{k\geq3}$	$\mathbf{440}^{k\geq3}$
θ_5	$300^{k\geq1}$	$\mathbf{582}^{k\geq2}$	$\mathbf{520}^{k\geq2}$
θ_6	$\mathbf{600}^{k\geq1}$	$\mathbf{607}^{k\geq1}$	$\mathbf{600}^{k\geq1}$

Table 6: Minimum k-level required for a player to choose her equilibrium action. Productivities in bold face indicate that this worker reveals in equilibrium.

Importantly, Table 6 also shows that taking the (equilibrium) decision to conceal merely requires level-1 throughout. By contrast, revealing may require up to $k = n - 1$ levels. As this property is central to our research question, we prove this generally.

Proposition 3. *Within the level-k model, workers who conceal if they are of type $k > 1$ also conceal if they a level-1 type.*

The proof can be found in the appendix. The proposition suggests that concealing already occurs for the lowest level of reasoning ($k = 1$): it is not possible, for example, that a worker reveals when she is a level-1 type but conceals when she is level-2.

The level-k patterns in Table 6 offer an explanation of Observations 1 to 3. The reason is that, as seen in Proposition 3, the revelation game requires increasingly higher levels of reasoning for the equilibrium decision to reveal, but only level-1 reasoning for equilibrium decisions to conceal. Under the assumption that at least some players display limited depth of reasoning, this implies (i) disproportionally more concealment in general, (ii) more consistency with the equilibrium prediction for workers who conceal than for those who reveal in equilibrium, and (iii) a negative correlation of equilibrium revelation decisions with productivities which does not hold for equilibrium conceal decisions.

[16] A different yet plausible assumption for level-0 types is that all workers conceal with probability one. In that case, it is straightforward to check that Markets A and B remain as in Table 6, but, in Market C, also worker 5 reveals when $k = 1$ and worker 4 when $k = 2$. Less plausible, in our view, is the level-0 assumption that all workers reveal with probability one. If so, the prediction is the same as when all workers conceal with probability one with all k-levels augmented by one. The logic is that when all players reveal, the $k = 1$ reply for all workers is to conceal with probability one.

More specifically, the level-k model predicts that the frequency of conceal decisions should be equal to the frequency of reveal decisions by worker 6 in all three markets because all of these decisions require at least level-1 reasoning. We find support for this hypothesis in NEUTRAL where we observe no significant differences in the fraction of equilibrium choices by those players (two-sided Wilcoxon matched pairs test, $p = 0.153$).[17]

	(4) Consistency	(5) Consistency	(6) Consistency
Min_k	-0.498***	-0.459***	-0.470***
	(0.0326)	(0.0339)	(0.0692)
Reveal		-0.443***	-0.444***
		(0.106)	(0.105)
Loaded		-0.421***	-0.457*
		(0.148)	(0.251)
Market A		0.0667	0.0670
		(0.0795)	(0.0799)
Market B		0.249***	0.249***
		(0.0564)	(0.0571)
Period		0.0744***	0.0744***
		(0.0200)	(0.0200)
Loaded×Min_k			0.0155
			(0.0780)
Constant	1.932***	2.102***	2.129***
	(0.0977)	(0.161)	(0.227)
Observations	3,060	3,060	3,060
Pseudo R^2	0.197	0.228	0.228

Robust standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 7: Probit regression results on the equilibrium *consistency* of choices.

The relevance of level-k reasoning can also be taken from the regression analysis summarized in Table 7 (the data are again clustered at the group level). In these regressions we consider the cardinal variable *Min_k*, defined as the minimum k-level required for an individual worker to choose her equilibrium action. This variable is highly significant in all regressions. That higher requirements on subjects' reasoning lower the likelihood for equilibrium play appears to have strong explanatory power. From column (5) it can be taken that adding the variables of the regressions in Table 4 hardly affects the coefficient of the minimum k-level required. In addition, we find that the variable *Min_k* fully explains the difference between the baseline Market C and Market A. The dummy variable *Market B* now has a positive influence on equilibrium play relative to Market C. Hence,

[17] In LOADED, there is more under-revelation by worker 6 than over-revelation by those workers who conceal in equilibrium. This can be attributed to the framing effect causing lower revelation rates.

the different behavior observed in the three markets is mainly a result of the different cognitive challenges of these markets.

The level-k model delivers an intuitive explanation for the behavioral patterns we observe in the experiments. As low-productivity workers with a prediction to reveal need to anticipate other workers' behavior much more accurately, their decisions are more challenging compared to high-productivity workers who should conceal. It follows that these low-productivity workers are more prone to making decisions that are inconsistent with the equilibrium and, consequently, there should be more under-revelation than over-revelation.

6.2 Quantal Response Equilibrium

Quantal Response Equilibrium (QRE), developed by McKelvey and Palfrey (1995), is another candidate for the analysis of deviations from standard Nash equilibrium. QRE is a generalization of Nash equilibrium that takes decision errors into account: workers do not always choose the best response with probability one but they choose better alternatives more frequently than others. Therefore, QRE allows for out-of-equilibrium choices to conceal and reveal one's productivity.

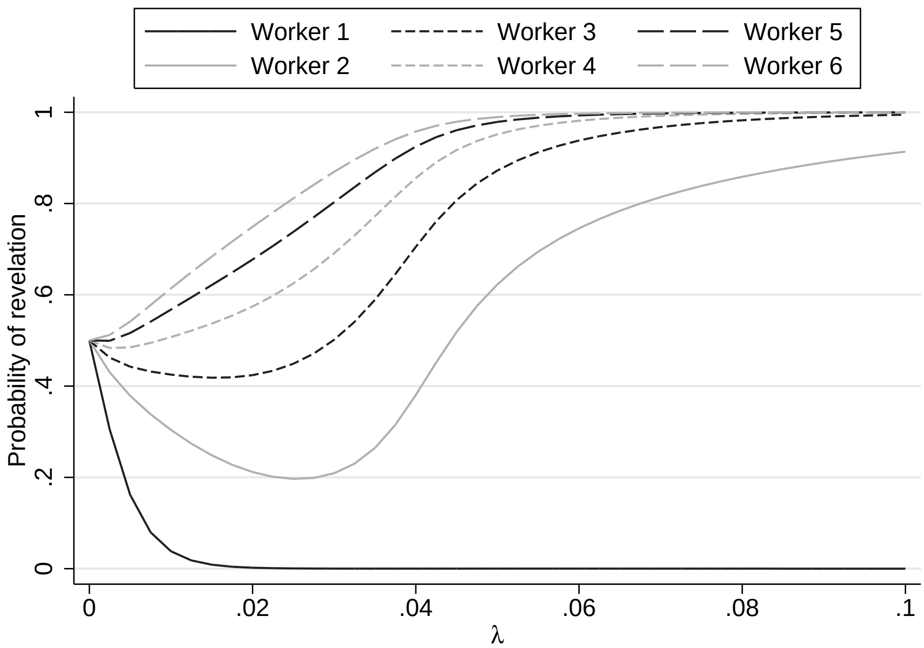

Figure 2: QRE predictions for Market B.

We employ the logit equilibrium variant of QRE. Worker i believes that the other workers will choose to reveal with certain belief probabilities and calculates her expected payoff from concealing based on this belief (the payoff from revealing is simply the productivity minus the revelation cost). Workers make better choices more frequently. In particular, choice probabilities are specified to be ratios of exponential functions where expected payoffs are multiplied with λ, the rationality parameter. This parameter captures deviations from the Nash equilibrium: if $\lambda = 0$, behavior is completely noisy and both choices are equally likely regardless of their expected payoff; as $\lambda \to \infty$, workers choose the best response with probability one. In the logit equilibrium, beliefs and choice probabilities are consistent.

As an example, Figure 2 displays the QRE predictions (revelation frequencies given the rationality parameter λ) for Market B. We note that QRE can explain the under-revelation result: for any $\lambda > 0$, the error probabilities are higher for workers 2 to 6 who reveal in equilibrium than for worker 1, suggesting too little revelation. The relationship between the probability of revealing and λ is even non-monotonic for some workers, so a higher λ can be associated with less revelation. The intuition is that the likelihood that worker 6 reveals must meet a certain threshold before other workers start preferring revelation over concealment. Thus, λ must be high enough. On the other hand, the higher the parameter λ, the more weight the best response gets such that the propensity to conceal can increase in λ as long as worker 6 does not reveal with a significantly high probability. Such a non-monotonicity cannot be observed for workers that should conceal in equilibrium in any of our markets. Qualitatively, Market C looks the same as Figure 2. In Market A, there are no non-monotonicities since all workers except worker 1 conceal in equilibrium.

We conduct a maximum-likelihood estimation of the QRE parameter λ for the treatment Neutral. Following Haile, Hortaçsu and Kosenok (2008), the estimation is implemented jointly for our three markets such that there is only one free parameter in the model we estimate. We find an estimate of $\lambda = 0.035$ with a standard error of 0.0015, suggesting that λ significantly differs from zero.[18]

Table 8 summarizes the QRE prediction for the λ we estimated from the data and contrasts this prediction with our findings. Overall, QRE fits the data well. It correctly predicts the degree of under-revelation (of workers 2, 3, 4, 5, and 6 in Market B; and workers 4, 5, and 6 in Market C). The predicted and observed frequencies of revelation are remarkably similar. Also, the low revelation frequencies of low-productivity workers who should conceal in equilibrium are predicted rather well (workers 1, 2, and 3 in Market A; and workers 1 and 2 in Market C). On the other hand, the QRE predictions for some of the workers who conceal in equilibrium do not perform as well. QRE predicts substantial rates of out-of-equilibrium revelation decisions with about 20% for worker 5 in Market A and for worker 3 in Market C. In both cases, less than 10% revelation is observed. Nevertheless, the QRE model captures the overall patterns of behavior well and can therefore account for the lower revelation rates that we observed compared to the equilibrium.

[18] Separate estimates for the three markets yield $\lambda_A = 0.026$, $\lambda_B = 0.039$ and $\lambda_C = 0.029$. The QRE estimate for the three markets in Loaded is $\lambda = 0.017$

Worker	1	2	3	4	5	6
			Market A			
Nash	0	0	0	0	0	1
QRE	<0.01	0.01	0.02	0.06	0.20	>0.99
NEUTRAL data	0.04	0.02	0.02	0.02	0.07	0.89
			Market B			
Nash	0	1	1	1	1	1
QRE	<0.01	0.27	0.60	0.78	0.87	0.92
NEUTRAL data	0.00	0.35	0.71	0.78	0.91	0.96
			Market C			
Nash	0	0	0	1	1	1
QRE	<0.01	0.02	0.21	0.67	0.93	0.99
NEUTRAL data	0.04	0.04	0.09	0.62	0.93	0.98

Table 8: QRE estimates and data from NEUTRAL

6.3 Inequality aversion

Does fairness prevent the revelation of private information? In our game, when the highest productivity worker chooses to reveal it increases her own payoff but imposes a negative externality on others.[19] Similarly, given the best worker reveals, the same can hold true for the second most productive worker. Accordingly, inequality-averse subjects may be less inclined to reveal their productivity than the standard model of selfish payoff maximizers suggests. While such motives may play only a minor role in large markets like the labor market, they may be important in smaller groups (small teams or enterprises) and in our experimental groups of six.

We use the model of inequality aversion proposed by Fehr and Schmidt (1999) (henceforth F&S) where players are concerned not only about their own material payoff but also about the difference between their own payoff and other players' payoffs. As a consequence the players' utility is

$$U_i(x_i, x_j) = x_i - \frac{\alpha_i}{n-1}\max[x_j - x_i, 0] - \frac{\beta_i}{n-1}\max[x_i - x_j, 0] \quad (1)$$

where, x_i and x_j denote the monetary payoffs to players i and j, and α_i and β_i denote i's aversion toward disadvantageous inequality (envy) and advantageous inequality (greed), respectively. Standard preferences occur for $\alpha = \beta = 0$. Following F&S, we assume $0 \leq \beta_i < 1$.

There are two complications regarding the impact of inequality aversion. One issue is that the effect on inequality of (not) revealing one's productivity will often be ambiguous: a worker may find that concealing reduces the advantageous inequality with respect to less

[19] As an example, consider Market A. The Nash equilibrium has only worker 6 revealing her productivity, and worker 6 earns 500 points in equilibrium whereas all others earn 240 points. If worker 6 did not reveal, everybody would earn 300 points. It follows that, for a sufficiently inequality-averse subject, concealing may yield a higher utility than revealing.

productive workers but it may also increase the payoff difference to the more productive workers provided they reveal. So this worker may stick with her (standard) equilibrium action even if she is inequality averse. Another complication is that there are multiple equilibria. It is not straightforward to show which of the $2^6 = 64$ possible outcomes can be an equilibrium for inequality-averse players and which cannot.

To tackle these issues we employ simulations based on a calibrated version of the model to identify the F&S equilibria of the revelation game. The model is calibrated using the joint distribution of the α and β parameters observed in Blanco, Engelmann and Normann (2011). For each subject, they derive an α_i from rejection behavior in the ultimatum game and a β_i from a modified dictator game. There are 61 subjects in this data set with 58 different α_i-β_i types.[20] Note that we need the *joint* distribution of the parameters, which is unavailable elsewhere. The computer simulations are implemented as follows: In each trial, the program randomly assigns an α_i-β_i parameter combination to each of the six workers (with replacement), where the 61 α_i-β_i types in the Blanco et al. (2011) data were equally likely. Given the realization of inequality parameters, the program then systematically checks which of the 64 possible outcomes turns out to be an equilibrium. Note that there can be multiple equilibria, which is also the reason why the percentages do not add up to 100%. For the three markets A, B, and C separately, we ran 100,000 trials.

	Actions of workers						Market		
No.	I_1	I_2	I_3	I_4	I_5	I_6	A	B	C
1	0	1	1	1	1	1	–	90.5%	–
2	0	0	1	1	1	1	–	3.9%	–
3	0	0	0	1	1	1	–	7.2%	61.9%
4	0	0	0	0	1	1	–	9.5%	20.2%
5	0	0	0	0	0	1	80.3%	14.8%	17.0%
6	0	0	0	0	0	0	19.7%	55.6%	8.4%
7	0	0	0	0	1	0	–	–	5.2%

Table 9: Summary of F&S equilibria. Note: because of multiple equilibria, the figures do not always add up to one hundred percent.

The simulation results are summarized in Table 9 which can be read as follows. First, note that seven equilibria emerge out of the 64 possible outcomes where each is described in a separate row of the table. In equilibrium 1, only worker 1 chooses to conceal while all the other workers reveal. This strategy profile was an F&S equilibrium in 90.5% of the 100,000 simulations of Market B where it is also the standard Nash equilibrium. There appear to be no F&S parameters which support this outcome as an equilibrium for Market A or C.

[20] There are no significant differences between the distributions of α that Blanco et al. (2011) elicit and the one assumed in Fehr and Schmidt (1999). The distributions of β differ, but they are still roughly comparable.

Overall, inequality aversion is consistent with our under-revelation result. The simulations show that there are equilibria with F&S preferences where fewer players reveal than in a standard Nash equilibrium, and there are no F&S equilibria where more players reveal than in a Nash equilibrium.

Having said that, there are some aspects of the simulations that show the limits of inequality aversion for rationalizing our data. Firstly, and perhaps surprisingly, the standard Nash equilibrium is very often also an equilibrium with F&S preferences. In all three markets, it is the most frequent equilibrium: 90.5% (Market B), 80.3% (Market A) and 61.9% (Market C) of the 100,000 random realizations of α_i-β_i parameter combinations. Relatedly, the F&S equilibria consistent with our data occur with rather low frequencies. In other words, there are only a few F&S parameter combinations that support these equilibria. For instance, in Market B, we observe especially minimal revelation by workers 2 and 3 which may be captured by the F&S equilibria numbered 2 and 3. However, these equilibria do not occur often in the simulations. Moreover, the calibrated F&S model predicts that there is an equilibrium in which no worker reveals (equilibrium 6), and this equilibrium occurs in more than 50% of the runs for Market B where we in fact observe a lot of revelation, in line with the equilibrium prediction.

Secondly, the simulations show that coordination problems may occur due to multiple equilibria. In Market B there is a unique equilibrium in 26.6% of the cases, two equilibria in 65.5%, and three equilibria in 7.9% of the cases. The corresponding values for Market C are 87.3% and 12.7% for one or two equilibria, respectively. It is unclear how inequality-averse players can resolve the coordination problems resulting from multiple equilibria. In Market A, we always found a unique equilibrium, but this market is not strongly supportive of inequality aversion either. The equilibrium for Market A can be found analytically: worker 6 will not reveal if and only if $\beta_i > 200/260 \approx 0.8$. This condition will be met for 20% in the data set of Blanco et al. (2011) (and our simulations indicate exactly the same frequency for the occurrence of this equilibrium). In NEUTRAL this equilibrium occurs, however, only with a frequency of 11%. While the loaded frame leads to results closer to the prediction, inequality aversion should not be driven by the frame. Overall, we can explain the observed outcomes as equilibria when players have F&S preferences. Thus, inequality aversion can account for the under-revelation observed in our revelation game experiment.

6.4 Discussion

Our goal in this section has been to show how three different behavioral models all predict that less unraveling than in the standard Nash equilibrium will occur. The three canonical behavioral models discussed all suggest that there are systematic reasons for players not to reveal. By contrast, we found hardly any support for a hypothesis suggesting that players reveal too much as compared to the equilibrium. This, together with the experimental evidence, implies a strong behavioral prediction that less unravelling occurs in real markets than predicted with fully rational and selfish players.

The analysis is *not* aimed at conducting a horse race among behavioral models to find out which of them best explains the data. Nevertheless, we believe that level-k or a limited depth of reasoning is a prime and parsimonious model for explaining our data. The privacy debate about the voluntary revelation of private information literally makes use of steps of reasoning when discussing unraveling (*given* some people reveal, more workers will do so, and so on). Level-k reasoning leads to two clear-cut propositions suggesting under-revelation: equilibrium concealment only requires $k = 1$ whereas revelation may require higher levels of reasoning. When higher levels of reasoning are increasingly rare among subjects, it follows for our setup that there is generally too little revelation; the lower the worker's productivity, the less likely the worker will reveal if the equilibrium calls for revelation; and there are virtually no equilibrium-inconsistent reveal decisions. This is what we see in the data.

With QRE, the frequency of the decision errors depends on the payoff magnitude of the decisions to reveal and to conceal and on the rationality parameter. QRE suggests that the payoff from concealing will, all else being equal, become more attractive than the payoff from revealing for workers with low productivity.[21] It follows that the (expected) payoff differences between concealing and revealing are small for workers with low productivity. Even when the equilibrium calls for revelation, QRE suggests (at least for the parameters we estimate) that a sizeable share of decisions will be mistaken. Boundedly rational players will therefore often fail to reveal but will rarely fail to conceal. The distribution suggested by QRE fits quantitatively well with the data, however, we note that this distribution is derived from a parameter estimated with our data. By contrast, with inequality aversion we used previous experiments for a comparison to our data and level-k reasoning produces only qualitative predictions. One aspect QRE does not capture well is that it also predicts substantial rates of out-of-equilibrium revelation decisions which, however, rarely occur in the data. In contrast, according to the level-k model only level-0 players may or may not conceal when the equilibrium calls for revelation. As a consequence, level-k does not predict an out-of-equilibrium revelation to be correlated with the worker's productivity which appears to be more in line with our data.

In different manners level-k and QRE take into account that the payoff from concealing will *ceteris paribus* become more attractive than the payoff from revealing, $\theta_i - c$, for workers with low θ. It requires a "high level of rationality" (high k or high λ) for unraveling

[21] In fact, due to the deviations from equilibrium in Markets B and C, for some players it is no longer a standard best reply to choose their equilibrium action given the choices of the other players. In these cases, deviating from the equilibrium choice is ex-post payoff maximizing. In particular, we find that in Market B workers 2 and 3 earn on average 407 and 431 points if they conceal, respectively, which is more profitable compared to the 348 and 410 points they earn if they reveal. In Market C only worker 4 should deviate from the equilibrium and conceal, thereby earning on average 342 points compared to 340 points after revelation. Note that payoff differences are small, however, so for moderate λ parameters QRE will suggest that both actions should be played frequently.

to occur to the extent predicted in equilibrium. Thus, both models suggest that the unraveling process might be stuck after a few players, leading to less revelation.

Markets played by fully rational yet inequality-averse players may also unravel only incompletely. The negative externality imposed on others may make even high-productivity workers conceal. On the other hand, inequality aversion supports the Nash equilibrium with standard preferences. Another difficulty is that multiple equilibria occur, which reduces the predictive power of such preferences. However, in small groups of players, perhaps non-binding communication may enable players to coordinate on equilibria with very little revelation.

7 Conclusion

We study experimental labor markets where workers have private information about their productivity which they can perfectly reveal at a cost. Whereas standard Nash equilibrium predicts unraveling and the disclosure of private information, we observe that workers do so less often than predicted. The propensity to conceal when the equilibrium calls for revelation is in stark contrast to the low frequency of decisions inconsistent with equilibrium when a worker should conceal. These findings are robust across both treatments we conducted.

Three behavioral models suggest the incomplete unraveling we observe: level-k reasoning, quantal-response equilibrium, and inequality aversion, although for different reasons. Level-k reasoning and quantal-response equilibrium predict that boundedly rational players will conceal frequently, and only with fully rational players will there be complete unraveling. Out-of-equilibrium revelation, by contrast, will be rare as concealing in equilibrium does not require more than one step of reasoning (level-1 type). Inequality-averse players may be reluctant to reveal when it increases payoff differences.

With the help of a treatment using a neutral frame we also identify a framing effect. When the wording suggests that the information to be disclosed is particularly sensitive subjects reveal significantly less frequently compared to the neutral frame. We believe that this framing effect is driven by subjects' privacy concerns, and that subjects have a taste for privacy *per se*.

The implications of our results for policy are as follows. Revelation costs are detrimental to welfare and hence under-revelation has a direct positive effect on welfare. In our setting, there are no benefits from sorting workers, so the higher level of concealment we observe improves welfare. That subjects reveal less than in the equilibrium benchmark can also be seen as desirable from the point of view of protecting privacy: if the unraveling argument is worrisome because it suggests that the protection of personal data is futile, limits to unraveling are a welcome counterforce. However, while our experiments show that the unraveling of private information is less severe than predicted with fully rational and selfish players, the overall level of information revelation is non-negligible and some unraveling can be observed. We therefore believe that the debate about how to limit the externalities of voluntary disclosure and how to regulate information disclosure is relevant, even though unraveling processes may be more sluggish or may stop earlier than the standard model predicts.

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Appendix

Proofs

Proof of Proposition 1.

Proof. We first show that $I_1^* = 0$. By concealing, the lowest productivity worker 1 earns at least θ_1 (namely when all other workers reveal, otherwise more), but worker 1 earns $\theta_1 - c < \theta_1$ by revealing. Hence, concealing is strictly dominant for worker 1 and we have $I_1^* = 0$ in equilibrium.

Next, we prove that $I_i^* = 0 \wedge I_j^* = 1$ only if $\theta_i < \theta_j$ strictly. Consider an equilibrium outcome with $I_i^* = 0$ and $I_j^* = 1$ and denote $\theta' = \sum_{m \neq i,j}(1 - I_m)\theta_m$ and $I' = \sum_{m \neq i,j}(1 - I_m)$. Now $I_i^* = 0$ and $I_j^* = 1$ are best replies to action profile I' if and only if

$$\theta_i - c \leq \frac{\theta_i + \theta'}{1 + I'} \tag{2}$$

$$\theta_j - c \geq \frac{\theta_i + \theta_j + \theta'}{2 + I'} \tag{3}$$

where the inequality for player i follows from $I_i = 0$ and the inequality for j follows from $I_j = 1$. Solving both equations for θ', we obtain

$$-c + (\theta_i - c)I' \leq \theta' \leq \theta_j - \theta_i - 2c + (\theta_j - c)I' \tag{4}$$

and

$$0 \leq -c + (\theta_j - \theta_i)(1 + I') \tag{5}$$

which holds only if $\theta_i < \theta_j$ strictly. Since $I_i^* = 0 < 1 = I_j^*$ only if $\theta_i < \theta_j$, we cannot have $I_{i+1}^* < I_i^*$ and thus $I_n^* \geq I_{n-1}^* \geq ...I_2^* \geq I_1^*$ as claimed. □

Proof of Proposition 2.

Proof. We first show that, if $\min(R) > \max(C)$ as asserted in the proposition, we get a unique equilibrium. Assume that, say, $R = \{n, n-1, ..., m\}$ and $C = \{m-1, m-2, ..., 1\}$. Then the pure strategy action profile

$$1 = I_n^* = I_{n-1}^* = ... = I_m^* > I_{m-1}^* = ... = I_2^* = I_1^* = 0$$

is a Nash equilibrium by the definition of R and C.

Now consider another pure strategy equilibrium candidate where, from Proposition 1, we only need to consider outcomes where $I_n^* \geq I_{n-1}^* \geq ... \geq I_2^* \geq I_1^* = 0$. Assume first that more workers reveal in this equilibrium candidate than in the first equilibrium, that is, workers $m-1$ to $m-k$, $k \geq 1$, reveal in this alleged equilibrium (whereas they conceal in the first equilibrium):

$$1 = I_n^* = I_{n-1}^* = ... = I_m^* = I_{m-1}^* = ... = I_{m-k}^* > I_{m-k-1}^* = ... = I_2^* = I_1^* = 0$$

For this to be a Nash equilibrium, we necessarily need $\theta_{m-k} - c \geq \frac{1}{m-k}\sum_{j=1}^{m-k}\theta_j$. However, this requires that $m-k \in R$ which is a violation of $\min(R) > \max(C)$. Consider a different pure strategy equilibrium candidate and where fewer workers reveal; say, workers m to $m+k$, $k \geq 0$ conceal (whereas they reveal in the first equilibrium). Here, we necessarily need $\theta_{m+k} - c \leq \frac{1}{m+k}\sum_{j=1}^{m+k}\theta_j$ for this outcome to be a Nash equilibrium. Hence, $m+k \in C$ which violates the assumption in the proposition. Hence, if $\min(R) > \max(C)$, the first Nash equilibrium is the unique pure strategy equilibrium.

We now show the "only if" part of the proposition by proving that, if $\min(R) > \max(C)$ is violated, we get multiple equilibria. Let m be the highest worker in C and l be the lowest worker in R and assume the violation: $m > l$. First, note that $m \in C$ iff $\theta_m - c \leq \bar{\theta}(m)$ which, implies that concealment is a best-response for the workers $1, ..., m$ given that the remaining workers reveal. From $m = \max(C)$ it follows that $\theta_{m+1} - c > \frac{\theta_{m+1} + \sum_{j=1}^{m}\theta_j}{m+1}$ and, by the definition of m, the inequality will also hold for all workers $m+1, ..., n$. Hence, we have a Nash equilibrium where the workers $1, ..., m$ conceal and the workers $m+1, ..., n$ reveal. Second, note that $l = \min(R)$ implies $\theta_{l-1} - c < \frac{\theta_{l-1} + \sum_{j=1}^{m-2}\theta_j}{l-1}$, that is, concealment is a best-response for the workers $1, ..., l-1$ given that the remaining workers reveal. As for the remaining workers, $l \in R$ implies $\theta_l - c \geq \frac{\theta_l + \sum_{j=1}^{l-1}\theta_j}{l}$ and the same inequality will hold for all workers $l, ..., n$. Hence we have a second Nash equilibrium where the workers $1, ..., l-1$ conceal and the workers $l, ..., n$ reveal. Hence, if $\min(R) > \max(C)$ is violated, multiple equilibria occur and the proposition follows. □

Proof of Proposition 3.

Proof. We prove the proposition by establishing a contradiction: suppose some worker conceals for $k = 2$ but reveals for $k = 1$. This yields a contradiction because, as we will show, the expected payoff from concealing is higher if $k = 1$ than if $k = 2$.

We first derive the best reply of a $k = 1$ player. Player i (when $k = 1$) believes that all other players randomize across both actions with a probability of 0.50. To calculate the payoff from concealing, player i needs to take into account all possible contingencies that may arise (no other player concealing, one of the $n-1$ other players concealing and so on) which yields a complex combinatoric expression. Specifically, player i (when $k = 1$) will reveal if and only if

$$\theta_i - c \geq \frac{\theta_i \sum_{a=0}^{n-1} \frac{\binom{n-1}{a}}{a+1} + (\sum_{j \neq i}\theta_j)(\sum_{a=1}^{n-1} \frac{\binom{n-2}{a-1}}{a+1})}{2^{n-1}} \tag{6}$$

or

$$\theta_i - c \geq \frac{\theta_i \sum_{a=0}^{n-2} \frac{\binom{n-2}{a}}{a+1} + (\sum_{j\in I} \theta_j)(\sum_{a=1}^{n-1} \frac{\binom{n-2}{a-1}}{a+1})}{2^{n-1}} \tag{7}$$

where the numerator arises because all possibilities occur with equal probability.

Note that, if (7) is met for player i, it will also be met for all workers with $\theta_j \geq \theta_i$. This follows from the observation that the factor of θ_i on the RHS of (7) is strictly smaller than one. Hence (when $k = 1$), workers $\theta_1, ..., \theta_m$ will conceal and workers $\theta_{m+1}, ..., \theta_n$ will reveal for some $m \geq 1$, unless we have the trivial case where all workers conceal.

As a next step, we show that a necessary condition for worker i to reveal (when $k = 1$) is $\theta_i > \frac{\sum_{j=1}^n \theta_j}{n}$. To prove this, we evaluate RHS of (7) when $\theta_i = \frac{1}{n}\sum_{j=1}^n \theta_j$. Simple but tedious combinatorics show a rather intuitive result, namely that this expression is greater or equal than the average worker productivity if and only if $\theta_i \geq \frac{1}{n}\sum_{j=1}^n \theta_j$. Thus, (7) will be met only if worker i's productivity is above average.

We now establish the fact that the condition for a $k = 2$ worker to conceal is weaker than the condition for a $k = 1$ worker to conceal. When $k = 2$, worker i believes that all other players are level $k = 1$, and, accordingly, that $\{\theta_1, \theta_2, ...\theta_m\}$ will conceal with probability one. Player i will conceal (when $k = 2$) if and only if

$$\theta_i - c \leq \frac{\theta_i + \sum_{i=1}^m \theta_j}{m+1}. \tag{8}$$

Now, for worker i to reveal when $k = 1$ necessarily requires $\theta_i - c \geq \frac{1}{n}\sum_{j=1}^n \theta_j$ but to conceal when $k = 2$ requires (8). Putting these condition together, we obtain

$$\frac{\theta_i + \sum_{i=1}^m \theta_j}{m+1} \geq \theta_i - c > \frac{\sum_{i=1}^n \theta_j}{n}. \tag{9}$$

This, however, cannot hold: it cannot be that the average of the low-productivity workers $1, ..., m$ plus worker i is larger than the average productivity of all workers because $\theta_i > \sum_j \theta_j/n$ for all $i > m$.

Since the condition for revealing as a $k = 1$ player contradicts the condition for concealing as a $k = 2$ player, it cannot be that player i reveals as a level $k = 1$ but but conceals as level $k = 2$. Hence, if player i conceals for $k = 2$, she will do so with $k = 1$ steps of reasoning.

Finally and intuitively, similar arguments show that a worker will conceal if $k = 2$ if she conceals when $k = 3$ and so on for a higher k. With a higher k, high types will "drop out" by revealing, leading to even lower concealment wages. Hence, workers who conceal for some k' will not reveal when $k < k'$. □

Instructions (Treatment Loaded)

Welcome to this experiment on economic decision making.

Please read these instructions carefully. The experiment is conducted anonymously, that is, you will not get to know which of the other participants interacted with you or which participant acted in which role. Please note that now that the experiment has started, you must not talk to other participants. If you have any questions, please raise your hand and we will come to you.

In this experiment all participants act as workers. The workers in this experiment differ with respect to their state of health. The state of health of a worker determines his or her productivity and hence also the revenue of a fictional employer (played by the computer). Furthermore, there are in total three different labor markets, which are played on a rotating basis: labor market A, labor market B and labor market C. At the beginning of each period, you will see a screen showing which market is being played in that period. There are six different workers with different states of health.

	Labor Market A	Labor Market B	Labor Market C
Worker 1	200	200	200
Worker 2	210	448	280
Worker 3	230	510	360
Worker 4	260	551	440
Worker 5	300	582	520
Worker 6	600	607	600
Average	300	483	400

Table 1: State of health of the workers 1-6 in the three labor markets.

In the table above you can see the different workers of this experiment and their state of health. Suppose market B is being played in this period. If the fictional employer (who is played by the computer) is hiring, for example, worker 3, then worker 3 will create a revenue of 510 points for the employer. Worker 1 will create a revenue of 200 points due to worse health. In a period where market C is being played the workers 1 and 3 create revenues of 200 (worker 1) or 360 points (worker 3). The state of health of any worker is of course completely fictional and is determined randomly by the computer.

The experiment lasts for 15 periods. At the beginning of a period a random draw will determine whether you act in the role of worker 1, 2, 3, 4, 5, or 6, and you will also be informed about the labor market being played in that period. Each group consists of six workers of different states of health. There is exactly one worker 1, one worker 2, one worker 3, and so on, and one worker 6 in each group. All workers 1 and 6 occur exactly once in each group. As mentioned before you will be informed about the market being played (A, B or C) at the beginning of a period.

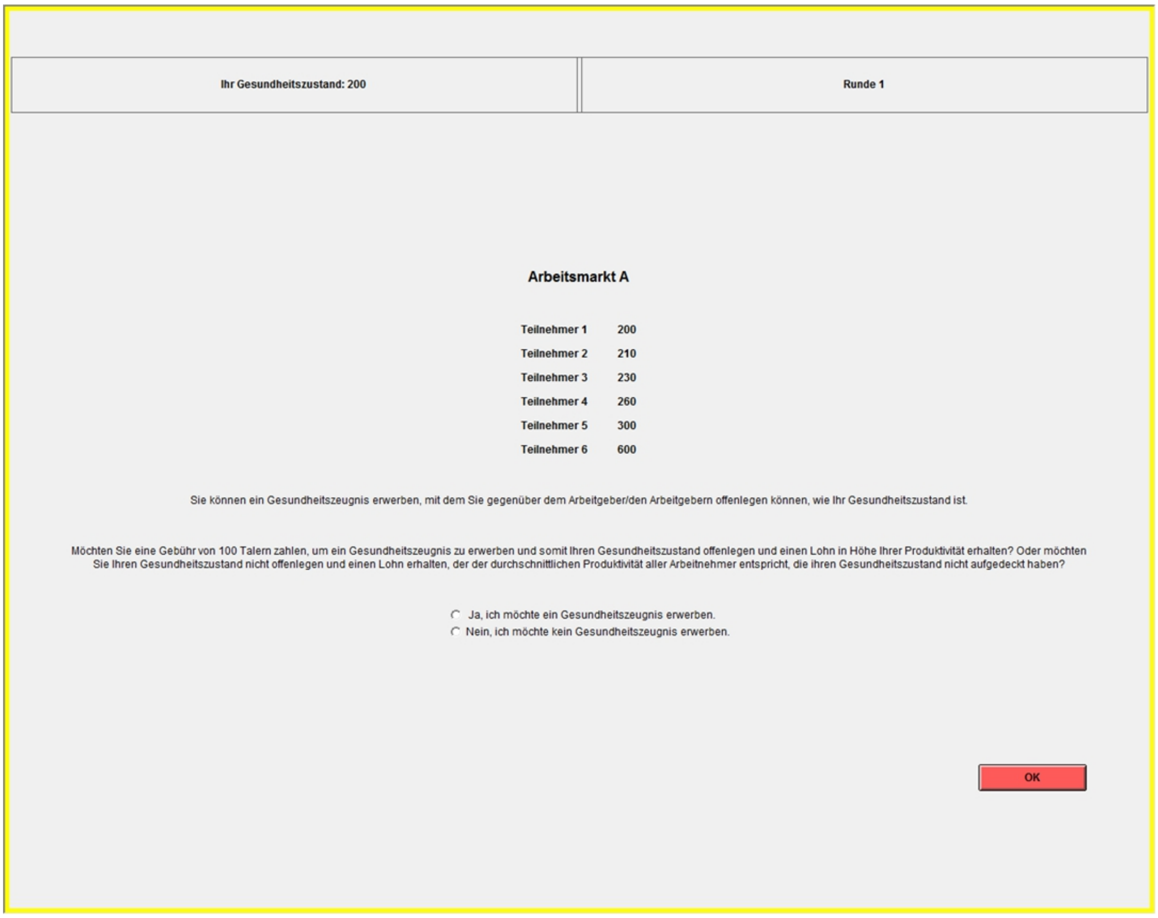
Your task in the experiment:

In each period all workers have to make the following decision. You choose whether or not to buy a health certificate at a cost of 100 points. The health certificate will reveal your state of health and will affect your payment in that period. Your payments depend on whether you purchased the health certificate:

1. If you choose to buy the health certificate you will receive your state of health in points as a wage payment minus the costs of 100 points.
2. If you do not purchase the health certificate your wage payment will be the average state of health of all participants who did not purchase the health certificate.

All workers decide simultaneously whether to purchase the health certificate. When you decide, you will not know how many (if any) of the other workers have chosen to buy the certificate. You will also not know the final market wage when making your decision. This information will be given only at the end of a period.

Once all workers have made their decisions you will receive detailed information on the period's results. The next period will begin as soon as all participants have read the summary and clicked on "Continue". Here is an example of the decision screen for market A and worker 1 with a state of health of 200:



Example:

Suppose market B is being played this period. The average state of health of all employees is:

$$\frac{200 + 448 + 510 + 551 + 582 + 607}{6} = \frac{2898}{6} = 483$$

The market wage would equal 483 points in this case. Now each worker decides whether to reveal his or her state of health. Once all participants have made their choice everybody will receive detailed information on the results. The table above also lists the average state of health for the markets A and C.

Assume that the workers 3 and 5 have revealed their state of health. In this case worker 3 would receive a wage payment of 510 points and worker 5 a wage payment of 582 points. Both chose to reveal their state of health and as a consequence both have to pay the costs of 100 points. Worker 3 earns 510-100 = 410 points and worker 5 earns 482 points in that period. The other workers (1, 2, 4, and 6) do not have to pay the costs and will receive the market wage as a payment. In this example the average state of health of all workers who do not have a health certificate is: $\frac{200+448+551+607}{4} = \frac{1806}{4} = 451.5$ points. This is also the market wage for the workers 1, 2, 4 and 6. In the experiment you receive this information after you have made your decision.

As mentioned earlier, the experiment will last 15 periods in total.

After the experiment your earnings will be converted at a rate of: 500 points = 1 Euro. Furthermore, we will round up your payoff to the next 50-cent amount.

At the end of the experiment, please wait inside your cubicle until we call you to pick up your payment. Please return any documents you have received from us.

If you have any further questions please raise your hand now!

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