Optimal Compensation in Online Labor Markets *

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Abstract

In online labor markets, workers with (partially) unobservable quality directly offer goods and services to consumers without firms intermediating production. We show that, in such an environment, optimal incentive provision interacts with consumption smoothing motives. A key element of optimal compensation schemes are stakes that reduce workers' income upfront and that are reimbursed upon the provision of high-quality output. If there is no firm to intermediate production, these stakes not only ensure self selection of high-quality workers into the online labor market, but also allow consumers to smooth consumption across states and, if they are liquidity constrained, also across time. We derive the optimal stake and find that it depends on the access of consumers to liquid funds. In addition, the optimal stake varies with characteristics of the consumer, the worker and the task. Our results have important implications for the optimal design of compensation schemes on platforms on which online labor services are traded.

Keywords: self selection, consumption smoothing, disintermediated production, online labor markets, asymmetric information.

JEL-codes: D15, D82, D86, E24, J33, M52.

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1 Introduction

Digital transformation has given rise to various types of online markets. A well-known example is the rapidly growing gig economy, an online labor market in which consumers can hire service providers on a freelance basis via digital platforms, e.g. Amazon MTurk, Fiverr, Guru, or UpWork. While some gig-economy business models, such as ride sharing, require buyer and service provider to be co-located, many other jobs can be delivered remotely. Examples are tasks related to graphics and design, programming, data analytics, or writing and translation. Despite its still relatively small size, the future potential of the gig economy is substantial. According to estimates of Blinder and Krueger (2013) for the U.S., 20-25% of occupations are amenable to online production.[1]

This paper shows that online labor markets give rise to a hitherto disregarded joint principal-agent and consumption smoothing problem. Specifically, because production or service provision in online labor markets is disintermediated, tasks which require some time imply that consumption smoothing motives directly interact with worker incentives.[2] In traditional markets, production or service provision is intermediated: firms hire workers and bear the liability for fraud, faulty work or other idiosyncratic output shocks, thus providing implicit insurance to workers (Guiso et al., 2005). Similarly, they offer their products and services to consumers through cash or credit purchases. Worker selection and the provision of consumer credit are separate issues for the firm. In online labor markets instead, performance pay systems for the self selection of workers can no longer be disentangled from the timing of payments relevant to consumers. Consumers become principals and need to worry themselves about adverse selection and mechanisms that reduce the risk of faulty work.

We contribute a detailed analysis of this novel situation in online labor markets and determine the optimal timing and size of payments between a risk-averse principal (the consumer) and a risk-neutral agent (the worker).[3] Because production is disintermediated, the principal has two simultaneous goals: (i) attract high-quality workers and (ii) smooth consumption across time and states. To our knowledge, the novel interaction of these goals has not been considered before. We focus on adverse selection because, for the typical gig-economy tasks mentioned above, worker quality is (at least partially) unobservable and ex ante information asymmetries are particularly severe in an online

[1] Blinder and Krueger (2013) provide measures for *offshorability* and ask survey participants whether their work can be done from a remote location without physical presence.

[2] Note that only production is disintermediated. Online markets themselves are intermediated through platform providers that match the transaction partners. The platform providers, however, typically neither produce the goods or services nor bear any liability for their quality.

[3] Although we focus on consumers for simplicity, the risk-averse principal could also be interpreted as a firm with possible financing constraints. In Appendix A.2, we extend the analysis to risk-averse workers.

setting (Autor, 2001; Stanton and Thomas, 2016, 2020). Reasons include the anonymity or pseudonymity of market participants, the shortcomings of existing signals such as reputation-based rating systems, and the dominance of one-off assignments.[4]

We find that a separating equilibrium is attainable with a variable compensation scheme, complementing a fixed wage payment with a stake (collateral) and a bonus.[5] The stake reduces the upfront payment from the consumer to the worker and is only reimbursed if the good or service has been provided with sufficient quality. The bonus is an additional reward for the successful completion of the project. Bonus and stake are neither perfect substitutes for the worker nor for the consumer. The bonus affects resources across states whereas the stake affects resources both across time and across states. We first derive the combinations of bonus and stake for which the expected marginal cost of employing a good or bad worker is equal. We do so from the perspective of the marginal employer across traditional and online labor markets. Subsequently, we demonstrate that the interplay between the self selection motive and the consumption smoothing motive determines a unique combination of bonus and stake in the separating equilibrium. Low-quality workers self select into jobs with the fixed wage and high-quality workers self select into jobs with the variable payment scheme, thereby extracting an information rent. At the same time, the variable compensation scheme allows the principal more flexibility in choosing the timing of the consumption stream.

The separating equilibrium improves welfare in two ways. First, self selection of good agents helps to reduce the risk of receiving a bad-quality product or service. Second, the variable compensation scheme allows the consumer (principal) to improve consumption smoothing across time and states. The first aspect is more valuable in the context of disintermediated production than in traditional markets, as consumers are not shielded from that risk by firms. In contrast to individual consumers, firms can diversify the risk of bad quality in production and mitigate the selection problem through screening, which is much more costly in online labor markets where principals and agents can act under pseudonymity and are not co-located. Moreover, in a digital setting, in which tasks are contracted and delivered remotely, enforcement is limited. This is because the transaction partners are dispersed across numerous jurisdictions worldwide and, at the same time, incentives to spend resources on lawsuits are curbed by the moderate size of typical transactions in online labor markets.[6]

[4]Based on proprietary data for five major English-speaking websites, representing almost three quarters of the online labor market, Stanton and Thomas (2020) report that more than half of all job postings between 2016 and 2020 did not strive for repeat transactions.

[5]Lazear (2000) and Dohmen and Falk (2011) show that performance pay matters for self selection.

[6]The limited enforcement together with the lack of intermediated production is what distinguishes online labor markets from more traditional markets for freelance work where the purchaser and worker often are based in the same jurisdiction.

Exploiting the timing of payments to the worker for consumption smoothing is particularly important for the consumer, if imperfect capital markets restrict access to liquidity. Empirically, a sizable part of the population faces severe liquidity constraints. A recent report on the economic well-being of U.S. households (Federal Reserve System, 2018), for example, finds that a third of all adults needs to sell assets, borrow from friends or family, use bank overdrafts or take out payday loans when confronted with an unforeseen expense of $400. 12% would not be able to cover such an expense at all. This is reflected by the size and importance of payday lending markets in developed countries, such as the U.S. and the U.K. (Stegman, 2007; Gathergood et al., 2018). Similarly, Kaplan et al. (2014) report that $20-30\%$ of households in developed countries are hand-to-mouth consumers. For members of these households, consumption smoothing is very costly, even over short horizons that may be considered particularly relevant in the context of tasks performed in the online labor market. Other households or individuals, in contrast, are able to smooth consumption at a much lower cost. Hence, we analyze the optimum for individuals both if they cannot borrow at all and if their consumption choices are not restricted by borrowing constraints.

Our work delivers important insights for practical applications. Risk-averse purchasers facing borrowing constraints are commonplace and comprise consumers, self employed or small businesses. These purchasers use online labor markets to source a range of services, such as web design, translations, photo editing or financial services. Our results suggest that platforms, running online labor markets, may exploit their data to come up with variable payment schemes for self selection which, at the same time, increase the demand by the aforementioned customers. Specifically, an online labor market platform may be more attractive than its competitors, if it offers a three-part compensation scheme and allows purchasers to flexibly determine the size and timing of the individual components, given their particular situation.

The remainder of the paper is structured as follows. In the next section, we review the relevant literature with an emphasis on our contribution. In Section 3, we present our model framework. Building on the classic contribution by Salop and Salop (1976) on self selection, we characterize wages in the pooling equilibrium and the variable compensation scheme in the separating equilibrium. We derive the set of combinations for the bonus and the stake that are consistent with a competitive equilibrium, in which the expected marginal cost of employing a worker of bad or good quality has to be equal for the marginal employer. In Section 4, we then derive the optimal compensation scheme chosen by a risk-averse consumer in online labor markets with disintermediated production. We analyze both the case with and without imperfect access of consumers to liquid funds. Extensions to the benchmark model setup are included in the Appendix. In Section 5, we provide comparative statics to illustrate how the optimal compensation scheme depends on characteristics of consumers, workers or tasks. In Section 6, we discuss the implications of our analysis for platforms on which online labor markets are implemented. Finally, in Section 7 we draw our conclusion.

2 Related literature

Our emphasis of the interaction between worker incentives and the timing of payments to and from consumers contributes to the growing literature on online labor markets. Recent work in this field includes Cullen and Farronato (2021) and Barach et al. (2020). The former analyze growth and matching efficiency in online labor markets across regions in the U.S., whereas the latter examine to which extent platforms, on which online labor markets are implemented, can improve matching quality by steering consumers. In related work, Stanton and Thomas (2016) find that outsourcing agencies increase the hiring probabilities and wages of online workers in the early stage of their career. Burtch et al. (2018) as well as Huang et al. (2020) consider how the growth of gig-economy platforms impacts local entrepreneurial activity and unemployment.

Our paper also contributes to the literature on principal-agent problems in the labor market. Adverse selection and moral hazard in the labor market have been the subject of a large number of studies, focusing on interactions between firms and workers. A comprehensive survey can be found in Oyer and Schaefer (2011).

We build on Salop and Salop (1976) who analyze a principal-agent problem between firms and employees and introduce a compensation scheme that incentivizes self selection to reduce labor market turnover. Our work differs in three major aspects. First, we consider the selection problem in a setting where firms do not intermediate production. The ensuing consumer perspective implies that incentive provision and consumption smoothing motives are intertwined. Second, instead of the two-part compensation scheme proposed by Salop and Salop (1976), we introduce a richer three-part scheme, consisting of wage, bonus and stake. Only with these three components, the compensation scheme can serve the purpose of consumption smoothing. Third, our stakes are not bounded by the size of the wage, because online markets can adopt technologies, such as smart contracts on a blockchain, that provide payment commitment upon objective verification of outcomes (see, e.g. Braun et al., 2021).

Our work also relates to recent work by Hoffmann et al. (2021) who examine the timing of pay in a principal-agent setting with moral hazard and an impatient, possibly risk-averse agent. In this context, Hoffmann et al. (2021) show that a trade-off arises between the backloading of payments and the agent's resources for consumption. Our problem is different from theirs in that we consider adverse selection rather than moral hazard and reveal the interactions between incentive provision and consumption smoothing. Moreover, we consider risk aversion of the principal rather than the agent.

If the stake in our model exceeds the fixed wage, the variable compensation scheme resembles a performance bond but there are key differences in our analysis relative to the literature on performance bonds in moral-hazard settings (see, e.g., Becker and Stigler, 1974; Lazear, 1979, 1981). Because of the objective verification and commitment technologies available in online markets, implementation in our setting is not hampered by bankruptcy risk and double moral hazard. The latter arises for classical performance bonds because principals may accuse agents of malfeasance to confiscate their collateral (Eaton and White, 1982; Shapiro and Stiglitz, 1984; Ritter and Taylor, 1994).

3 Self-selection in online labor markets

We extend the classic self selection model of Salop and Salop (1976) in several directions. Specifically, we allow for both intermediated and disintermediated production of the same type of goods and services, a risk averse principal, capital-market imperfections as well as a more elaborate variable compensation scheme.

Given our focus on online markets, we follow Belavina et al. (2020) in assuming limited enforceability of claims in case of low-quality work. We do not assume limited verifiability of outcome quality, however, as common in the literature on relational contracting (Levin, 2003; MacLeod and Malcomson, 1989).[7]

We consider the problem of a principal (the consumer), who orders goods or services from an agent (the worker). Workers are risk neutral and can be of good and bad type. Risk neutrality of workers is assumed for expositional simplicity. In Appendix A.2, we show how the analysis can be extended to a setting with risk-averse workers and that our main insights continue to hold.

The quality of produced goods or services can differ across workers. If a worker produces bad quality, the principal suffers a loss of size $\mathcal{L}$. The probability of producing low quality is higher for a bad than a good worker: $q_b > q_g$. The fractions of good and bad workers in the economy equal ϕ and $1-\phi$, respectively. This implies an average loss probability $\bar{q}$ of

$$\bar{q} = \phi q_g + (1-\phi) q_b. \tag{1}$$

[7] In online labor markets, the quality of outcomes can be verified and attributed to the specific worker ex post. For example, a low-quality or wrong translation can be spotted by native speakers. Similarly, an erroneous piece of software code can be identified because of bugs that prevent full execution of the program.

Compensation in online labor markets, as implemented by UpWork or Guru, e.g., takes the form of hourly wages with the possibility of bonus payments or fixed-price payment schedules based on achieved milestones. Our model captures the key features of these compensation schemes through the choice between a fixed wage and a variable compensation scheme consisting of a wage, bonus and stake. Our analysis will show that the variable compensation scheme offers enough flexibility to provide incentives for the worker and to allow consumers to smooth consumption across time and states.

Risk-neutral firms and risk-averse consumers both act as principals who hire workers in the labor market. Wage, bonus and stake in equilibrium, however, are determined by the marginal employer, which we assume to be the (representative) risk-neutral firm. This assumption is plausible because (i) risk-averse consumers have a higher willingness to pay for high-quality workers than risk-neutral firms to reduce the risk of losses,[8] and (ii) it is an empirical fact that employment in disintermediated production is still much lower relative to intermediated production. Therefore, not all good-quality workers are employed in disintermediated production. To isolate the role of the compensation scheme for self selection, we abstract from any other form of heterogeneity among firms and consumers in the recruiting process.[9]

Before we consider the problem of the consumer in Section 4, we derive the feasible combinations of bonus and stake, given (i) incentive compatibility for self selection of good-type workers into disintermediated production and (ii) consistency with a competitive equilibrium where a risk-neutral firm is the marginal employer. From these combinations, the consumer then selects the compensation scheme that allows for the optimal timing of consumption.

3.1 Self selection of workers in competitive equilibrium

3.1.1 Pooling equilibrium

It is instructive to briefly characterize the pooling equilibrium, with intermediary firms as marginal employers, before we turn to the analysis of the separating equilibrium. Assume that N homogeneous firms maximize expected profits and face a potential loss of $\mathcal{L}$. Furthermore, assume L workers that are employed by firms and each supply one unit of labor

[8]Implicitly, we assume that firms can better diversify potential losses caused by low-quality production than consumers so that they are approximately risk neutral. As explained further in Appendix A.1, a change of measure to obtain risk-neutral probabilities for the consumer's decision problem then implies, as is well known, that consumers behave *as if* they faced larger expected losses than firms. Thus, they have a higher willingness to pay for good workers to reduce these losses. We discuss this heterogeneity between firms and consumers further in subsection 5.1 in which we discuss welfare implications.

[9]Explicitly modeling the more severe asymmetric information problem in disintermediated production (Autor, 2001; Stanton and Thomas, 2016) would further increase the willingness to pay for good-quality workers in disintermediated relative to intermediated production.

to produce a single product or service on their own.[10] Firms can maintain job portfolios and thus hire several workers. Labor markets are characterized by perfect competition, i.e., both N and L are large.

The payments in the production process occur at different points in time. Workers receive the real wage w ex ante (in the current period $t = 1$), while the potential loss $\mathcal{L}$ occurs ex post (in the next period $t = 2$). The probability for a faulty outcome equals $\bar{q}$ because the workers' type cannot be distinguished in the pooling equilibrium. For a firm with L workers or tasks, the present values of the expected total cost TC and of the expected marginal cost MC are

$$TC = \left(w + \frac{\bar{q}\mathcal{L}}{1+r}\right)L, \tag{2}$$

$$MC = \frac{\partial TC}{\partial L} = w + \frac{\bar{q}\mathcal{L}}{1+r}, \tag{3}$$

with r denoting the real interest rate. For a marginal product of labor $MPL(\cdot)$, the wage payment is determined as follows.

Remark 1 *In a symmetric pooling equilibrium, the equilibrium wage is*

$$w^* = MPL\left(\frac{L}{N}\right) - \frac{\bar{q}\mathcal{L}}{1+r}. \tag{4}$$

Proof. Given our assumption of homogeneous firms, each firm employs labor input L/N. Rearranging (3) and setting the marginal product of labor $MPL(\cdot)$ equal to the (expected) marginal cost MC, implies (4). ■

3.1.2 Separating equilibrium

For the analysis of the separating equilibrium, we introduce a three-part variable compensation scheme with both upfront and retroactive payments. This scheme is designed to exclusively attract high-quality agents so that low-quality agents prefer the contract paying a non-contingent wage. The compensation scheme is independent of the principal type: it can be deployed by firms in intermediated production or by consumers in disintermediated production. It has the following components. At the beginning of the production process, the principal owes the agent a non-contingent wage w and the agent owes the principal a stake S. The stake serves as collateral. If the agent produces good quality so that no loss occurs upon completion of the task, the principal returns the stake

[10] We abstract from collaborative joint production of workers. Given the O-ring theory by Kremer (1993), this would add additional dimensions to the problem, such as joint incentive provision to induce assortative matching of high-skill workers.

S to the agent and additionally pays out a bonus B. Otherwise the principal retains the stake and pays no bonus.

We impose no *a priori* restrictions on the bonus and the stake other than that they are finite. Several standard cases are nested in the variable compensation scheme. If $S = 0$, we obtain a performance-based payment scheme with an ex-ante wage and an ex-post bonus. If $S = w$, the good or service is paid after successful completion of the task. The intermediate case $0 < S < w$ implies a partial down payment by the principal before the completion of the task. If $S > w$, the agent provides the principal with credit.[11]

Incentives for self selection.– Let $\mathcal{V}_i$ denote the present value of the expected variable payments from the perspective of the agent, which depend on the type-dependent probability q_i $(i = b, g)$:

$$\mathcal{V}_i \equiv -S + (1 - q_i)\frac{S + B}{1 + r}. \tag{5}$$

If $\mathcal{V}_i > 0$, the agent prefers the three-part variable compensation scheme. If $\mathcal{V}_i < 0$, the agent prefers the contract with the exclusive non-contingent wage. If $\mathcal{V}_i = 0$, the agent is indifferent. The principal searches for a combination of S and B, which ensures self selection of only good-quality agents into the variable compensation scheme.

Remark 2 *Only good-quality agents select into the variable compensation scheme if the combinations of bonus B and stake S satisfy*

$$\frac{r + q_g}{1 - q_g} \leq \frac{B}{S} \leq \frac{r + q_b}{1 - q_b}. \tag{6}$$

Proof. Because $q_g < q_b$, $\mathcal{V}_g > \mathcal{V}_b$. Thus, there exists an interval for the ratio B/S, in which good-quality agents prefer the variable compensation scheme because $\mathcal{V}_g \geq 0$ and bad-quality agents prefer the non-contingent wage because $\mathcal{V}_b \leq 0$. Solving $\mathcal{V}_g = 0$ and $\mathcal{V}_b = 0$ for the respective ratio B/S provides the bounds of the interval given by (6). ■

To simplify the analysis, we assume that the principal breaks the possible indifference of agents between compensation schemes using infinitesimally small side payments. Thus, at the bounds of the interval for B/S characterized in the previous proposition, the principal ensures that good agents select into the variable compensation scheme at $B/S = (r + q_g)/(1 - q_g)$ and bad agents do not at $B/S = (r + q_b)/(1 - q_b)$.

[11] As we show in Appendix A.3, $S > w$ implies that the principal needs to post collateral to ensure repayment of that part of the stake that exceeds the wage payment. Without this requirement, the presence of enforcement constraints would cause a "take the money and run" problem (Martimort et al., 2017).

Competitive equilibrium.– Risk-averse consumers in disintermediated production only employ good workers because they have a higher willingness to pay for those than risk-neutral firms (see the discussion at the beginning of Section 3). It follows that the marginal employer of good workers in the separating equilibrium is a representative risk-neutral firm. This firm has to be indifferent between hiring either one of the two worker types. In other words, from the firm's perspective, the expected marginal cost of employing bad workers with a non-contingent wage

$$MC_b = w + q_b \frac{\mathcal{L}}{1+r} \tag{7}$$

has to equal the expected marginal cost of employing good workers with a variable compensation schedule

$$MC_g = w + q_g \frac{\mathcal{L}}{1+r} - S + (1-q_g)\frac{B+S}{1+r}. \tag{8}$$

This leads to the following equilibrium relationship between the bonus B and the stake S.

Remark 3 *In the separating equilibrium with competitive markets*

$$B = \Delta(\mathcal{L}) + \frac{q_g + r}{1-q_g} S, \tag{9}$$

where $\Delta(\mathcal{L})$ represents the information rent extracted by the good workers:

$$\Delta(\mathcal{L}) \equiv \frac{q_b - q_g}{1-q_g}\mathcal{L}. \tag{10}$$

The non-contingent wage payment is

$$w^{**} = MPL\left(\frac{L}{N}\right) - q_b \frac{\mathcal{L}}{1+r}. \tag{11}$$

Proof. In competitive markets, the expected marginal cost of employing a bad worker equals the expected marginal cost of employing a good worker. Setting (7) equal to (8) yields (9). Good workers extract an information rent. Moreover, equating the marginal product of labor $MPL(\cdot)$ with the marginal cost for the bad workers MC_b as shown in (7), we obtain (11). The non-contingent wage payment in the separating equilibrium is paid to both worker types and is complemented with the bonus and stake for the good type. ∎

Intuitively, the bonus in (9) consists of the information rent $\Delta(\mathcal{L})$ as well as the expected loss of the stake $q_g S$ plus interest on the stake rS, scaled by the probability of success $1 - q_g$. Workers receive a higher bonus for a given stake if the interest rate r is higher. This term premium serves as a compensation for the stake being locked in during the production process. The information rent in (10) increases in the size of the loss and the unobservable heterogeneity in the workforce, as reflected by the difference between q_b and q_g. The interaction between these two magnitudes implies that smaller potential losses make the trait of having a lower loss probability less valuable.

The equilibrium relationship between B and S in (9) and the upper bound of the ratio B/S implied by the incentive constraint in (6) determine the minimum viable stake $S^{\min}$. At this stake, bad workers are indifferent between the non-contingent and the variable compensation scheme. For values of $S < S^{\min}$, separation of worker types through self selection would break down.

Corollary 1 *The minimum viable stake in the separating equilibrium is*

$$S^{\min} = (1 - q_b)\frac{\mathcal{L}}{1 + r}. \tag{12}$$

Proof. Using (5) to solve $\mathcal{V}_b = 0$ for the bonus B and substituting B into equation (9), we obtain (12). ■

$S^{\min}$ (together with the corresponding bonus B) increases in the success probability of the bad-type worker $(1 - q_b)$ and increases in the present value of the loss $\frac{\mathcal{L}}{1+r}$. In combination with the equilibrium relationship (9), $S \geq S^{\min}$ with $S^{\min}$ given by (12) determines the set of combinations (B, S) which ensure self selection of good workers into the variable compensation scheme and, in turn, consistency with a competitive equilibrium, i.e., zero profits of the marginal employer.

4 Consumption smoothing in online labor markets

We show that disintermediated production with risk-averse consumers as principals implies a unique pair (B, S), for which good workers self select into the variable compensation scheme and consumers maximize their expected utility. More specifically, risk-averse consumers take (9) and (12) as given and choose the combination of B and S, for which they optimally smooth consumption across time and states.

Our key results depend on the consumer's access to capital markets. In case of unlimited access, the bonus and the stake are perfect substitutes for the purpose of consumption smoothing and the optimal consumption stream can be decoupled from the payments to the worker. However, if the consumer has limited access to a non-contingent asset, then the bonus and the stake are imperfect substitutes. The reason is that the stake allows the consumer to achieve some degree of consumption smoothing across time, whereas the bonus does not.

Against this background, it is instructive to begin with the assumption that consumers do not have access to capital markets (Subsection 4.1). In the next step, we then extend the analysis to consumers with access to a non-contingent bond and a possibly binding borrowing constraint (Subsection 4.2). We show that the results for consumers at the borrowing constraint are qualitatively the same as for consumers without access to capital markets.

4.1 No access to capital markets

Without access to capital markets, the maximization problem of the consumer (risk averse principal) is subject to the following flow budget constraints at times $t = 1$ (start of task) and $t = 2$ (end of task):

$$c_1 = y_1 - (w - S), \tag{13}$$

$$c_2 = \begin{cases} y_2 - \mathcal{L} & \text{with probability } q_g \\ y_2 - (B + S) & \text{with probability } (1 - q_g) \end{cases}, \tag{14}$$

where $q_i = q_g$ because it is optimal for the consumer to implement the variable payment scheme so that good-type workers perform the task.[12] The endowment of the consumer at each point in time is represented by y_t ($t = 1, 2$). The consumer's preferences are described by utility function $u(\cdot)$ over consumption c. The utility function is upward sloping ($u'(\cdot) > 0$) and strictly concave ($u''(\cdot) < 0$); ρ denotes the subjective discount rate (impatience), with $0 \leq \rho < \infty$. Inserting the flow budget constraints for consumption in $t = 1, 2$ into the utility function and substituting the bonus using equilibrium condition (9),[13] we obtain

[12]Recall that the marginal cost of employing a bad-type or good-type worker is equal for the risk-neutral firm and the risk-averse consumer has a higher willingness to pay for the good-type worker than the firm.

[13]Substituting the equilibrium condition (9) for the bonus ensures that the consumer decisions are consistent with the relationship between bonus and stake imposed by the zero-profit equilibrium condition of the representative intermediary firm that is the marginal employer. The consumer takes this relationship as given. If the consumer offered a higher bonus for a given stake than implied by the zero-profit condition, utility would not be maximized. If the consumer offered a lower bonus, then the good-type worker would prefer to work at the firm.

the following maximization problem:[14]

$$\begin{aligned} \max_{S} \quad & u(y_1 - (w - S)) + \\ & + \frac{1}{1+\rho}\left[q_g u(y_2 - \mathcal{L}) + (1-q_g) u\left(y_2 - \Delta(\mathcal{L}) - \frac{1+r}{1-q_g} S\right)\right] \end{aligned} \tag{15}$$

$$\text{s.t. } S \geq S^{\min} = (1-q_b)\frac{\mathcal{L}}{1+r} \ . \tag{16}$$

The consumer selects the stake above $S^{\min}$ that maximizes (expected) utility.[15] The first-order condition for S implies that, at an interior optimum,

$$u'(c_1) = \frac{1+r}{1+\rho} u'(c_{2,nl}), \tag{17}$$

where $c_{2,nl}$ denotes consumption at time $t = 2$ in the no-loss state.[16] Assuming $u(\cdot) = \ln(\cdot)$ for concreteness, we obtain the following utility-maximizing combinations of B and S:

$$B = y_2 - \frac{1+r}{1+\rho}(y_1 - w) - \lambda(r,\rho) S. \tag{18}$$

The slope in the (B,S)-space,

$$-\lambda(r,\rho) \equiv -\left[1 + \frac{(1+r)}{(1+\rho)}\right], \tag{19}$$

depends on the impatience of the consumer relative to the market. In contrast to the slope of the equilibrium condition (9), it is negative. Equation (18) implies that the bonus and the stake are *imperfect* substitutes for the constrained consumer.[17] The parameter λ takes a value greater than one if $r > -1$ and $-1 < \rho < \infty$, which is plausible. This implies that the consumer values an increase of the stake more than an increase of the bonus by the same

[14]For parsimony, we have not added an explicit positive utility shifter to the objective function upon delivery of the good with satisfactory quality because with a separable utility function the results of the maximization problem are invariant to positive affine transformations of the objective function. If utility derived from the delivered good were non-separable from the utility derived from other goods, the marginal utility in the no-loss state would have to be multiplied by an additional scalar.

[15]If the stake S exceeds the non-contingent wage w, possible commitment problems may be addressed by pledging illiquid collateral, as discussed in Appendix A.3.

[16]The difference to the standard consumption Euler equation for non-contingent assets (see equation (29) in subsection 4.2) is that the marginal utility of consumption in the no-loss state enters on the right-hand side of (17) instead of the expected marginal utility of consumption. This is because both the reimbursement of the stake and the payment of the bonus are contingent on the no-loss state.

[17]As will be shown in subsection 4.2, for the unconstrained consumer the bonus and the stake are perfect substitutes: $B + S = \mathcal{L}$. In this case, the consumer can smooth consumption across time by means of the non-contingent asset. The bonus and the stake instead are used to smooth consumption across states.

amount because the stake also enables intertemporal consumption smoothing.

For the loci represented by (9) and (18) to cross in the (B,S)-space, the intercept of the latter needs to be larger than the intercept of the former:

$$y_2 - \frac{1+r}{1+\rho}(y_1 - w) > \frac{q_b - q_g}{1-q_g}\mathcal{L}. \tag{20}$$

If this condition holds, there exists an interior optimum in which the optimal stake and bonus are determined as follows.

Proposition 1 *At an interior optimum, in which consumers do not have access to capital markets, the optimal stake is*

$$S^* = \frac{(1+\rho)(1+r)^{-1}(y_2 - \Delta\mathcal{L}) - (y_1 - w)}{1 + (1+\rho)(1-q_g)^{-1}}. \tag{21}$$

The bonus B^* associated with this optimal stake S^* follows from (9).

Proof. Inserting the consumer's set of optimal (B,S) combinations (18) into the equilibrium condition (9) yields (21). ■

Intuitively, the risk-averse consumer uses S and B to smooth consumption across time and states, given the lack of access to capital markets. Equation (21) shows that if the income profile is backloaded ($y_2 > y_1$), asking for a large stake allows the consumer to lower consumption at time $t = 2$ in the no-loss state and increase consumption at time $t = 1$. The bonus adjusts to ensure that the zero-profit equilibrium condition is satisfied. If the income profile of the principal is less backloaded instead, the optimal stake is smaller and makes a corner solution more likely. Inequality (16) implies that the equilibrium stake $S^\dagger$ has to be at least as large as $S^{\min}$:

$$S^\dagger = \max\left(S^{\min}, S^*\right). \tag{22}$$

Figure 1 illustrates how the optimal combination of variable payments is obtained. The upward-sloping dashed (dotted) line is the (B,S) indifference locus (6) of the good (bad) worker. The solid grey line is the equilibrium relationship (9) between B and S. The intersection of the dotted and the solid grey line determines $S^{\min}$. (B,S) combinations on the solid grey line to the right of $S^{\min}$ illustrate the set of potential interior separating equilibria. The negatively-sloped, solid black line represents the indifference locus of a consumer with no access to capital markets and a backloaded income profile. In this case, the solid grey line and the solid black line intersect to the right of $S^{\min}$. A less backloaded income profile implies a parallel shift of the solid black line to the left. The $S^{\min}$-constraint may become binding in this case.

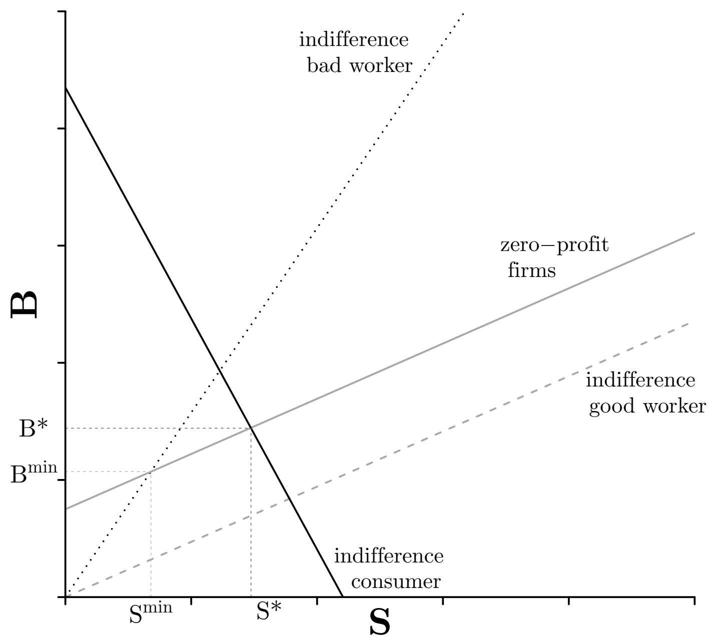


Figure 1: Illustration of the separating equilibrium without access to capital markets

This figure illustrates the separating equilibrium in the space spanned by bonus (B) and stake (S). The slope of the indifference locus for good types (dashed line) is strictly less steep than for bad types (dotted line). The slope of the zero-profit locus from (9) (solid grey line) is the same as the one of the indifference locus for good types from (6) (dashed line). Competitive equilibrium determines the former such that the zero-profit conditions of firms as marginal employers are satisfied. The unique interior equilibrium indicated by S^* is at the intersection of the downward-sloping consumer indifference locus (18) (solid black line) and the upward-sloping zero-profit locus (9) (solid grey line).

4.2 Access to capital markets

Even if consumers do have access to capital markets in general, many of them face binding borrowing constraints (see, e.g., Jappelli and Pistaferri, 2017). This holds even in developed economies as well as over relatively short horizons[18] and restricts individuals' ability to smooth consumption. We consider this more realistic case in the following. Assume that consumption can be smoothed across time using an asset a_t with non-contingent return r. However, the consumer faces a borrowing constraint $a_t \geq \underline{a}$ (where $\underline{a} \leq 0$). The flow

[18]See the remarks on overdrafts and payday loans in the introduction.

budget constraints at time $t = 1, 2$ are then:

$$c_1 = y_1 + (1+r)a_1 - a_2 - (w - S), \tag{23}$$

$$c_2 = \begin{cases} y_2 + (1+r)a_2 - \mathcal{L} & \text{with probability } q_g \\ y_2 + (1+r)a_2 - (B+S) & \text{with probability } (1-q_g) \end{cases}. \tag{24}$$

Once more, inserting the flow budget constraints (24) and (24) into the utility function and substituting the bonus with the equilibrium condition (9), we obtain the consumer's optimization problem. Specifically, the consumer chooses the stake S and the asset position a_2 to maximize expected utility subject to the stake being larger than the minimum viable stake $S^{\min}$ and subject to the borrowing constraint:

$$\max_{S,a_2} \quad u(y_1 + (1+r)a_1 - a_2 - (w-S)) + \tag{25}$$

$$+\frac{1}{1+\rho}\left[q_g u(y_2 + (1+r)a_2 - \mathcal{L}) + (1-q_g)u\left(y_2 + (1+r)a_2 - \Delta(\mathcal{L}) - \frac{1+r}{1-q_g}S\right)\right]$$

s.t.

$$S \geq S^{\min} \tag{26}$$

$$a_2 \geq \underline{\mathrm{a}}\,. \tag{27}$$

Slack borrowing constraint

The two first-order conditions at an interior optimum imply

$$u'(c_1) = \frac{1+r}{1+\rho}u'(c_{2,nl}), \tag{28}$$

$$u'(c_1) = \frac{1+r}{1+\rho}\left[q_g u'(c_{2,l}) + (1-q_g)u'(c_{2,nl})\right]. \tag{29}$$

Equating the right-hand sides of (28) and (29) yields

$$u'(c_{2,nl}) = u'(c_{2,l}). \tag{30}$$

Equation (30) implies that the optimal stake provides complete smoothing of consumption across states so that the consumer has the same marginal utility in the loss state and in the no loss state.

Proposition 2 *At an interior optimum, in which consumers have access to capital markets, the* *optimal stake*

$$S_{FI} = \frac{1-q_b}{1-q_g}\mathcal{L} < \mathcal{L}, \tag{31}$$

enables full insurance (FI) of consumption (or perfect smoothing) across states. The bonus associated with the optimal stake is thus determined by $B + S_{FI} = \mathcal{L}$*.*

Proof. Full insurance implies that $c_{2,l} = c_{2,nl}$. Inspecting (24), it is straightforward to see that this implies $B + S = \mathcal{L}$. Inserting in (9) yields the optimal stake (31). ■

Note that S_{FI} is larger than the minimum viable stake $S^{\min}$ as derived in (12). With access to capital markets, the consumer uses two instruments, i.e., the asset position a_2 and the stake S, to smooth consumption over time and across states. As long as the stake is (weakly) larger than the minimum viable stake, incentives are compatible with self selection. At an interior optimum with access to capital markets, the stake thus provides the consumer with an instrument to fully smooth consumption across states.

For intertemporal consumption smoothing instead, the asset a_2 dominates the stake S: the right-hand side of (29) is larger than the right-hand side of (28) unless there is full insurance. That is, the expected marginal utility generated by saving a unit of the asset a is larger than the marginal utility generated by the stake S. The reason is that changing the stake shifts resources between time $t = 1$ and the no-loss state at time $t = 2$. The non-contingent asset instead shifts resources between time $t = 1$ and both states at time $t = 2$. Additional resources are particularly valuable in the loss state, since $c_{2,l} < c_{2,nl}$ and hence $u'(c_{2,l}) > u'(c_{2,nl)}$ as long as $B+S < \mathcal{L}$. Therefore, the consumer will prefer to smooth consumption across periods using the asset rather than the stake unless the borrowing constraint is binding.[19]

Binding borrowing constraint

If the borrowing constraint binds so that $a = \underline{a}$, the consumer has only one instrument left to smooth consumption across time and states. The optimal stake then obtains from the

[19]For $B + S > \mathcal{L}$ the analogous argument applies because $c_{2,l} > c_{2,nl}$ in this case. Only in the knife-edge case of full insurance with $B + S = \mathcal{L}$, the consumer is indifferent between using the stake or the non-contingent asset for intertemporal consumption smoothing. This indifference only holds locally because discrete changes in S starting from full insurance imply that $c_{2,l} \neq c_{2,nl}$.

modified maximization problem

$$\max_{S} \quad u(y_1 + (1+r)a_1 - (w - S) - \underline{a}) + \tag{32}$$
$$+\frac{1}{1+\rho}\left[q_g u(y_2 + (1+r)\underline{a} - \mathcal{L}) + (1-q_g)u\left(y_2 + (1+r)\underline{a} - \Delta(\mathcal{L}) - \frac{1+r}{1-q_g}S\right)\right]$$
$$\text{s.t. } S \geq S^{\min}$$

The first-order condition with respect to S is qualitatively the same as equation (17) in subsection 4.1. The consumption levels c_1 and $c_{2,nl}$ will differ if agents can borrow, i.e. $\underline{a} < 0$, or if agents start with some initial assets, $a_1 > 0$. If $\underline{a} = a_1 = 0$, the maximization problems (15) and (32) are the same and so are the consumption levels. A difference to the case without access to capital markets is that the incidence of the borrowing constraint itself depends on the model parameters and the size of the stake.

If the consumer's resources are sufficiently backloaded, we obtain $S^* > S_{FI}$.[20] This implies that, relative to the case with full consumption smoothing across states as reflected by S_{FI}, the consumer without access to capital markets sacrifices smoothing across states for more smoothing across time. If $S^* < S_{FI}$, on the other hand, the consumer without access to capital markets opts for more smoothing across states, because smoothing over time is less effective with the stake than with a non-contingent asset.

5 Comparative statics

In this section we demonstrate how the optimal stake varies with the characteristics of the consumers, workers and the task. Consistent with our previous analysis, we consider consumers with and without access to liquid funds.

Proposition 3 *Consider a stake larger than the minimum viable stake $S^{\min}$, which ensures self selection of good workers into the variable compensation scheme. The optimal stake then depends on the characteristics of the consumers, the workers and the task as follows.*

[20] The required restriction on parameters is not informative so that we omit it for brevity.

(a) No access to capital markets or binding borrowing constraint

$$\begin{aligned} &\textit{consumer characteristics:} && \frac{\partial S^*}{\partial y_2} > 0, \frac{\partial S^*}{\partial (y_1 - w)} < 0, \frac{\partial S^*}{\partial \rho} > 0\ , \\ &\textit{worker characteristics:} && \frac{\partial S^*}{\partial q_b} < 0, \frac{\partial S^*}{\partial q_g} > 0 \textit{ for sufficiently backloaded resources,} \\ &\textit{task characteristic:} && \frac{\partial S^*}{\partial \mathcal{L}} < 0. \end{aligned}$$

(b) Access to capital markets or slack borrowing constraint

$$\begin{aligned} &\textit{consumer characteristics:} && \frac{\partial S_{FI}}{\partial y_2} = \frac{\partial S_{FI}}{\partial (y_1 - w)} = \frac{\partial S_{FI}}{\partial \rho} = 0\ , \\ &\textit{worker characteristics:} && \frac{\partial S_{FI}}{\partial q_b} < 0, \frac{\partial S_{FI}}{\partial q_g} > 0\ , \\ &\textit{task characteristic:} && \frac{\partial S_{FI}}{\partial \mathcal{L}} > 0. \end{aligned}$$

For the proof of Proposition 3, we refer to Appendix A.4. In this proof we also show that, in most cases, the change of the bonus has the same sign as the change of the stake with the following two exceptions:

$$\frac{\partial B^*}{\partial \mathcal{L}} > 0, \frac{\partial B^*}{\partial q_b} > 0.$$

Below, we illustrate these comparative statics and discuss their economic intuition.

No access to capital markets or binding borrowing constraint

If the consumer has no access to capital markets or faces a binding borrowing constraint, bonus and stake are imperfect substitutes for the purpose of consumption smoothing across time and states. Facing a more backloaded income stream, i.e., a larger income in the second period y_2 relative to the income in the first period net of wage payments $y_1 - w$, the constrained consumer strives to shift resources for consumption from $t = 2$ to $t = 1$. This increases the optimal stake. Figure 2 (a) illustrates this effect in the (B, S)-space. Backloading the income profile leads to a larger intercept of the consumer's indifference locus (18) (dashed black line), which then intersects further to the right with the zero-profit equilibrium locus (9) (solid grey line).

Figure 2 (b) illustrates that the equilibrium stake demanded by the constrained consumer decreases with a higher loss probability for the bad workers q_b. From (9) we know that an increase in q_b leads to a higher bonus for a given stake because good workers can extract a larger information rent. Figure 2 (b) shows the corresponding increase in the intercept of (9), as illustrated by the parallel upward shift of the dashed black line.[21] The intersection with the consumer's optimal (B, S)-schedule (18) is now located further to the left, implying a smaller equilibrium stake. Intuitively, the need to pay a larger bonus (for any given stake) reduces consumption in the no-loss state at time $t = 2$ ($c_{2,nl}$). Accordingly, the optimal stake is reduced to counterbalance this effect by shifting resources from time $t = 1$ into the no-loss state at time $t = 2$.

In Figure 2 (c), we observe that the intercept of the zero-profit equilibrium line (9) decreases in the loss probability of the good workers (q_g) because their information rent $\Delta(\mathcal{L})$ falls. At the same time, the slope of (9) increases.[22] Anticipating the lower success probability, the good workers will only risk a stake of given size, if the achievable bonus is larger. For a sufficiently backloaded income stream, (9) and (18) intersect further to the left, because the increase of the slope dominates the reduction of the intercept of (9). In this case, we obtain a smaller equilibrium stake together with a larger bonus.

Finally, Figure 2 (d) shows that an increase of the subjective impatience parameter ρ reduces the slope of the consumer's indifference locus (18). Similarly, it increases the intercept, as long as $y_1 > w$. Both of these effects imply a larger equilibrium stake. Intuitively, a more impatient constrained consumer has a stronger desire to increase consumption at time $t = 1$ relative to time $t = 2$ by using the stake. Algebraically, a larger discount rate ceteris paribus reduces the discounted marginal utility in the no-loss state which constitutes the right hand side of the first-order condition (17).

Access to capital markets and slack borrowing constraint

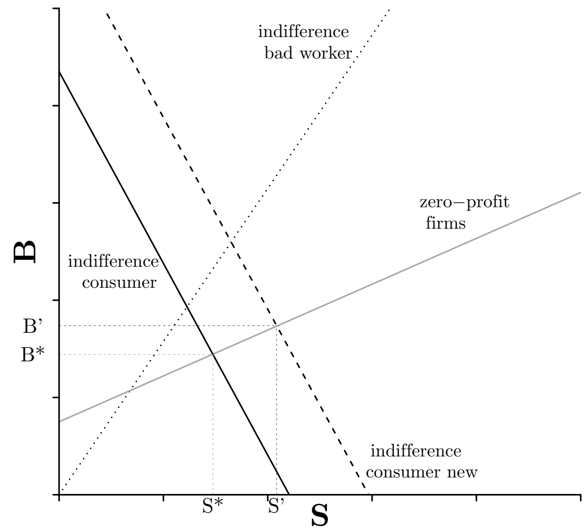
With full access to capital markets, the consumer is able to decouple consumption smoothing across time, achieved through the non-contingent asset, from consumption smoothing across states, implemented through the stake (and bonus). Accordingly, the equilibrium stake at an interior optimum is independent of the timing of the consumer's resources (y_2 vs. $y_1 - w$) as well as the subjective discount rate ρ.

The comparative statics for the worker characteristics on q_b and q_g are analogous to those for the constrained consumer. The reason is that these parameters exclusively affect the zero-profit equilibrium condition (9) for the marginal employer, but do not enter the indifference locus of the consumer (30).

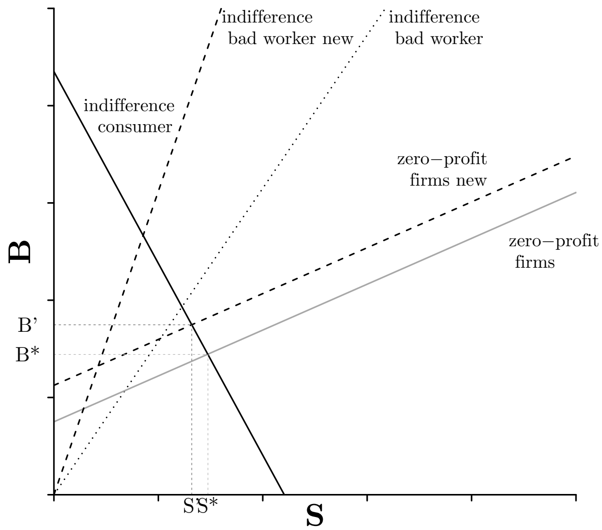
In the following, we therefore focus on the effect of the loss size $\mathcal{L}$. We first consider the case of a consumer with full access to capital markets and then provide a comparison

[21] At the same time, the indifference curve of the bad workers rotates upwards, implying a decrease in the minimum viable stake or a larger range of potential interior separating equilibria.

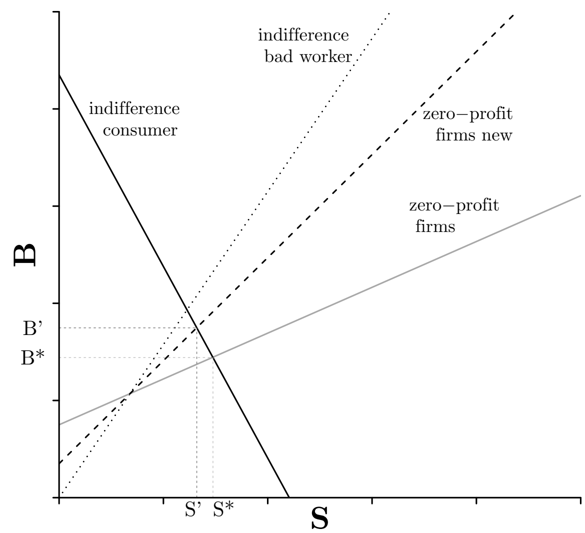
[22] Note that, for clarity of the figure, we deliberately refrain from plotting the indifference curve for the good worker in Figure 2 and its rotation.



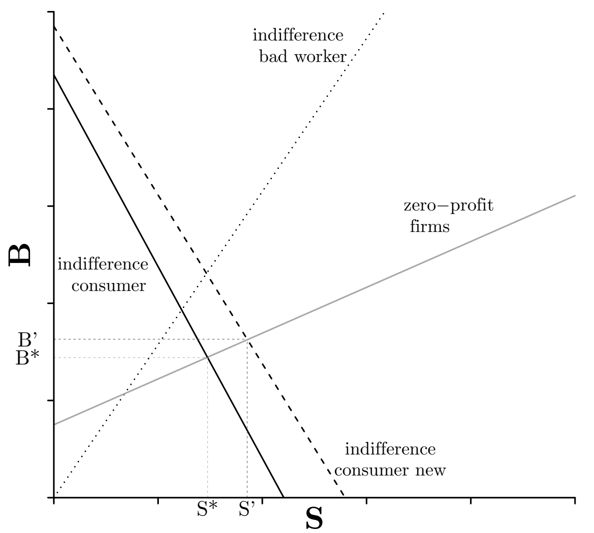
(a) Backloading of income



(b) Higher loss probability of bad types



(c) Higher loss probability of good types



(d) Higher impatience

Figure 2: Comparative statics for the credit constrained consumer

This figure illustrates the comparative statics of Proposition 3 (a) in the space spanned by bonus (B) and stake (S). S^* denotes the optimal stake at the initial equilibrium and S' the optimal stake after the respective change. Loci which shift or tilt in the comparative static are depicted as dashed. The slope of the zero-profit locus from (9) (solid grey line) is the same as the one of the indifference locus for good types from (6) not shown in the graph). Competitive equilibrium determines the former such that the zero-profit conditions of firms as marginal employers are satisfied. The indifference locus for bad types (dotted line) has a steeper slope. The unique interior initial equilibrium indicated by S^* is at the intersection of the downward-sloping consumer indifference locus (18) (solid black line) and the upward-sloping zero-profit locus (9) (solid grey line). The equilibrium S' is at the analogous intersection after the change.

to the situation with a binding credit constraint. In the presence of a non-contingent asset, a greater loss size $\mathcal{L}$ increases the equilibrium stake. Intuitively, the consumer relies on the non-contingent asset to smooth consumption across time and can therefore use the stake exclusively to balance consumption across states (see (30)). Given a higher loss, this means reducing consumption in the no loss state, which can be achieved by paying back a higher stake (plus bonus).

Interestingly, we obtain the opposite result for the credit constrained consumer: without full access to capital markets, a larger loss size leads to a lower optimal stake. The higher loss increases the information rent that can be extracted by good-type workers, implying a larger bonus for any given stake. This causes a need for the consumer to rebalance resources between states. In the absence of a non-contingent asset, the consumer is prepared to sacrifice consumption at time $t = 1$ (c_1) in favor of consumption in the no-loss state ($c_{2,nl}$) at time $t = 2$. The consumer does so by choosing a lower stake (see (17)).

Figure 3 illustrates the different responses of the optimal stake for the constrained and the unconstrained consumer. The dashed grey line with the flat negative slope represents the indifference locus of the unconstrained consumer, whereas the steeper negatively sloped black line illustrates the indifference locus of the constrained consumer. To highlight the different comparative statics in these two cases, we specify parameter values so that the optimal stake corresponding to the initial loss size is exactly the same for the constrained and the unconstrained consumer ($S^* = S_{FI}$). The larger loss $\mathcal{L}$ then reduces the optimal stake for the constrained consumer ($S' < S^* = S_{FI}$) and increases it for the unconstrained consumer ($S'_{FI} > S^* = S_{FI}$).

In the graphical illustration, first note that the increase of the loss size has no effect on the indifference locus of the constrained consumer (see (18)). Hence, the solid black line in Figure 3 does not change. The indifference locus of the unconstrained consumer, in contrast, is $B = \mathcal{L} - S$ (see (30)). Therefore, an increase in $\mathcal{L}$ ceteris paribus raises the sum of the variable payment components $B + S$ one for one. Graphically, the increase in $\mathcal{L}$ manifests itself in a greater intercept of the indifference locus. This causes a parallel shift to the right, as illustrated by the negatively-sloped dashed black grey line. At the same time, a larger $\mathcal{L}$, through an increased information rent for the good-type workers, implies an upward shift of the marginal employer's zero-profit line (9). The magnitude of this shift does not depend on whether the consumer is constrained or not.

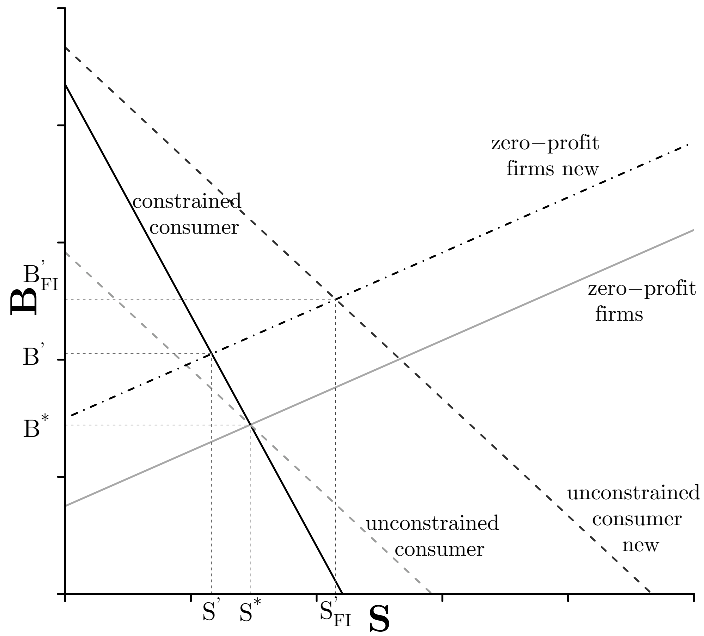


Figure 3: Effect of a higher loss size for consumers with and without credit constraint

This figure illustrates the comparative static for the loss size in the space spanned by bonus (B) and stake (S). S^* denotes the optimal stake at the initial equilibrium and S' the optimal stake after the respective change. We use parameter values so that $S^* = S_{FI}$ at the initial loss size. Loci which shift or tilt in the comparative static are depicted as dashed. The slope of the zero-profit locus from (9) (solid grey line) is the same as the one of the indifference locus for good types from (6) (not shown in the graph). Competitive equilibrium determines the former such that the zero-profit conditions of firms as marginal employers are satisfied. The unique interior initial equilibrium indicated by S^* is at the intersection of the downward-sloping consumer indifference locus (18) (solid black line) and the upward-sloping zero-profit locus (9) (solid grey line). The respective equilibrium S' and S'_{FI} is at the analogous intersection after the change.

5.1 Welfare effects

Optimal compensation in online labor markets impacts welfare for two reasons. First, welfare in the separating equilibrium is higher than in the pooling equilibrium. To see this, recall that our online labor market setting with disintermediated production comprises two types of employers: homogeneous risk-neutral firms and risk-averse consumers.[23] The different risk preferences of firms and consumers are motivated by the fact that firms can diversify losses across multiple projects whereas consumers cannot.[24] Therefore, the consumers have a higher willingness to pay for good workers than the firms.

[23]Using a change of measure to compute the risk-neutral probabilities for the risk-averse consumers, we could alternatively assume that consumers are risk neutral but face a larger potential loss when purchasing disintermediated products rather than intermediated products. In Appendix A.1 we provide further background on this heterogeneity, which obtains if consumers are risk averse and losses are not perfectly correlated across agents.

[24]In practice, limited liability implies that firms may also pass some of their losses to consumers.

Our three-part compensation schedule ensures that good workers self select into transactions with consumers in online labor markets. Owing to the smaller size of the online labor market relative to the classical labor market, the marginal employer of good workers is a firm. The information rent that can be extracted by good workers is thus determined by the risk-neutral firms and hence is lower than what the risk-averse consumers would be willing to pay. The consumers in the online labor market thus reap welfare gains from self selection.

Secondly, the three-part compensation scheme, which enables self selection, also allows borrowing-constrained consumers to improve consumption smoothing across time and states. The associated welfare gains depend on the extent of capital market imperfections and the degree of backloading of the consumer's income stream. The borrowing-constrained consumer can never fully smooth consumption, however. In other words, notwithstanding the optimal compensation scheme, welfare of a constrained consumer remains smaller than in an economy without capital market imperfections.

6 Implications for online labor markets

Our results are relevant for risk-averse purchasers of goods or services in online labor markets. These may be consumers, self employed or small businesses with financing constraints. Online labor markets allow them to source freelancers for a multitude of services, such as website design, data analysis or the translation of documents.

Platforms that run online labor markets may exploit their data to suggest payment schemes, which improve self selection and, at the same time, increase the demand by the aforementioned customers. Such increase of demand is particularly relevant from a practical point of view because potential credit constraints of customers are unobservable to platform providers. They can therefore not directly target these prospective purchasers through advertising or special offers. However, an online labor market platform may be more attractive than its competitors if it offers a three-part compensation scheme with flexible payments across states and time. Purchasers could then select the values of each of the payment components according to their specific needs.

Below, we briefly comment on further matters that seem relevant for practical implementation. First of all, using stakes to increase the demand of consumers with restricted liquidity does not introduce default risk if consumers can offer illiquid assets as guarantees in escrow accounts. However, in case platforms require full collateralization with liquid assets, before the workers can start to accomplish the task, demand of liquidity constrained purchasers will be curtailed.

Moreover, there may be a need for warranty periods because the quality of the goods or services sold on the platform cannot be instantly verified at the time of delivery. Verifying whether features of a website are of sufficient quality, for example, will likely require extended testing after delivery. In this case, stake and bonus would be released at the end of the warranty period. The time, in which payments are exchanged between workers and consumers so that they affect consumption smoothing, may thus extend well beyond the actual work period.

Apart from compensation schemes that induce self selection, adverse selection in online markets may, of course, also be mitigated by alternative mechanisms. Classical screening and monitoring, however, are more costly to implement in an online setting. At the same time, individual consumers as principals tend to be more resource constrained than firms that act as intermediaries. Instead, reputation-based rating or review systems are popular alternatives in practical applications. These alternatives tackle the selection problem by signaling worker quality to the consumer (Stanton and Thomas, 2016; Yoganarasimhan, 2013). Unfortunately, reputation mechanisms are known to be imperfect (Shapiro and Stiglitz, 1984). As long as rating inflation (Filippas et al., 2018, Kokkodis, 2021), rating bias (Chen et al., 2021) and rating manipulation through false positive or false negative reviews (Luca and Zervas, 2016; Mayzlin et al., 2014) can cause incomplete or noisy signals, the insights we provide in this paper will remain relevant.

Furthermore, rating systems may not be well suited to mitigate the adverse selection problem for risk-averse consumers when the probability of faulty work is low but the damage, if it occurs, is high. In this case, even low-quality workers may achieve a decent rating because their weaknesses rarely come to the fore. Our findings help to mitigate such low-frequency high-severity quality risk, in which the misleading nature of ratings can have severe consequences for consumers.[25] Similarly, they help to tackle the asymmetric information problem right after market entry of workers when track records are short and ratings therefore not yet informative. This entails the potential to lower entry barriers in online markets which is a key prerequisite for their further development (Stanton and Thomas, 2020).[26]

Finally, the focus on self selection makes our analysis relevant for the design of decentralized autonomous organizations (DAOs). DAOs are an emerging institutional arrangement, allowing for disintermediated economic exchanges with full anonymity and permissionless entry and exit of agents. The statutes of a DAO and its complete transaction history are stored on a tamper-proof distributed ledger (Buterin, 2013). In this context, self selection becomes highly relevant because screening or signaling services are largely

[25]Extreme outcomes are possible, even though most gig economy tasks are relatively simple in nature. An example are major liability issues which could materialize due to low product quality.

[26]Stanton and Thomas (2016), for example, show that the probability of finding a job is substantially lower when workers have not yet been able to amass a sufficient amount of public feedback scores.

inapplicable. Our insights apply particularly well to DAOs for which product quality is verifiable through data on the ledger and can thus directly trigger actions specified in smart contracts.

7 Conclusion

We analyze a novel joint principal-agent and consumption-smoothing problem that arises in online labor markets, in which workers of unobservable quality (the agents) transact with risk-averse and possibly borrowing constrained consumers (the principals). We show that the timing of compensation payments does not only affect the incentives of good-type workers to self select into jobs and for the bad-type workers to stay away, but also the extent of consumption smoothing achievable by consumers.

We characterize a separating equilibrium, in which high-quality workers self select into a three-part compensation scheme that, at the same time, allows constrained consumers to shift resources for consumption across time and states. Our analysis shows that the optimal size of the variable payments in this compensation scheme depends on the characteristics of the consumer, the worker and the task. We emphasize that optimal compensation in online labor markets impacts welfare for two reasons: i) welfare with self selection is higher than without it because of the heterogeneity between traditional firms and purchasers in online markets and ii) the three-part compensation scheme, which enables self selection, also allows borrowing-constrained consumers to smooth their consumption stream.

The results presented in this paper are useful for the design of online labor market platforms. By specifying the set of feasible payment options available to consumers, such platforms can incentivize the quality of the exchanged services and, at the same time, ensure that consumers obtain liquidity if desired. The relatively lower maintenance cost required by this incentive scheme compared to alternatives, such as screening or reputation-based rating systems, should make it particularly attractive for decentralized exchanges.

Future research could extend our analysis in several directions. From a theoretical perspective, one could investigate whether optimal compensation schemes can provide workers with insurance against the risk of task completion. Moral hazard, which prevents full insurance, in this case may not only interact with adverse selection but also with the consumption smoothing motive of the purchaser. From an empirical perspective, it would be interesting to provide evidence on the response of the demand for goods and services on online platforms to the type of available payment schemes.

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A Appendix

A.1 Lack of diversification and effective expected losses

Effective losses in disintermediated productions are larger because the losses cannot be diversified given that payments occur separately for each production-consumption pair. Instead an intermediary, such as a firm consisting of many production-consumption pairs, can diversify the losses across different pairs as long as the losses are not perfectly correlated. With a change of measure to obtain risk-neutral probabilities, consumers thus implicitly face a larger expected loss when they purchase disintermediated goods. We explain this below in an intuitive way.

Applying the law of large numbers, the intermediary firm only cares about the expected loss and this reduces the wage paid to workers ex ante, as shown in equations (4) and (11). In a perfectly competitive market, the price paid by the consumer for the good equals the marginal cost, i.e., the wage and the expected loss per consumed unit which we denote by $\Lambda \equiv q\mathcal{L}$.

The expected utility of the consumer, who buys goods from an intermediated firm, is thus

$$\begin{aligned} \mathbb{E}[U_I(\cdot)] &= (1-q)U(y-pC) + qU(y-pC) \\ &= U(y-(w+\Lambda)C). \end{aligned} \tag{A.1}$$

In disintermediated production the consumer pays the price for the good and bears the risk of the loss in the bad state of the world. If, for the sake of a simple comparison with the previous case, the consumer buys all goods produced in an disintermediated way and cannot diversify the risk so that the loss increases linearly with the amount of consumption, the consumer's expected utility is

$$\begin{aligned} \mathbb{E}[U_D(\cdot)] &= (1-q)U(y-wC) + qU(y-wC-\mathcal{L}C) \\ &= (1-q)U(y-wC) + qU(y-(w+\mathcal{L})C). \end{aligned} \tag{A.2}$$

Jensen's inequality implies that, for a strictly concave utility function, exchanging the operator for the expectation and the utility,

$$\begin{aligned}\mathbb{E}[U_D(\cdot)] <& U((1-q)(y-wC)+q(y-wC-\mathcal{L}C))\\ =& U(y-wC-q\mathcal{L}C))\\ =& \mathbb{E}[U_I(\cdot)].\end{aligned} \tag{A.3}$$

Given that expected utility $\mathbb{E}[U_I]$ is decreasing in the expected loss Λ, we can define $\tilde{\Lambda}$, which would imply that $\mathbb{E}\left[U_I(\tilde{\Lambda})\right] = \mathbb{E}[U_D(\Lambda)]$. Clearly, $\tilde{\Lambda} > \Lambda$. Based on these results, for modeling purposes one can transform the different risk borne by consumers relative to firms into a higher expected loss for consumers.

A.2 Risk-averse workers

We show that the scope for consumption smoothing becomes smaller for the consumer if workers are risk averse rather than risk neutral. In particular, we show that the risk aversion of workers restricts the size of the stake.

Figure 4 illustrates that risk aversion of workers imply indifference curves of good and bad workers that are convex in the (B,S)-space. A higher stake increases the risk of the payoffs of the worker. Hence, the compensation of workers with a bonus ex post for paying a higher stake ex ante becomes increasingly costly for a higher stake.

Figure 4 shows that the bonus for a given stake increases beyond what is implied by the equilibrium locus (9) for values of the stake to the right of the intersection between the indifference locus of the good worker and the equilibrium locus (9). Thus, in this case, the relationship between the bonus and the stake defined by the upper envelope of the two loci has to be used in the maximization problem of the consumer (15), when substituting out B. The implied steeper slope to the right of the intersection makes consumption smoothing with stakes more costly for the consumer but otherwise the analysis remains qualitatively similar. Note that risk aversion of the worker only matters for the equilibrium stake and the comparative statics at those bonus-stake combinations at which the indifference locus of the risk-averse good worker determines the shape of the upper envelope in Figure 4.

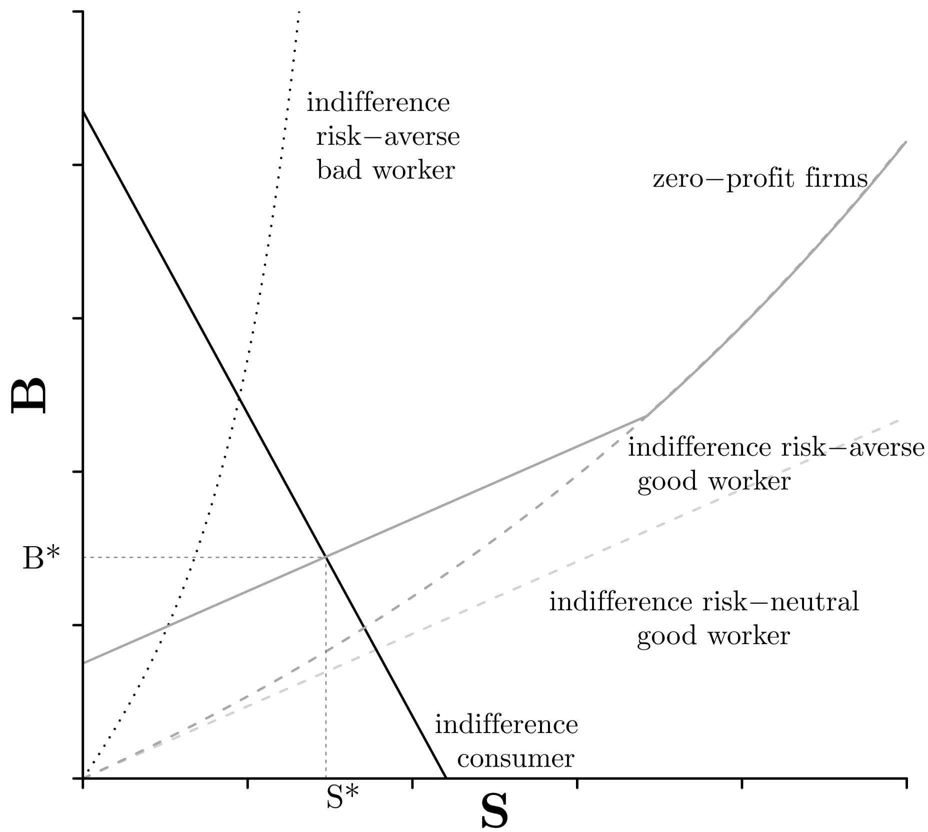

Figure 4: Risk Aversion

This figure illustrates the equilibrium with risk averse agents. Compared to the risk neutral counterparts, the loci become convex in the B, S-space. The slope for bad types again is steeper than for good types. The range of B, S combinations for a separating equilibrium is determined analogously as in the benchmark but for the B, S combinations to the right of the intersection of the indifference locus of the risk-averse good worker and the zero-profit equilibrium locus. This is where the participation constraint of the good types becomes binding and the B, S combinations in the separating equilibrium are bounded by the indifference curve of risk-averse good type workers.

We now derive the slope of the indifference locus of the workers in the (B, S)-space. Recall that the worker has to pay S in period 1 and that the worker receives the bonus B and the stake S in period 2 if no loss occurs. For comparison with the indifference locus of risk-neutral workers in the main text, we assume that the worker discounts the future at rate r. Totally differentiating the expected utility of the worker with respect to B and S for a given utility level, we obtain

$$-u'(c_1)dS + \frac{1-q_i}{1+r}u'(c_{2,nl})(dB + dS) = 0 \text{ , for } i = b, g. \tag{A.4}$$

The slope of the indifference locus for type $i = b, g$ is thus

$$\frac{dB}{dS} = \frac{1+r}{1-q_i}\frac{u'(c_1)}{u'(c_{2,nl})} - 1 \; . \tag{A.5}$$

For risk-neutral workers with constant marginal utility, the slope simplifies to (6). For risk-averse workers, a higher stake increases the marginal utility of consumption in period 1 (because consumption c_1 decreases) and it reduces the marginal utility in the no-loss state in period 2 (because consumption $c_{2,nl}$ increases). Thus, a higher stake increases the slope of the indifference locus, implying the convex shape in the (B,S)-space. For illustration purposes, we have assumed in Figure 4 that the ratio of marginal utilities in (A.5) approaches one for a small stake and bonus.

A.3 Commitment and stakes $S > w$

In the main text we have not discussed commitment issues. For a stake $S \leq w$, the stake resembles a trade credit or consumer credit. For $S > w$, there may be commitment issues similar to the literature on double moral hazard in the context of bonds issued by workers before executing work at a firm. In our application, the credit to the consumer might not always be honored.

Posting of illiquid collateral of value $S-w$ by the consumer, for example by putting the collateral into an escrow account, may prevent default for stakes $S > w$ at the same time as the credit provides the borrowing constrained consumer with additional liquidity. The execution of the credit contract can be fully committed to, for example by using smart contracts.

If the consumer has no collateral to post, the stake is bounded above by w. The maximization problem (15) of the constrained consumer and (25) of the unconstrained consumer then feature the additional constraint $S \leq w$. The optimal stake of the constrained consumer is thus given by

$$\tilde{S} = \max\left\{S^{\min}, \min\{S^*, w\}\right\} \tag{A.6}$$

and the optimal stake of the unconstrained consumer is given by

$$\tilde{S}_{FI} = \max\left\{S^{\min}, \min\{S_{FI}, w\}\right\}. \tag{A.7}$$

Existence of a separating equilibrium, which ensures self selection of good workers, thus requires $w > S^{\min}$ in this case. This is illustrated in Figure 5 for the constrained consumer.

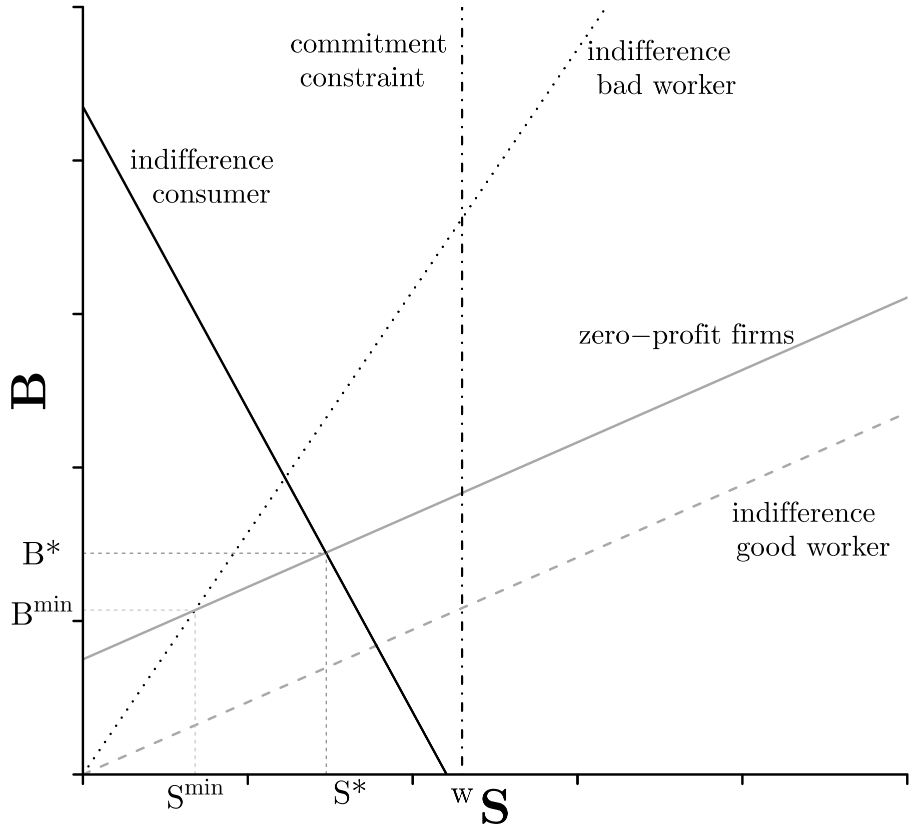

Figure 5: Illustration of a unique solution with partial commitment

This figure illustrates the equilibrium with partial commitment. Compared to the benchmark case, there is an additional constraint, the dot-dashed boundary line. This boundary is an upper bound for the feasible Bonus-Stake space, determined by the equation $S = w$.

A.4 Proof of Proposition 3

Proof. Concerning part (a) of the proposition, we obtain the following results differentiating (21).

Consumer characteristics.–

$$\frac{\partial S^*}{\partial y_2} = \frac{1+\rho}{(1+r)\Big((1+\rho)(1-q_g)^{-1}+1\Big)} > 0, \tag{A.8}$$

$$\frac{\partial S^*}{\partial (y_1 - w)} = -\frac{1-q_g}{2+\rho-q_g} < 0, \tag{A.9}$$

and

$$\frac{\partial S^*}{\partial \rho} = \Big[y_2 - \Delta\mathcal{L} + (1+r)(1-q_g)^{-1}(y_1 - w)\Big]\psi \tag{A.10}$$

with

$$\psi = \frac{1}{(1+r)\Big(1+(1+\rho)(1-q_g)^{-1}\Big)^2} > 0.$$

Inspecting (21), we observe that the effect is positive for any $S^* > 0$.

Worker characteristics.–

$$\frac{\partial S^*}{\partial q_b} = -\frac{(1+\rho)\mathcal{L}}{(1+r)(2+\rho-q_g)} < 0. \tag{A.11}$$

The effect for a change in the loss probability of good types q_g depends on whether resources are sufficiently backloaded because

$$\frac{\partial S^*}{\partial q_g} = [(1+\rho)y_2 - (1+r)(y_1 - w) - (2+\rho-q_b)\mathcal{L}]\,\xi \tag{A.12}$$

with

$$\xi = \frac{(1+\rho)}{(1+r)(2+\rho-q_g)^2} > 0.$$

For the term in square brackets in (A.12) to be positive, more backloading of resources is required, if $q_b < 1$, than what ensures that the stake exceeds $S^{\min}$.

Task characteristic.–

$$\frac{\partial S^*}{\partial \mathcal{L}} = -\frac{(q_b - q_g)(1+\rho)}{(1+r)(2+\rho-q_g)} < 0. \tag{A.13}$$

Concerning part (b) of the proposition, the derivatives $\frac{\partial S_{FI}}{\partial \mathcal{L}} > 0$, $\frac{\partial S_{FI}}{\partial q_b} < 0$, $\frac{\partial S_{FI}}{\partial q_g} > 0$, $\frac{\partial S_{FI}}{\partial y_2} = \frac{\partial S_{FI}}{\partial w} = \frac{\partial S_{FI}}{\partial \rho} = 0$ follow immediately from differentiating (31) in subsection 4.2.

Comparative statics for the bonus.– We obtain the following comparative static results for the bonus, substituting (21) into equation (9) and differentiating.

Consumer characteristics.–

$$\frac{\partial B^*}{\partial y_2} = \frac{(q_g + r)(1+\rho)}{(1+r)(2+\rho-q_g)} > 0, \tag{A.14}$$

$$\frac{\partial B^*}{\partial (y_1 - w)} = -\frac{q_g + r}{2+\rho-q_g} < 0, \tag{A.15}$$

$$\frac{\partial B^*}{\partial \rho} = \left[y_2 - \Delta\mathcal{L} + (1+r)(1-q_g)^{-1}(y_1 - w)\right]\tilde{\psi} \tag{A.16}$$

with

$$\tilde{\psi} = \frac{(r+q_g)(1-q_g)}{(1+r)(2+\rho-q_g)^2} > 0.$$

Inspecting (21), we observe that the effect is positive for any $B^* > 0$.

Worker characteristics.–

$$\frac{\partial B^*}{\partial q_b} = \frac{2+\rho+r}{(1+r)(2+\rho-q_g)}\mathcal{L} > 0. \tag{A.17}$$

Again, the effect for a change in the loss probability of good types q_g depends on whether resources are sufficiently backloaded because

$$\frac{\partial B^*}{\partial q_g} = [(1+\rho)y_2 - (1+r)(y_1 - w) - (2+\rho-q_b)\mathcal{L}]\,\tilde{\xi} \tag{A.18}$$

with

$$\tilde{\xi} = \frac{2+\rho+r}{(1+r)(2+\rho-q_g)^2} > 0.$$

Task characteristic.–

$$\frac{\partial B^*}{\partial \mathcal{L}} = \frac{(q_b - q_g)(2+\rho+r)}{(1+r)(2+\rho-q_g)} > 0. \tag{A.19}$$

■