Corvinus University of Budapest
Doctoral School of Economics, Business and Informatics

THESIS
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Uncertainty, vulnerability and self-respect in the gig economy

A dynamic principal-agent model

Péter Kerényi

Ph.D. dissertation

Supervisors:

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I Introduction

The gig economy is a work schedule or form of employment. Its most important criteria are that employees work based on contracts, for a fixed, usually short time frequently repeated. Work is often organised through an online platform. Some authors focus on that aspect, a digital platform, which efficiently collects and manages information, and describe the phenomenon with its help. The terms 'crowdsourcing' or 'crowdwork' are also used for that form of employment indicating, on the one hand, that the platform is in connection with a large crowd of workers, and on the other hand, the platform outsources several tasks and responsibilities of the traditional employer to the workers (e.g. Bergvall-Kåreborn and Howcroft [2014]). The terms 'platform economy' and 'work-on-demand via app' (e.g. De Stefano [2015]) can also be found. As opposed to this, the term 'gig economy' is used in studies focusing on short-term, repeated contract work rather than on online work arrangements (e.g. De Stefano [2015]). The term 'gig economy' is also used in that wider sense in this paper. We believe it is not inevitable in the gig economy that work is organised via an online platform, it can take place through a traditional intermediary (e.g. placement services or temporary employment), or gig workers may sell their labour directly.

This kind of self-employment increases the autonomy of employees. Workers decide for themselves when, what, and how much they want to work and thus can control their own work life. Many workers start it as a supplement to earnings, while others do it as a full-time job. The gig economy is present widespread (Broughton et al. [2018], Spreitzer et al. [2017]), from lower-skilled jobs (taxi drivers in Wu et al. [2019], Ford and Honan [2019], Josserand and Kaine [2019], bicycle couriers in Goods et al. [2019]) to the most highly skilled (IT consultants Kunda et al. [2002]) or creative jobs (stand-up comedians Reilly [2017], Butler and Stoyanova Russell [2018]). The gig-based form of employment is constantly expanding and accounts for an increasing share of employment contracts (Katz and Krueger [2019], Huws et al. [2019]).

The gig economy is fundamentally changing people's attitudes to work. One can call it the 'new world of work'. Ashford et al. [2018] summarize and systematize that individuals face a myriad of emotional and financial challenges to thrive. However, this new world and the freedom it offers people also means increased responsibility, insecurity, and risk (Fleming [2017], MacDonald and Giazitzoglu [2019]). In the flexible gig economy, workers' jobs (Ashford et al. [2018]), working hours (Gandhi et al. [2018]), and wages (Doucette and Bradford [2019]) are continually changing.

This ever-changing work environment increases the workers' insecurity and frustration (Lee et al. [2018]). The strengthening of individualism entails loneliness and a sense of belonging to nowhere, and therefore workers often question their work identity (Petriglieri et al. [2019], Josserand and Kaine [2019]). The employment of gig workers is subject to weaker rules (Stewart and Stanford [2017]), so they have fewer rights than those in traditional forms. Gig workers do not have a minimum wage, their working hours are not limited, and, as a consequence, self-exploitation also appears (Wood et al. [2019]). These workers typically also do not have health and pension insurance (Fox et al. [2018]), which further increases their anxiety about a precarious future (Ashford et al. [2018]). Even though the gig economy has many benefits, workers can still be extremely vulnerable, and there is more and more public discussion about the unregulated situation of gig workers.

An important question is what opportunities in the assertion of interests the various actors in this new world have in shaping working conditions. In the gig economy literature, this issue is approached mainly from the side of the workers, and the ability of the workers to assert their interests is examined from the point of view of collective action (Bergvall-Kåreborn and Howcroft [2014], Schiek and Gideon [2018], Wood et al. [2019], Poon [2019], Ford and Honan [2019], Veen et al. [2020]). In the gig economy, workers' ability to self-organize and assert their interests is declining due to diminishing social relations and the weakening of trade unions (Johnston et al. [2018]). In job negotiations, workers most often rely only on themselves, so individual negotiation strategies become more valuable. In contrast to the collective action-based approach, in this study we introduce a model in which the worker's negotiation is based on an individual emotional rule arising from his own self-respect. This heuristic strategy, based on the worker's own lived experience, creates a new situation in his bargaining position with the employer and can also help the worker cope with the gig economy's emotional challenges.

The contract is at the heart of the gig economy, so we apply a contract theory approach to our analysis. Cachon et al. [2017] notes the role of dynamic wage and commission contracts and uses a demand-supply-based dynamic model to examine the impact of different contract types in the gig economy. In this paper, we do not explicitly model supply-demand effects but instead focus on the relationship between the employer and the worker. We introduce a continuous-time dynamic principal-agent model to describe the relationship between the employer (as the principal) and the worker (as the agent), similarly to Holmström and Milgrom [1987], DeMarzo and Sannikov [2006], and Sannikov [2008]). In this setup, the principal continuously adjusts the parameters of the contract – an output-independent fix wage, and the share of the output.

In principal-agent models, the agent's decision whether he accepts the contract or not (participation constraint), is captured by a minimum utility he expects from the job. Generally speaking, we can view this as a reference value, and it is most often introduced as the utility of an outside option. For example, Holmström and Milgrom [1987] chooses the outside option of the agent as constant, while Wang and Yang [2019] in their model, the outside option is stochastic (but still exogenous).

In contrast to these models, we do not derive the agent's reference value from an outside option. Motivated by not necessarily rational, but psychological and emotional arguments, we take a heuristic approach. In our model, the reference value is determined by the agent's lived experience, namely by the wage levels he achieved in the recent past. The agent accepts a gig job if and only if the utility of the offer is at least as large as his current reference value, which is the exponentially weighted moving average of previously realized net wages. As the reference value capturing the self-respect of the agent is not related to any available outside option, the agent has to commit to it to gain bargaining power. If a gig job is not accepted, then there is no output, the realized wage is zero, and the reference value of the agent becomes lower for the next round, when he might do a gig job again. The agent views the periods staying out of gig work as inherent in a flexible system. He knows that it goes hand in hand with the decision-making rule that gives him the bargaining power by sticking to his principles and not allowing himself to be exploited. The worker's self-respect captures the emotional fluctuations inherent in the gig economy and represents the coping mechanism and decision-making associated with it. From a modeling point of view, our reference value specification leads to a dynamic and endogenous participation constraint, which is our model's main novelty and its contribution to the principal-agent modelling literature.

The idea of reference value-based decision rules or preferences is gaining popularity in related research areas. Using psychological games (see Geanakoplos et al. [1989] and Battigalli and Dufwenberg [2009]), the reference value, the wage demand can also be interpreted as the principal's belief about the agent's minimal utility expectation of a job, based on adaptive expectations. The reference value is also related to habit formation (see, for instance, Pollak [1970] and Abel [1990]), where the previously realized net wages form a consumption habit for the agent. However, in habit formation models, if the agent receives a contract with lower expected utility than the reference value, then he will work more. In contrast, in our model he will not work at all. The reference value in our model has a backward-looking nature, whereas forward-looking expectations appear in the literature on job search (see

Mortensen [1986], Van den Berg [1990], or DellaVigna et al. [2017], among others) and also in recent papers with reference-dependent preferences (see Macera [2018a] and Macera [2018b]). Relatedly, a forward-looking dynamically changing participation constraint also appears in Wang and Yang [2019], who work with an exogenous stochastic outside opportunity. Interestingly, our participation constraint can also be interpreted as the agent having extreme loss aversion below the reference value in the reference-dependent utility function of Kőszegi and Rabin [2006].

Both the labor market's structure and the observability of the agent's effort in a gig job crucially influence the wage negotiation. We analyze the two extreme labor market models within our setting; perfect competition and monopsony. In the former case, many employers compete for the worker, while in the latter, a single principal is the only buyer of the agent's workforce. Both cases are relevant, but most of the time employer power can be substantial in online labor markets (Dube et al. [2020]).

It is characteristic of many gig economy segments that an employer can observe the worker's activity with advanced sensors, algorithms, and consumer rating systems (Wood [2018], Allon et al. [2018], Wu et al. [2019], Woodcock [2020]). In the principal-agent model, depending on what the principal can observe, two solution concepts can be formulated. The first-best solution means that the principal can prescribe the agent's effort in the contract. In the second-best solution, only the output is observable, and the principal must incentivize the agent by offering a share from the output. Most of the time, reality is somewhere in between these special cases, but both offer interesting insights to the inner workings of the gig economy. We consider the observable effort (first-best) as well as the unobservable effort (second-best) case for both labor market structures (perfect competition, monopsony) to have four cases in total.

II Structure of the dissertation

The dissertation consists of three separate studies, but these are strongly related. In each section, we are primarily interested in the relationship between short-term incentive contracts, the associated uncertainty, and the workers 'bargaining power and their vulnerability.

Part I, *Incentives in the gig economy*, presents the background and characteristics of the gig economy. The heart of our description and analysis, the incentive and performance-based wage are less discussed so far in the literature. This essay provides the theoretical basis that can help the reader to better navigate the different terms used in the literature and that motivates the dissertation Part II and III. Part I of the dissertation, entitled *Incentive in the gig economy*, was published in June 2021 in the 2nd issue of the 8th volume of the journal Economy and Finance. (Kerényi [2021])

In Part II, *The role of self-respect in the gig economy*, we examine the gig economy through the principal-agent model. As a novelty, we introduce the worker's (as an agent) self-respect, which also makes the model dynamic. In the model, the idea behind self-respect is the heuristic behavior that a worker is unwilling to take on the gig work offered to him for less than a certain reference value, even if he knows he will be left with no money at all. By not taking the job, not only he is left without wage, but he also hurts his employer, who has to say goodbye to her profits due to a loss of production. In the model, the worker's expectation of wages, which is embodied in the reference, is based on his experience. This means his expectation depends on how much he earned in the past. Of course, this also means that when a worker is not working due to self-respect, his or her expectations are constantly declining in the lack of wages. The two opposite effects result in a non-trivial control problem and interesting dynamics that allow a good grasp of the relationship and bargaining power between the worker and the employer. The Part II of the dissertation is an edited version of our working paper Self-respecting worker in the gig economy: A dynamic principal-agent model, which is written with my supervisors, Zsolt Bihary and Péter Csóka, and co-author Alexander Szimayer, published in June 2021. (Bihary et al. [2021])

In Part III, *Wage level, unemployment, and exploitation in the gig economy*, we examine the stationary state of the dynamic principal-agent model introduced earlier, thus determining how, in the long run, on average, the employer and the employee perform and how they share the results of production.

III Methodology

III.1 Model setup

Our model captures the interaction of an employer (a principal, she) and a worker (an agent, he) on the labor market of the gig economy. The principal offers a contract to the agent that the agent can decide to accept or not. The agent's decision depends on whether the utility of the offer is greater than his reference value. The agent chooses his effort, which affects the output. The agent receives a wage specified by the contract, and the remaining part of the output is the principal's profit. Our model is formulated in a dynamic setting with a repeated flow of contracts. The agent's reference value is determined by previously realized wages.

We follow the well established continuous-time model (e.g. DeMarzo and Sannikov [2006], Sannikov [2008]). A standard Brownian motion $B = \{B_t, \mathcal{F}_t; 0 \le t < \infty\}$ on $(\Omega, \mathcal{F}, \mathcal{Q})$ drives the noisy *output* process X as

$$dX_t = \chi_t \left(a_t \, dt + \sigma \, dB_t\right),$$

where σ is the *volatility* of the random component, a_t is the agent's *effort level* and χ_t is the *contract indicator* at time t. $\chi_t = 1$ if a contract is struck between the principal and the agent (contract regime), and $\chi_t = 0$ if not (no-contract regime).

The principal continuously offers contracts to the agent that specify the instantaneous wage as a linear function of the output. In this dissertation, we limit our model to the study of linear contracts because even this simple specification illustrates the different mechanisms of action that occur during the interaction between the two parties. We also note that the linear contract is the type of contract most frequently discussed in the literature (in many cases optimal) and the most commonly implemented in reality. The agent's *wage* process W thus evolves according to

$$dW_t = \chi_t \left(s_t \, dX_t + f_t \, dt\right) = \chi_t \left(\sigma \, s_t \, dB_t + \left(s_t \, a_t + f_t\right) dt\right) ,$$

where s_t is the *share* of the output and f_t is the *fix* wage component offered to the agent at time t. This fix amount may be negative, in that case it is interpreted as a rent.

The principal's *profit* process P, which is determined by the remaining part of the output

$$dP_t = dX_t - dW_t = \chi_t \left(\left(1 - s_t\right) \sigma \, dB_t + \left(\left(1 - s_t\right) a_t - f_t\right) \, dt\right) .$$

The principal is risk-neutral in our model. This means she is interested only in expected profits. We define the principal's *expected instantaneous profit* or simply *profit* p_t as

$$p_t = E\left[dP_t \mid \mathcal{F}_{t-}\right] / \, dt = \chi_t \left(\left(1 - s_t\right) a_t - f_t\right) . \tag{1}$$

We will define and investigate *myopic* and *far-sighted* principals in the next sections, but for all the cases, we make the natural assumption about the principal's participation constraint, that p_t is at least zero.

We define an instantaneous utility for the agent that incorporates the disutility of his effort as well as both the expected value and the uncertainty of his wage. We specify the agent's *cost of effort* in the usual form $c \cdot \frac{a_t^2}{2}$. The coefficient c makes it possible that the cost of effort is in the same monetary units as the wage. With this understanding and without loss of generality we choose $c = 1$. The quadratic form provides a monotonic increase in effort cost and convexity as increasing marginal cost. The agent's *net wage* is evolving according to

$$d\tilde{W}_t = dW_t - \frac{a_t^2}{2}\, dt = \chi_t \left(\sigma\, s_t\, dB_t + \left(s_t\, a_t + f_t - \frac{a_t^2}{2} \right) dt \right) .$$

If the agent accepts the contract, he can expect the fix salary but, due to the random output, the share component is risky. We do not explicitly model the agent's savings; we assume that he is hand to mouth, that is, his current consumption is always the same as his current wage. We express his instantaneous *utility* u_t in mean-variance form as

$$u_t = \frac{E\left(d\tilde{W}_t\right) - \frac{\gamma}{2}\, d\left[\tilde{W}\right]_t}{dt} = s_t\, a_t + f_t - \frac{a_t^2}{2} - \frac{s_t^2}{2}\, \gamma\, \sigma^2 \,, \tag{2}$$

where $\gamma \in \mathbb{R}^+$ is the agent's *coefficient of absolute risk aversion* and the notation $[\tilde{W}]_t$ stands for the quadratic variation of the net wage process. The agent's utility is only relevant if the contract is struck, therefore we omitted χ_t here. The agent accepts the contract at time t if the utility of the offer u_t is greater or equal than his current *reference value* R_t. Note that this decision is not irreversible, after a rejection, the agent can pick up the work again if so he wishes.

The contract indicator formally satisfies

$$\chi_t = \mathbf{1}_{p_t \geq 0} \cdot \mathbf{1}_{u_t \, \geq R_t} \,. \tag{3}$$

The first factor in equation (3) means the principal always wants to reach at least zero profit. The second factor captures the agent's behavior related to his self-respect. Finally we remark that using psychological games (see Geanakoplos et al. [1989] and Battigalli and Dufwenberg [2009]), R_t can also be interpreted as the principal's belief about the agent's minimal utility expectation of a job, based on adaptive expectations. Then, the psychological instantaneous utility of a job is $\hat{u}_t = u_t - R_t$ and with a zero utility outside option the contract indicator can be written as

$$\chi_t = \mathbf{1}_{p_t \geq 0} \cdot \mathbf{1}_{\hat{u}_t \geq 0} \,,$$

which practically corresponds to the rearrangement of the contract indicator in equation (3).

One of the main novelties in our paper is that we define the reference value in a backward-looking endogenous manner. In particular, let R_t be the exponentially-weighted running average of previous realized net wages:

$$R_t = \int_{-\infty}^{t} \kappa\, e^{-\kappa\,(t-z)}\, d\tilde{W}_z\,, \tag{4}$$

where $\kappa \in \mathbb{R}^+$ is a time-scale parameter characterizing the agent. This specification means that the worker's self-respect is based on his previously realized wages. He only accepts the next contract if he can expect to maintain his income level. Process R_t follows the SDE

$$dR_t = -\kappa\, R_t\, dt + \kappa\, d\tilde{W}_t = -\kappa\, R_t\, dt + \chi_t\, \kappa \left(\sigma\, s_t\, dB_t + \left(s_t\, a_t + f_t - \frac{a_t^2}{2}\right) dt\right)$$

as can readily be shown by differentiating equation (4). Distinguishing the $\chi_t = 0$, $\chi_t = 1$ cases we can write this also as

$$dR_t = \begin{cases} -\kappa R_t\, dt, & \chi_t = 0 \\ \left(s_t\, a_t + f_t - \frac{a_t^2}{2} - R_t\right)\, \kappa\, dt + \kappa\, \sigma\, s_t\, dB_t, & \chi_t = 1 \end{cases}. \tag{5}$$

The reference value follows a stochastic diffusive dynamics in the contract regime ($\chi_t = 1$). In the no-contract regime ($\chi_t = 0$), when the agent realizes zero wage, the reference value decreases at rate κ. The parameter κ captures the worker's vulnerability: at high κ values, the worker has to lower his wage demand rapidly and this leads to unfavorable contracts once he picks up work again. In this case, the bargaining power stemming from the worker's self-respect is compromised as the threat of him staying out of gig job for an extended amount of time becomes less credible. Hereinafter, we refer to κ as the *vulnerability parameter.*

III.2 Stochastic control problems

To determine the optimal contract parameters for the principal (a_t^*, s_t^*, f_t^*), we need to solve the principal's control problem using Hamilton–Jacobi–Belmann euquations (HJB equations). In the dissertation, we examine the optimal contracts for the short-sighted and the far-sighted principal, in the case of perfect competition and monopsony. The optimal parameters are determined in both the first-best and second-best cases.

III.2.1 Myopic strategy

We consider a myopic principal who optimizes her instantaneous profit p_t (see equation 1) at every time t. In our dynamic approach, this model corresponds to a series of one-shot decisions. The results in this section are directly transported from the Holmström–Milgrom solution. The role of the outside option in the agent's participation constraint is replaced by the dynamically changing reference value.

In the case, when there is *perfect competition* for the agent's workforce, on the one hand, this means that the principal has to settle for zero profit. On the other hand, she also has to offer a contract with the highest possible utility for the agent. Mathematically, these translate to the principal optimizing the agent's utility u_t with her zero-profit constraint.

If the optimized contract satisfies the agent's requirement $u_t \geq R_t$, then he accepts it. If this contract, that is formulated solely in the interest of the agent, still falls short of his reference value, then he rejects the offer, and in this case, there is no work, no production and no profit.

The first-best solution in the principal-agent literature is defined as follows. The principal can observe not only the output but also the effort exerted by the agent. This means the principal can and does prescribe the necessary effort in the contract. The contract parameters a_t, s_t and f_t are all control variables at the principal's disposal. Therefore u_t in this case is optimized with respect to a_t, s_t, and f_t with the principal's zero-profit constraint.

In the second-best case, the principal cannot observe and enforce the agent's effort a_t, therefore she needs to incentivize him by offering a share of the output. The agent determines a_t autonomously, optimizing his utility, given the contract parameters s_t and f_t.

The other extreme situation is that, where the principal is *monopsonistic*, the only buyer of the agent's workforce. In our proposed model, monopsony means that the principal maximizes her profit with the agent's binding participation constraint.

III.2.2 Far-sighted strategies

We consider a far-sighted principal whose objective is not merely an instantaneous profit, but rather a discounted life-time profit. Perfect competition in our model means that the principal offers a contract that is optimal for the agent, while she is satisfied with zero instantaneous profit. This translates to a zero life-time profit, so there is no room for long-time strategies on the principal's part. However, a monopsonistic principal is able to realize a positive profit and her aim is to maximize it. In this case, it is meaningful to study far-sighted strategies on the principal's part. In what follows, we explore whether such far-sighted strategies can increase the principal's profit and the ways the principal can control the agent's wage demand.

The far-sighted principal's performance depending on the policies a_t, s_t, and f_t

is measured by the present value of her lifetime profit

$$E_r \left[\rho \int_0^\infty e^{-\rho t} \left(dX_t - dW_t \right) \right] = E_r \left[\rho \int_0^\infty e^{-\rho t} \chi_t \left(\left(1 - s_t\right) a_t - f_t \right) dt \right], \tag{6}$$

where ρ is her subjective discount rate and E_r denotes the expectation conditional on $R_0 = r$. The factor ρ in front of the integrals normalizes total pay-offs to the same scale as flow pay-offs.

Applying a (not necessarily optimal) contract policy a_t, s_t, and f_t, the performance still depends on the agent's initial reference value r. To highlight the significance of the principal's far-sighted approach, we will calculate the performance for two different policies. First, we explore how the myopic strategy obtained in the previous section performs under the far-sighted objective (equation 6). The myopic strategy is, of course, suboptimal, yet it establishes a benchmark for comparison. Next, we will properly solve the control problem defined by equation (6), thereby obtaining the optimal solution. We present our results both for the first-best and for the second-best cases below.

We solve for the optimal first-best *value function*. The first-best optimal value function is thus defined as

$$V(r) = \max_{\{a_t, s_t, f_t\}_{t \geq 0}} E_r \left[\rho \int_0^\infty e^{-\rho t} \chi_t \left(\left(1 - s_t\right) a_t - f_t \right) dt \right], \tag{7}$$

where the dynamics of R_t is given by equation (5).

The Hamilton–Jacobi–Bellman equation (HJB equation) for the value function in equation (7) and the dynamics of the reference value in equation (5) can be formulated as

$$\rho V(r) = \begin{cases} -\kappa \, r \, V'(r), & r \geq \bar{r}, \\ \max\limits_{\{a,s,f\}} \{ \rho \left((1-s)a - f \right) + & \\ + \kappa \left(s\, a + f - \frac{1}{2} a^2 - r \right) V'(r) + \frac{1}{2} \kappa^2 \sigma^2 s^2 V''(r) \}, & r < \bar{r} \end{cases} . \tag{8}$$

In the second-best case, when the principal control only the contract variables s_t and f_t, the HJB equation is still the same as the former in the contract regime, and in the no-contract regime the HJB equation is

$$\rho V(r) = \max_{\{s,f\}} \left\{ \rho \left((1-s)\, s - f \right) + \left(\frac{s^2}{2} + f - r \right) \kappa V'(r) + \frac{1}{2} \kappa^2 \sigma^2 s^2 V''(r) \right\} .$$

III.3 Stationary distribution of the reference value

In the model, the process of the reference value influences the actors' decisions: the principal determines and offers the contract depending on the current level of the agent's reference value, and the agent decides whether or not to accept the offered contract depending on the reference value. The threshold reference value $\bar{r}$ separates between contract and no-contract (or, in other words, no-work) regimes. We examine how long the system spends in each regime in the long run and the average performance of the actors. Mathematically, this means first finding the stationary distribution of the reference value (denoted by the density function $\phi(r)$) and then determining the average performance of the principal and the agent with respect to this distribution.

The first quantity that illustrates the performance of the system is the *average output*:

$$\mathbf{x} = x(\bar{r})\,\Phi + \int_{-\infty}^{\bar{r}} x(r)\,\phi(r)\,dr\,,$$

where Φ denotes the probability that the value of the reference process is at the $\bar{r}$ threshold reference value, and ϕ denotes the density function of the other states. Furthermore

$$x(r) = E\left[x_t \,|\, R_t = r\right] = a(r)\,,$$

i.e., the conditional expected value of the instantaneous output, which is equal to the instantaneous effort of the agent. It follows that the average output is equal to the average effort (which can be defined similarly to the average output):

$$\mathbf{x} = \mathbf{a}\,.$$

The principal and the agent share the average output. The principal receives the *average profit*, i.e.

$$\mathbf{p} = p(\bar{r})\,\Phi + \int_{-\infty}^{\bar{r}} p(r)\,\phi(r)\,dr\,,$$

where

$$p(r) = E\left[p_t \,|\, R_t = r\right]$$

denotes the expected value of the principal's instantaneous profit. The higher the ratio of the average profit to the average output, the more the principal shares in the result of production. The average output actually depends on the effort of the agent. In other words, this ratio also means how the principal's profit is proportional to the agent's effort. According to this interpretation, this quotient is called *exploitation rate* and is denoted by Λ:

$$\Lambda = \frac{\mathbf{p}}{\mathbf{x}} = \frac{\mathbf{p}}{\mathbf{a}}\,.$$

If the exploitation rate is 0, it means that the agent receives the total result of the work, the principal does not share in the result of production. The higher the exploitation rate, the smaller part of the agent's effort goes to the agent itself and the greater to the principal.

The rest of the average output after the principal's profit is the agent's *average (gross) wage*, i.e.

$$\mathbf{w} = w(\bar{r})\,\Phi + \int_{-\infty}^{\bar{r}} w(r)\,\phi(r)\,dr\,,$$

where

$$w(r) = E\left[w_t \,|\, R_t = r\right]$$

denotes the expected value of the agent's instantaneous wage. The agent's average net wage reduced by the average effort cost is

$$\tilde{\mathbf{w}} = \tilde{w}(\bar{r})\,\Phi + \int_{-\infty}^{\bar{r}} \tilde{w}(r)\,\phi(r)\,dr\,,$$

where

$$\tilde{w}(r) = E\left[\tilde{w}_t \,|\, R_t = r\right]$$

denotes the expected value of the agent's instantaneous net wage. As the reference value is defined as the exponential average of net wages, the average net wage is also equal to *average reference value.*

$$\mathbf{r} = \bar{r}\,\Phi + \int_{-\infty}^{\bar{r}} r\,\phi(r)\,dr\,.$$

We can interpret it as the agent's average wage level or simply the standard of living.

As we mentioned several times before, the average amount of time the system spends in the no-contract regime is the amount of time the agent is without work or, more nicely worded, 'rest', is given by the value of Φ. Therefore, starting now, we refer to this quantity as *no-work rate.*

Since the different instantaneous quantities (profit, wage, net wage) are additive, we can also formulate an additive expression between the average quantities. The average output is equal to the sum of the average profit and the average wage, i.e.

$$\mathbf{x} = \mathbf{p} + \mathbf{w}\,.$$

We can further split the average wage into the average cost of effort and the average net wage:

$$\mathbf{w} = \mathbf{c} + \tilde{\mathbf{w}}\,.$$

IV Results

IV.1 Solutions of the control problems

By solving the control problems prescribed for each strategy and market situation, we can determine the optimal contract parameters for the principal.

IV.1.1 Myopic strategy

In perfect competition , the first best contract optimizes the agent's utility with respect to the variables a_t, s_t, and f_t, under the principal's zero-profit condition. We obtain

$$\begin{aligned} a_t^* &= 1 \\ s_t^* &= 0 \\ f_t^* &= 1\,. \end{aligned}$$

Note that $s_t^* = 0$. This is a general property in first-best solutions. As the principal can directly observe and enforce the agent's effort, she does not need to incentivize him with a share of the output.

Substituting the optimized contract parameters, we obtain the optimized utility as

$$u_t^* = \frac{1}{2}\,.$$

This is the utility the principal offers to the agent. If u_t^* is greater or equal to the agent's reference value R_t, then he accepts the offer otherwise he does not. Using the principal's zero-profit constraint, in this case the contract indicator (see equation 3) is simplified to the following form:

$$\chi_t = \mathbf{1}_{u_t^* \geq R_t}\,.$$

It follows that the agent's participation constraint translates to a threshold condition

$$\chi_t = \mathbf{1}_{R_t \leq \bar{r}}\,,$$

where the *threshold reference value* in this case is

$$\bar{r} = \frac{1}{2}\,.$$

In the second-best case, the principal cannot observe and enforce the agent's effort a_t in the second-best case, therefore she needs to incentivize him by offering a share of the output. The agent determines a_t autonomously, optimizing his utility, given the contract parameters s_t and f_t. Using equation (2), this yields the optimal effort

$$a_t^* = s_t\,. \tag{9}$$

The optimal contract parameters now take the form

$$\begin{aligned} a_t^* &= \frac{1}{1+\gamma\,\sigma^2} \\ s_t^* &= \frac{1}{1+\gamma\,\sigma^2} \\ f_t^* &= \frac{\gamma\,\sigma^2}{(1+\gamma\,\sigma^2)^2}\,, \end{aligned}$$

and the agent's utility is

$$u_t^* = \frac{1}{2\,(1+\gamma\,\sigma^2)}\,.$$

Then the threshold reference value is

$$\bar{r} = \frac{1}{2\,(1+\gamma\,\sigma^2)}\,.$$

As expected, now we obtain a non-zero share s_t^*, which is necessary for incentivizing the agent. With this non-zero share, the agent's wage becomes random, exposing the agent to income risk as well as consumption and utility risk due to the hand-to-mouth assumption. The results above are driven by a trade-off between the principal's need to incentivize the agent and the agent's risk-aversion. The cost of moral hazard is reflected in the fact that the expected output a_t^*, the fix wage f_t^*, and the utility u_t^* are smaller than in the first-best case.

In monopsonistic labour market the agent's binding participation constraint means the fix wage f_t can be expressed and hence we obtain the contract parameters as previously

$$a_t^* = 1 \tag{10}$$

$$s_t^* = 0 \tag{11}$$

$$f_t^* = R_t + \frac{1}{2}\,, \tag{12}$$

and the optimal profit

$$p_t^* = \frac{1}{2} - R_t\,. \tag{13}$$

The principal is only interested in the contract if this optimized profit is non-negative or $p_t^* \geq 0$. It follows that the principal's participation constraint translates to the same type of threshold condition, that is $R_t \leq \frac{1}{2}$, as in the perfect competition case and

$$\chi_t = \mathbf{1}_{R_t \leq \bar{r}}$$

When $R_t > \bar{r}$, there is no contract and the principal's profit is zero. We can thus write the optimized profit function for all $R_t \in \mathbb{R}$ as

$$p_t^* = (\bar{r} - R_t)^+$$

From expression (13) we can see, the threshold reference value is

$$\bar{r} = \frac{1}{2}\,.$$

In the second-best case, as previously, we obtain the optimal contract parameters

$$s_t^* = \frac{1}{1 + \gamma\,\sigma^2} \tag{14}$$

$$a_t^* = \frac{1}{1 + \gamma\,\sigma^2} \tag{15}$$

$$f_t^* = R_t - \frac{1 - \gamma\,\sigma^2}{2\,(1 + \gamma\,\sigma^2)^2}\,. \tag{16}$$

Now the optimal profit takes the form

$$p_t^* = \frac{1}{2\,(1 + \gamma\,\sigma^2)} - R_t \tag{17}$$

and the threshold reference value is

$$\bar{r} = \frac{1}{2(1 + \gamma\,\sigma^2)}\,. \tag{18}$$

We can see that in the second-best case, the share offered by the principal is no longer zero, as opposed to the first best case. Expression $\frac{1}{1+\gamma\,\sigma^2}$ represents the trade-off between the need to incentivize the agent, and the risk the agent is exposed to as he receives a share of the noisy output.

In each cases, substituting the optimal contract parameters a_t^*, s_t^* and f_t^* into equation (5), we obtain the dynamics of the reference value R_t, and in particular, for the perfect competition first-best case as

$$dR_t = \begin{cases} -\kappa\,R_t\,dt, & R_t \geq \frac{1}{2} \\ \kappa\left(\frac{1}{2} - R_t\right)dt, & R_t < \frac{1}{2} \end{cases} \tag{19}$$

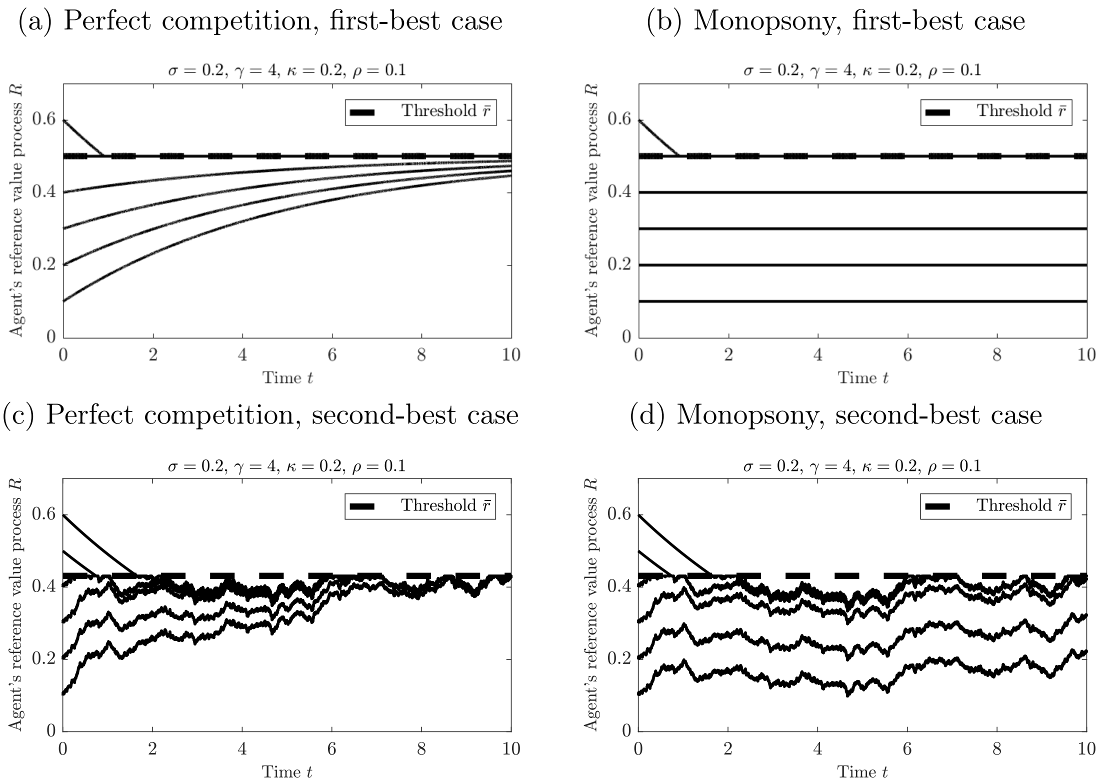

Figure 1: Examples of the dynamics of the reference value in the benchmark model

for the monopsony first-best case as

$$dR_t = \begin{cases} -\kappa\, R_t\, dt, & R_t \geq \frac{1}{2} \\ 0, & R_t < \frac{1}{2} \end{cases} \tag{20}$$

for the perfect competition second-best case as

$$dR_t = \begin{cases} -\kappa\, R_t\, dt, & R_t \geq \frac{1}{2\,(1+\gamma\,\sigma^2)} \\ \kappa\left(\frac{1+2\,\gamma\,\sigma^2}{2\,(1+\gamma\,\sigma^2)^2} - R_t\right) dt + \kappa\, \frac{\sigma}{1+\gamma\,\sigma^2}\, dB_t, & R_t < \frac{1}{2\,(1+\gamma\,\sigma^2)} \end{cases} \tag{21}$$

and for the monopsony second-best case as

$$dR_t = \begin{cases} -\kappa\, R_t\, dt, & R_t \geq \frac{1}{2\,(1+\gamma\,\sigma^2)} \\ \kappa\, \frac{\gamma\,\sigma^2}{2\,(1+\gamma\,\sigma^2)^2} dt + \kappa\, \frac{\sigma}{1+\gamma\,\sigma^2}\, dB_t, & R_t < \frac{1}{2\,(1+\gamma\,\sigma^2)} \end{cases} \tag{22}$$

We illustrate the four different dynamics in Figure 1. We show trajectories with different initial reference values. All the trajectories are generated from the simulation of one particular Brownian motion trajectory.

In all four cases, if the initial reference value is above the threshold, the players do not contract for a while, and the reference value then decays exponentially. This corresponds to a gig worker who has too high initial demands. He does not find work as the employer cannot realize positive profits by contracting at such high wages. As time passes, out of gig jobs and thus with zero income, the worker's demands drop. The higher the value of the parameter κ, the faster the worker is forced to lower his demands, or in other words, the more vulnerable he is.

In both second-best cases, the reference value follows a *sticky reflecting Brownian motion* on $(-\infty, \bar{r}]$. Starting below $\bar{r}$, the reference value process behaves like a Brownian motion with some drift and variance. When the upper boundary $\bar{r}$ is reached, it is reflected back below the boundary. However, the overall time spent at the boundary is positive as the reflection is sticky. See in particular Theorem 5 of Engelbert and Peskir [2014] for the SDE specification of sticky reflecting Brownian motion and the existence of a weak solution.

IV.1.2 Far-sighted strategies

From the solution of HJB equations we obtain the first-best optimal contract parameters as

$$\begin{aligned} a^*(r) &= 1 \\ s^*(r) &= 0 \\ f^*(r) &= r + \frac{1}{2}, \end{aligned}$$

the threshold reference value as

$$\bar{r} = \frac{\rho}{2(\kappa + \rho)}, \tag{23}$$

and the optimal value function as

$$V(r) = \begin{cases} \frac{1}{2} - r, & r < \frac{\rho}{2(\kappa+\rho)} \\ \frac{\kappa}{2(\kappa+\rho)} \left(\frac{r}{\bar{r}}\right)^{-\frac{\rho}{\kappa}}, & r \geq \frac{\rho}{2(\kappa+\rho)} \end{cases}.$$

Inspecting our result for the threshold $\bar{r}$ (equation 23) allows for the analysis of this trade-off in terms of the principal's and agent's attributes. The value of $\bar{r}$ is indicative of how the principal and the agent share the fruits of production. The higher the threshold is, the higher the wage the agent can secure for himself and the lower the principal's profit. According to equation (23), $\bar{r}$ depends on the ratio between ρ and κ, if ρ is large (small) relative to κ, $\bar{r}$ becomes larger (smaller).

The parameter ρ is the employer's subjective discount rate, in financial terms her expected return. A large ρ means the employer greatly discounts long-term profits, she is more focused on making profits in the short-term. She cannot afford the delay in production and is forced to employ the worker sooner rather than later, even for a high wage. Her bargaining power is relatively weak and her share of the output will be low.

On the other hand, κ measures the worker's vulnerability, the rate at which the worker's reference value decreases when unemployed (see equation 5). The greater κ, the sooner the worker is ready to take up work, even at low wages. This decreases his bargaining power, his share of the output will be low. Our model thus connects the employer's and the worker's relative bargaining power to characteristic time-scale attributes of them. How long can the employer afford to wait for the worker to drop his wage demands? How long can the worker go without contract, and thus without gig income? Whoever can afford to be more patient, will be relatively less vulnerable, and will win out in the wage battle.

The second best-case is more complicated than the previous one in that the effect of the share incentive also reappears. In this case, the control problem is characterized as follows. The optimal value function V is twice continuously differentiable and satisfies the ordinary differential equation

$$0 = \frac{1}{2} \frac{1}{1 + \gamma\,\sigma^2 - \frac{\kappa}{\rho}\,\gamma\,\sigma^2\,V'(r) - \frac{\kappa^2}{\rho}\sigma^2\,V''(r)} - r - V(r) \tag{24}$$

on $(-\infty, \bar{r})$, where $\bar{r}$ is a free boundary, with boundary conditions

$$\begin{aligned} 0 &= \lim_{r \searrow -\infty} V''(r)\,, \\ 0 &= \lim_{r \nearrow \bar{r}} -\kappa\,r\,V'(r) - \rho\,V(r)\,, \\ 0 &= \lim_{r \nearrow \bar{r}} -\kappa\,r V''(r) - [\rho + \kappa]\;V'(r) \end{aligned}$$

The first boundary condition states that for an ever increasing distance to the boundary $\bar{r}$, the value function becomes linear. The second boundary condition states that V is continuously differentiable at $\bar{r}$. The third boundary condition further states that V is twice continuously differentiable at the boundary $\bar{r}$ and relates to the optimality of the free boundary choice. It is sometimes called super contact condition. The corresponding optimal control in the contract regime, that is, for $r < \bar{r}$, is given by

$$\begin{aligned} a^*(r) &= s^*(r) \\ s^*(r) &= \frac{1}{1 + \gamma\,\sigma^2 - \frac{\kappa}{\rho}\,\gamma\,\sigma^2\,V'(r) - \frac{\kappa^2}{\rho}\sigma^2\,V''(r)} \\ f^*(r) &= \left(r - (s^*(r))^2/2 + \gamma\,\sigma^2\;(s^*(r))^2/2\right) \end{aligned}$$

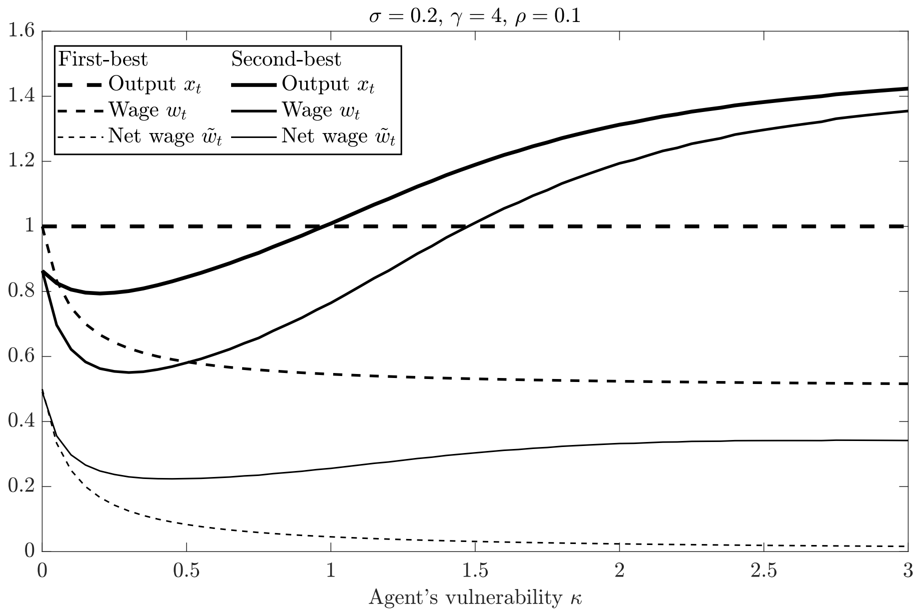

Figure 2: Effects of the agent's vulnerability parameter κ on the output x_t, wage w_t and net wage $\tilde{w}_t$ for $R_t = \bar{r}$. The principal is far-sighted and monopsonistic.

Note that these results still contain differential equations that need to be solved. The second order differential equation for V on $(-\infty, \bar{r})$ in (24) is non-linear and a well-known path to a closed-form solution does not exits. Thus, we solve the differential equations numerically. In particular, we employ a Picard-type iteration and some heuristics motivated by our results of the previous cases to determine the free boundary $\bar{r}$.

IV.1.3 Vulnerability and self-exploitation

We examine how the worker's vulnerability parameter κ affects the worker's effort and his wage level, then we compare the effects in the first-best case and the second-best case.

In the case of second-best solutions (see the solid curves Figure 2), firstly we can observe declining phase, then the output, the wage, and the net wage all tend to increase. Above a certain κ, the effect of incentivization becomes very pronounced as the employer offers more and more share of the output. In fact, the share becomes even greater than one, which means that the employer not only offers all the output to the worker but also complements it with an output-proportional premium. As the incentive increases, the worker chooses to invest more and more effort and thus the output and his gross wage also increases. On the other hand, the worker's net wage only increases moderately and soon levels off. The relative weakness of the worker in this regime is exhibited in a new way: as his vulnerability increases, he works harder and harder, but his net wage (essentially, his utility) remains nearly constant. This phenomenon represents self-exploitation in our model.

IV.2 Stationary distribution

To determine the stationary distribution of the reference value, we have to start from the dynamics of the process, which is described in the optimal control by the following stochastic differential equation:

$$dR_t = \begin{cases} -\kappa\, R_t\, dt\,, & R_t \geq \bar{r} \\ \kappa\,\gamma\,\sigma^2\,\frac{s^2(r)}{2}\,dt + \kappa\,\sigma\,s(r)\,dB_t\,, & R_t < \bar{r} \end{cases}.$$

Due to simplicity, we have omitted the asterisks of the function $s^*(r)$ obtained in the optimal control in the above equation. Still, the fact that the contract parameter s depends on the state r is emphasized by consistently writing the argument r of the function. The stochastic process of the reference value is thus, in this case, a sticky-reflected Brownian motion, where, moreover, both the degree of drift and the degree of volatility are state-dependent. The infinitesimal generator of the process $\mathcal{A}$ is:

$$\mathcal{A}\,g(r) = \begin{cases} -\kappa\,r\,g'(r)\,, & r = \bar{r} \\ \frac{1}{2}\,\kappa^2\,\sigma^2\,\left[s^2(r)\,g(r)\right]'' + \frac{1}{2}\,\gamma\,\kappa\,\sigma^2\left[s^2(r)\,g(r)\right]'\,, & r < \bar{r} \end{cases}.$$

Φ denotes the probability that the reference value process is at threshold $\bar{r}$, and ϕ is the density function of the other states. The stationary distribution of stochastic process with sticky boundary is ϕ if and only if

$$0 = \int_{(-\infty,\bar{r}]} \mathcal{A}\,g(r)\,\phi(r)\,dr\,,\ \forall g\,. \tag{25}$$

For further details, see Harrison and Lemoine [1981], page 221.

Solving the the equation, we obtain

$$\Phi = \frac{\kappa\,\sigma^2\,s^2(\bar{r})}{2\,\bar{r}}\,\phi(\bar{r}) \tag{26}$$

and

$$\phi(r) = \frac{c_1}{s^2(r)}\,\exp\left\{\frac{\gamma}{\kappa} r\right\}\,, \tag{27}$$

where $c_1 \in \mathbb{R}$ is constant. These two expressions together with the normalization condition

$$\Phi + \int_{-\infty}^{\bar{r}} \phi(r)\,dr = 1 \tag{28}$$

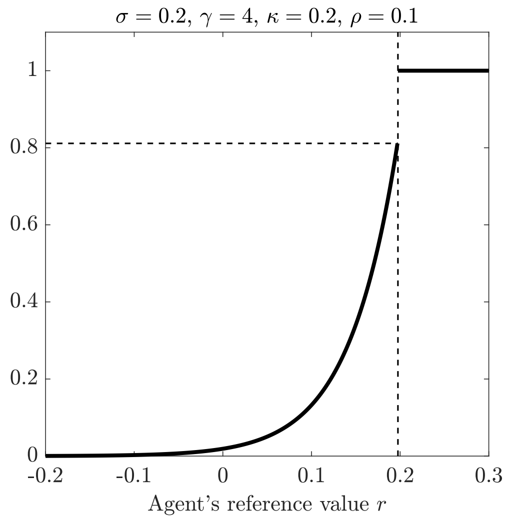

Figure 3: The cumulative distribution function of the stationary distribution of the reference value in the second-best case

determine the probability Φ and the density $\phi(r)$.

Figure 3 shows the stationary distribution of the reference value. The CDF decays exponentially in the range below the threshold reference value $\bar{r}$, and this decay is relatively fast. This means that the system spends most of its time close to the threshold reference $\bar{r}$. The jump in the distribution function at the threshold corresponds to Φ, which means how much time the system spends in no-work regime. In the example shown, this value is nearly 20 percent.

Inspecting the quantities as a function of the vulnerability κ, we find that as a non-trivial combination of different effects (incentive-risk trade-off, job rationing), the threshold reference value and the unemployment rate fluctuate (see Figure 4). The threshold reference value $\bar{r}$ decreases sharply for a while as κ increases, then rises slightly, and finally remains quasi constant. On the other hand, the unemployment rate Φ increases sharply and then declines more slowly after a certain level. A significant change in both the threshold reference value and the unemployment rate is observed when the vulnerability parameter is on a similar order of magnitude as the principal's discount rate. In the case of an order of magnitude higher vulnerability, the change in the two quantities is more moderate.

As κ increases, so does the average output $\mathbf{x}$, the average wage $\mathbf{w}$, and the average net wage $\tilde{\mathbf{w}}$ (see Figure 5). This means that the average effort (and the average output) is equal to the average share $\mathbf{s}$, and thus the average effort cost (the gap between $\mathbf{w}$ and $\tilde{\mathbf{w}}$) also decreases. The gap between $\mathbf{x}$ and $\mathbf{w}$, which means the principal's average profit $\mathbf{p}$ is monotonously increasing, i.e., the principal can

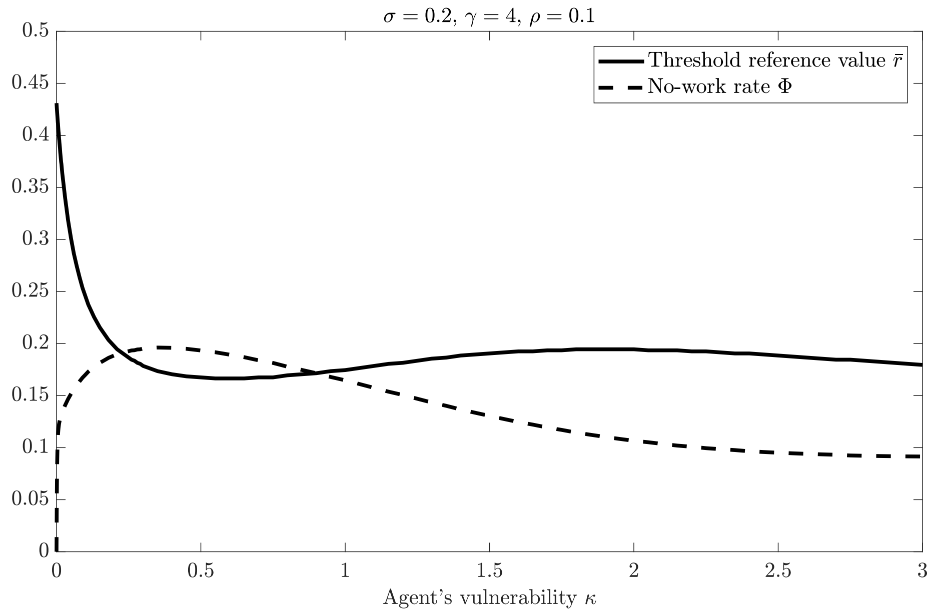

Figure 4: The effect of the agent's vulnerability parameter κ on the threshold $\bar{r}$ and unemployment rate Φ.

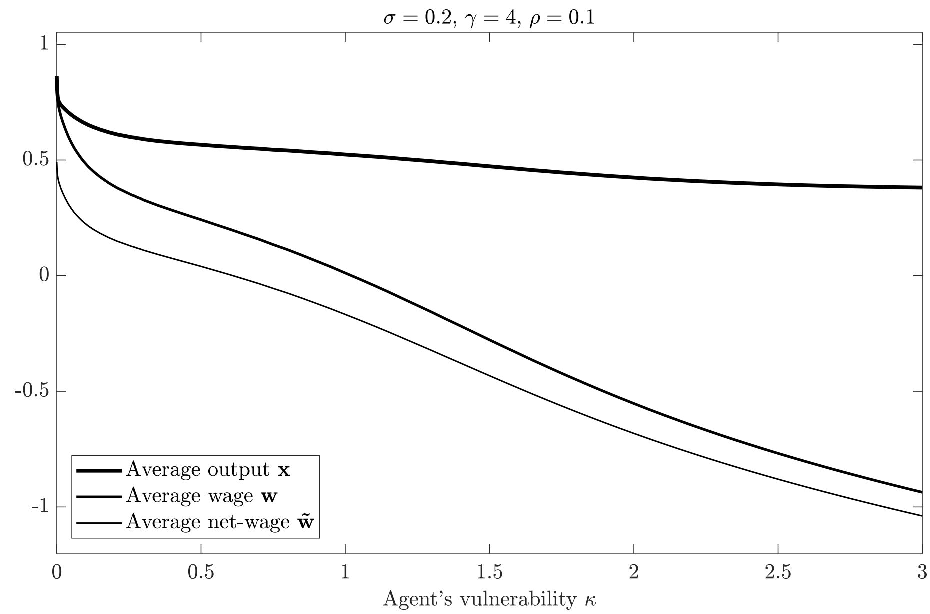

Figure 5: The effect of the agent's vulnerability parameter κ on the average output $\mathbf{x}$, average wage $\mathbf{w}$ and average net wage $\tilde{\mathbf{w}}$.

expect more and more profit from the output, the exploitation rate Λ increases. This demonstrates the increasing vulnerability of the agent. On average, the agent works and produces less, but more goes to the principal.

V List of publications

Bihary, Z., Csóka, P., Kerényi, P., and Szimayer, A. (2021). Self-respecting worker in the gig economy: A dynamic principal-agent model. Working Paper *Available at SSRN 3866721*
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