

Reference Dependence and the Role of Information Frictions

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Abstract

Decades of research highlight the importance of social preferences in strategic interactions. However, most studies assume full information and stable conditions. We relax both by introducing endowment shocks and information frictions into a labor market experiment. Workers evaluate wages consistently with a reference wage that depends on economic conditions and adjusts instantaneously to information but sluggishly and asymmetrically to experience. Firms form accurate beliefs about how shocks and information reshape effort responses and act on their beliefs, acting almost optimally in all scenarios. Counter-intuitively, information frictions do not always benefit the informed party.

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1 Introduction

Ample experimental evidence convincingly demonstrates that other-regarding preferences lead people to deviate from the self-interested outcomes predicted by standard economic theory (Camerer, 2011). A significant stream in this literature models experimental labor markets under full information and stable economic conditions to study how variation in structural parameters influences wages, effort, and employment (Charness and Kuhn, 2011). A general finding is that reciprocity and fairness motives prop up wages and effort above the Nash equilibrium prediction (Fehr et al., 1993, 1998). Such other-regarding preferences motivate many behavioral theories of labor market dynamics.¹

However, the assumptions of full information and stable economic conditions may not be benign. Economic volatility, information structure, or both may affect behavior on both sides of a market. For example, a worker may be more willing to accept wage cuts during economic downturns triggered by shocks unrelated to the firm’s performance (i.e. inflation in inputs, negative transitory shocks, etc.). Similarly, workers may expect wage hikes in times of economic prosperity.

Likewise, relaxing both conditions can also provide insight into whether extrinsic or intrinsic motives explain supra market-clearing wages in the gift exchange game.² For example, if intrinsic motives (i.e. a desire for equality or fairness) explain this empirical regularity, then introducing information frictions following a positive economic shock should not distort wage dynamics. However, extrinsically motivated firms will likely capitalize on wage frictions and pass through a significantly lower proportion of the positive shock to workers via wages.

These examples convey the main intuition of our paper, wherein we propose that a worker evaluates wages with respect to a reference wage that depends on the firm’s economic conditions. Because of this relationship between reference wages and economic conditions, information structure can play a crucial role in wage-effort dynamics. Understanding this is important since most real-world employment relationships feature at least some degree of information asymmetry.³

¹Examples of theories include the fair wage-effort hypothesis (Akerlof, 1982; Akerlof and Yellen, 1988, 1990), reference dependence (Tversky and Kahneman, 1979), adverse selection in quits and hires (Weiss, 1980, 1990), and reciprocity and fairness (Rabin, 1993). For evidence on labor market dynamics, see (Altonji and Devereux, 2000; Agell and Lundborg, 2003; Dickens et al., 2007; Babecky et al., 2010; Kaur, 2019; Jo, 2019).

²This is similar to Falk et al. (1999), who consider whether social approval and repeated interactions motivates worker behavior in a labor market game with incomplete contracts.

³ See Cullen and Perez-Truglia (2018, 2022) for evidence of information frictions.

This paper relaxes these assumptions by introducing information frictions and economic shocks into a gift exchange game, yielding a 2×2 between-subjects design. In this design, we match subjects into stable pairs and randomly assign one to act as a firm and the other as a worker and have them interact for 20 periods. In each period, the firm receives an endowment that it splits between the worker's wage and savings. The worker responds to the wage offer by choosing a costly level of effort. At the end of each period, both the firm and worker learn of their own and their counterpart's payoff. Halfway through each session we either increase or decrease (*positive* and *negative*) the firm's endowment by one third. Sometimes the workers know of this shock (*full information*) and sometimes they do not (*asymmetric information*).

We introduce a novel approach to belief elicitation that allows us to study how firm beliefs about worker effort evolve with experience, in response to shocks, and under different information conditions. Importantly, we also elicit the full effort response function via strategy method so that we can evaluate the accuracy of the firm's beliefs. This feature allows us to observe the optimality of firm decisions and to demonstrate that workers adjust their effort responses following economic shocks.

We find that under full information, wages adjust in the direction of endowment shocks, and firms and workers share shocks equally. On average, firms increase wages following a positive shock by about half the size of the shock and decrease wages following a negative shock by about the same magnitude. Belief elicitation reveals firms do this because they know fully-informed workers expect wages to adjust following endowment shocks. Because workers' expectations adjust upon learning of the shock, post-shock wages offer little surprise and effort remains relatively stable.

Introducing information frictions significantly changes wage dynamics following endowment shocks. Wages increase, on average, by about half as much following a positive shock and fall by about 20% less following a negative shock whenever firms know that workers are uninformed. Thus, information frictions moderate wages and better align them with the theoretical predictions of a self-interested, profit-maximizing firm. This moderative effect of information frictions suggests that extrinsic motives explain a significant amount of firm behavior following economic shocks.

Because uninformed workers' wage expectations do not adjust following endowment shocks, wage

changes come as a surprise and lead to much stronger effort responses, which lead to a significant change in profit shares. Despite significantly smaller wage hikes, effort increases by about as much as under full information. And despite the average wage falling by 20% less, effort decreases by about four times as much. Negative shocks with information frictions are the only case in our setting where firms' beliefs are inaccurate and do not anticipate such a strong punitive response from the worker.

Thus, information frictions benefit firms following a positive shock and harm firms following a negative shock. Counter-intuitively, it is not always the more informed party who benefits from information frictions. The one exception we observe comes in our negative asymmetric information treatment, where firms do not anticipate workers retaliating unexpected wage cuts with punitive effort cuts. Thus, the average firm's offer is too low relative to the actual average profit-maximizing wage.

Workers adjust their wage expectations with subsequent experience. However, adjustment is sluggish relative to a full-information setting and adjustment dynamics depend on the direction of wage surprises. Succinctly, we find that wage expectations are much more strongly anchored in response to negative wage surprises than to positive wage surprises. In positive asymmetric treatments, the initial wedge between wage expectations and offers vanishes by period 15. This is in sharp contrast to full information conditions, where adjustment is immediate. For negative asymmetric shocks, wage expectations remain above wage offers in all the post-shock elicitation periods. Hence, we find subjects are less willing to adjust expectations downward following unexpected wage cuts than upward following unexpected wage hikes.

Finally, in a structural exercise, we demonstrate that introducing state-dependent reference wages into the worker's utility function almost always increases out-of-sample predictive power. Using only pre-shock data, we estimate a model with an adjustable reference wage and then obtain predictions for the post-shock periods. As a comparison, we benchmark our predictions against a model with a constant reference wage that does not react to endowment shocks. Our model significantly outperforms the benchmark model when forming out-of-sample predictions of worker behavior and at predicting firms' post-shock beliefs following negative shocks. In addition, our model significantly outperforms the benchmark model at prediction post-shock wages. In general, this exercise

highlights the benefits of incorporating information frictions into models of reference dependence.

Section 2 summarizes related literature and highlights our contributions. Section 3 describes our conceptual framework, highlighting the role of information asymmetries. Section 4 describes our experimental design on eliciting beliefs and effort responses. Section 5 contains our main analysis and results. We show the results of our structural exercise in section 6. Finally, section 7 concludes.

2 Literature Review

Our work integrates extant experimental literature on how economic shocks and information influence labor markets. ⁴ Rubin and Sheremeta (2016) use a gift exchange experiment to show that random productivity shocks impede gift exchange even with fully informed firms. Davis et al. (2017) replicate the gift exchange finding but argue providing information about shocks to firms *can* restore gift exchange. In our context, shocks corresponds to aggregate economic conditions and not to productivity signals or within firm comparisons. Bejarano et al. (2021) show the relationship between economic stability and gift exchange also holds when using a real effort task in a stylized gift exchange setting. Kujansuu and Schram (2021) show that temporary, probabilistic tax shocks that hit wages, productivity, or both can mute gift exchange following a wage shock but that neither shock type systematically affects wages.⁵

Relative to these studies, we introduce permanent endowment shocks into stable firm-worker pairs where firms must allocate a shock whenever deciding wages. Further, we couple these permanent shocks with information frictions, the elicitation of beliefs about the full effort response function, the elicitation of the full effort response function, and the elicitation of wage expectations. Differences in our design relative to these existing studies let us study *when and why* firms choose to pass shocks through to workers, how information conditions influence workers' responses to wage changes, and the role of both information and experience in determining wage expectations as reference points.

Few experimental studies examine how information about available surplus influences allocations. Evidence from dictator and ultimatum games suggests that people strategically exploit asymmetric

⁴There is an extensive literature modeling experiment labor markets as partial gift-exchanges. Examples using chosen effort are Fehr et al. (1993); Fehr et al. (1998) and Charness (2004). Examples using real-effort tasks are Cohn et al. (2015); Greiner et al. (2011) and Hennig-Schmidt et al. (2010).

⁵Other papers study the role of social information in experimental labor markets. For examples, see Charness and Kuhn (2007) or Gächter et al. (2013).

information in their favor when making pro-social decisions (Dana et al., 2006, 2007) and that varying information in ultimatum games shows that relative payoffs and fairness enter players' utility functions (Mitzkewitz and Nagel, 1993; Kagel et al., 1996; Schmitt, 2004; Croson, 1996).

Another important strand of literature focuses on how workers react to wage cuts whenever they actually do occur. Buchanan and Houser (2020) find in a stylized gift-exchange game with multi-period wage contracts that the wage-effort relationship responds to nominal but not real wage cuts. Chen and Horton (2016) find that workers in online labor markets working for piece-rate wages are more likely to quit a working relationship following wage cuts. However, if the online employer justifies wage cuts using productivity-based or peer-based (i.e. others have accepted this lower wage) arguments, then workers quit less than if the worker uses a profit-based rationalization (i.e. we are trying to minimize our wage bill). Importantly, Chen and Horton (2016) features neither a change in economic conditions nor information frictions that lead to an asymmetric information structure. Doerrenberg et al. (2019) find via an online experiment that workers respond more strongly along the extensive margin to wage cuts than to wage hikes. Koch (2021) uses a laboratory experiment to show that contracts can serve as reference points and lead to slightly more rigid wages whenever firms are hit by negative profit shocks. In this experiment, both the firm and worker have full information about the effective effort and economic conditions. Further, the author shows that providing information about worker reactions to wage cuts does not lead to significantly different wage and effort dynamics than just informing firms about effective wages.

Our work also relates to the literature on reference dependence. Köszegi and Rabin (2006) endogenized reference points theoretically by assuming expectations can form a reference point. This assumption found support in the laboratory (Abeler et al. (2011)) and in the field (Crawford and Meng (2011)). Thakral and Tô (2021) show that reference points adjust dynamically in response to accumulated income, with agents placing more weight on recent earnings. This aligns with DellaVigna et al. (2017), who provide evidence from a natural experiment in Hungary that workers anchor their expectations around recent paychecks.

We contribute to both literatures by exploring the relationship between economic shocks, information, and reference points. This allows us to make at least two important contributions. First, we consider reference dependence in conjunction with information frictions. Restricting information to

workers so that changes in reference points depend solely on experience leads to more muted and sluggish adjustments. Second, we study wage-effort dynamics in response to both expansionary and recessionary shocks. We find an asymmetry in experience-based adjustments: workers update more rapidly to wage increases than to cuts. In contrast, news-based adjustments are immediate and symmetric across conditions. Finally, our coupling of information frictions with extensive belief elicitation allows us to show that firm beliefs about worker effort provide an additional mechanism to explain firms' reluctance to cut wages, consistent with survey evidence from [Bewley \(1995, 1999\)](#).

Recent evidence from [DellaVigna et al. \(2022\)](#) shows that charity workers are insensitive in productivity to unexpected positive and negative 'gifts' (i.e. wage shocks) from the employer. However, they find evidence that workers are more willing to do extra work in response to positive gifts and suggestive evidence that positive reciprocity may be stronger than negative reciprocity. We find the opposite: workers drastically reduce effort in response to unexpected wage cuts and do not increase effort substantially following unexpected wage hikes. Taken together, this suggests that workplace context, the nature of work, and a worker's source of motivation can play an important role in wage-effort dynamics.

3 Theoretical Framework

This section uses a stylized model and comparative statics to illustrate how information frictions and economic shocks can influence wage-effort dynamics. For simplicity, we consider a static framework where neither experience nor reputation play any role.⁶ This simple, static model is enough to highlight the potential role of information frictions in conjunction with economic shocks, which motivates our experiment and rationalizes our empirical results.

The key intuition is that workers have reference-dependent preferences that depend on available information about firms' economic conditions. Changes in economic conditions can then reshape the effort response function *only if* the worker is aware of the changes. Previous models employ similar logic by allowing for effort to respond to the introduction of minimal wages ([Brandts and Charness \(2004\)](#); [Falk et al. \(2006\)](#); [Owens and Kagel \(2010\)](#)), a rise in inflation levels or a threat to firm profits ([Kahneman et al. \(1986\)](#); [Kaur \(2019\)](#)).

⁶While our actual design uses a dynamic setting so that we can study belief updating, we find that previous experience and reputation play a very minor role in explaining our results.

3.1 Basic set up

Consider a labor market with a single firm and single worker formed into a firm-worker pair. The firm has an endowment R which she uses to set a wage $w \in [\underline{w}, \dots, R]$. The worker provides costly effort $e \in [0, \bar{e}(w)]$, with $c(e)$ being the monetary cost of effort and $\bar{e}(w)$ is the maximum possible effort that yields non-negative monetary payoffs (i.e, $w - c(\bar{e}) = 0$). For now, we assume that both the worker and firm have symmetric information regarding economic conditions, captured by R .

We adopt a widely-used profit function, first introduced in [Fehr et al. \(1993\)](#); [Fehr and Schmidt \(1997\)](#), that models a profit-maximizing firm with no altruistic motives whose profit function depends on the endowment, the wage, and the worker's effort.

$$\pi_i(w, e) = (R - w)e. \tag{1}$$

We show in [Appendix B](#) that our hypotheses are robust to assuming a recently-popularized alternative profit function, $\pi = Re - w$.⁷⁸

The worker's utility function incorporates monetary incentives, reference-dependence, and other-regarding preferences. This yields a modified version of the effort response function introduced in ([Akerlof and Yellen \(1988, 1990\)](#)) and similar in spirit to [Dickson and Fongoni \(2019\)](#):

$$U_j(e, w, \tilde{R}) = w - c(e) + M(w, \tilde{R}, w_0(\tilde{R})) \cdot e \tag{2}$$

where $c(e)$ is a strictly convex cost function of effort. The first component $w - c(e)$ captures the monetary incentive of the worker while the last component M is the 'morale function,' which captures three distinct features comprising the worker's reference dependence and other-regarding preferences.

First, the worker forms a reference wage $w_0(\cdot)$ that depends on her beliefs, \tilde{R} , about the firm's

⁷The advantage of this form is that the marginal product of the effort is not decreasing in the wage. However, it has the caveat of possible negative payoffs. Hence, we decided not to implement it in our experimental design.

⁸Another alternative we have encountered is $\pi = R - we$. However, with this functional form, profits are decreasing in the effort, and a firm could maximize profits by simply offering a wage of zero. Further, this solution is not unique. Imagine instead that the firm pays a wage of R . If the worker responds with $e = 0$ then the firm still earns $R - R * 0 = R$.

economic conditions, R . When both parties have full information about economic conditions, $\tilde{R} \equiv R$. We assume $w_0(\cdot)$ is order-preserving so that a higher endowment always warrants a higher wage. Formally, all else equal, $\forall(R, R')$ where $R > R'$, $w_0(R) > w_0(R')$.

Second, the worker evaluates the offered wage w in relation to the reference wage $w_0(\cdot)$. Wages above the reference wage induce positive reciprocity while wages below the reference wage induce negative reciprocity. This produces a gain or loss in the worker's utility, respectively.

Finally, the worker considers wages relative to the firm's endowment. Suppose a worker receives a wage larger than her reference wage. Intuitively, our model says the worker will more strongly reward this wage coming from a poorer firm than a richer firm. This adds an additional channel through which changes in (information about) economic conditions impact the worker's effort choices.

Given these preferences, we assume the functional form of M to resemble a gain-loss function as follows:

$$M(w, \tilde{R}, w_0(\tilde{R})) = \alpha_j \left(\frac{\mu + w - w_0(\tilde{R})}{\tilde{R}} \right)^{\beta_j}$$

where μ represents the utility value when the worker receives the reference wage, $w = w_0(\tilde{R})$. We also allow $M(\cdot)$ to depend on parameters $\alpha_j, \beta_j \geq 0$ to account for individual traits of reciprocal behavior (Cox et al. (2006); Buchanan and Houser (2019)). When $\alpha = 0$, the worker does not respond reciprocally to wages and our model yields the classical Nash equilibrium prediction of minimum wages and effort. If $\beta_j = 1$ the reciprocal component of equation 2 becomes linear, which implies effort responds equivalently to both wage surprises and shortfalls of equivalent magnitude. If $\beta_j > 1$ then workers reward positive wage surprises more strongly than they punish wage shortfalls, and vice versa if $\beta_j < 1$.⁹

3.2 Endowment shocks and the role of information frictions

Solving the model via best response analysis (details in Appendix B) yields the following optimal effort and wage levels:

⁹A noteworthy addition to the model could be the introduction of loss aversion in the spirit of Kahneman (1979), Tversky and Kahneman (1991). This could be captured by different values of α_j that correspond to wages that are either above or below the reference wage. While we think that loss aversion is an important factor in workers' effort response (see Dickson and Fongoni (2019); Buchanan and Houser (2019)), we prefer keeping our model parsimonious.

$$e_i^*(w, \tilde{R}, w_0(\tilde{R})) = \alpha_j \left(\frac{\mu + w - w_0(\tilde{R})}{\tilde{R}} \right)^{\beta_j} \quad (3)$$

$$w^*(e^*) = \frac{\beta_j R + w_0(\tilde{R}) - \mu}{1 + \beta_j} \quad (4)$$

Using both equations 3 and 4, we can now illustrate the dynamics of the model in response to an endowment shock under both full and asymmetric information conditions.

Suppose there is an exogenous expansionary (recessionary) increasing R to R' that is known to both the firm and the worker. This shock puts upward (downward) pressure on wages via R and $w_0(R)$. Thus, both the worker's reference wage and the optimal wage adjust in the direction of an endowment shock under full information. In this scenario, a change in R changes the optimal wage $w^*(e^*)$ by $\frac{\partial w^*}{\partial R} = \frac{\beta_j + w'_0(R)}{1 + \beta_j}$.

Hypothesis 1: Under full information, a positive (negative) shock to the firm's endowment leads to an increase in the (decrease) wage offered by the firm.

Now let us consider the worker's effort response to a given wage w . Changes in the endowment R impact effort levels through two channels: $w_0(R)$ and the scaling factor R . When R increases, both imply a decrease in the effort level for any given wage. This yields the following hypothesis:

Hypothesis 2: Under symmetric information, a positive (negative) shock to the firm's endowment leads to the worker providing less (more) effort, relative to pre-shock effort levels, for each wage in the wage distribution.

Suppose instead that only the firm knows about the exogenous expansionary shock. Firm's endowment shifts from R to R' , leading to an increase in $w^*(\cdot)$ directly through the change in the endowment. However, the worker does not adjust her belief about R , \tilde{R} , to its new level so that $R = \tilde{R} < R'$. As a result, $w_0(R) = w_0(\tilde{R}) < w_0(R')$. Since equation 4 is strictly increasing in $w_0(\cdot)$, the optimal wage w^* under asymmetric information is lower than its analog under full information.

Hypothesis 3: Information frictions moderate wage changes following an endowment shock.

When the worker is unaware of the endowment shock, her effort response function remains un-

changed, $R = \tilde{R}$. Because of this, the worker will react more strongly to a given wage increase than how she would react to the same wage increase under full information since $\frac{w-w_0(R)}{R} < \frac{w-w_0(R')}{R'}$ when $R' > R$.¹⁰ This leads to the following hypothesis:

Hypothesis 4: Workers respond more strongly to wage changes following an endowment shock under asymmetric information than full information.

Overall, this simple model reveals that information structure can play a critical role in determining allocations following economic shocks. Our experimental design, which closely mimics the intuition of this model, provides a direct test for these hypotheses.

Throughout this section we have assumed that the firm engages in best response analysis – a common feature of principle-agent models – even in the presence of economic shocks. Our experimental design offers a novel approach to test the validity of this assumption about accurate contingent reasoning. Further, we test whether or not subjects assigned to the role of firm act on these beliefs (i.e. employ best-response analysis when making decisions).¹¹

4 Experimental Design

Our experimental design extends the classic gift-exchange game in three important ways. First, firms face either a positive or negative permanent shock to their endowment. Second, we introduce information frictions by varying workers’ awareness of the shock. Finally, we elicit firms’ beliefs and workers’ effort strategies both before and after the shock occurs.¹² The confluence of these extensions allows us to distinguish between self-interest and other-regarding motives in firms’ wage choices and to understand the role of information frictions in wage-effort dynamics.

The firm receives an endowment of R at the beginning of each period and makes a wage offer w using a simple input box. We inform the worker of w , then allow the worker to choose costly effort $e \in \{0, \dots, \bar{e}(w)\}$, where $\bar{e}(w)$ is the largest effort level that does not yield a negative payoff for the worker. We provide the worker with a slider tool that displays payoff information for both the firm and worker based on hypothetical effort levels to help them make this choice. We provide examples

¹⁰This assumes $\alpha_j > 0$, which is akin to assuming at least some degree of other-regarding behavior.

¹¹We find strong evidence that firms form accurate beliefs about workers’ effort response functions and correctly predict how endowment shocks reshape effort response functions (or not) under both asymmetric and full information.

¹²Armouti-Hansen et al. (2020) use a similar elicitation method in their recent working paper.

of both the firm’s and the worker’s decision screens in the appendix (see section E).¹³ Both players then receive feedback on their respective payoffs and the firm also learns about the worker’s effort. After 10 rounds of baseline play where $R = 12$, we introduce a permanent session-level endowment shock: $R = 16$ following a positive shock and $R = 8$ following a negative shock. Shocks are common knowledge in the full information treatment. However, only firms learn of the shock in the asymmetric information treatment, and workers have no possibility to learn or infer the change in endowment.¹⁴ The only exception is firms that offer wages higher than 12 in the positive asymmetric condition, which in our sample occurs only twice. In those instances, we reveal the shock to that particular worker in the same fashion as in the full information treatments. To ensure that firms understand the information structure in our asymmetric information treatments, we add a short comprehension test regarding firms’ beliefs about workers’ knowledge of the shock.¹⁵ Variation in these two factors, shock direction and information structure, yields a 2×2 between-subjects design summarized in Table 1.

Table 1: Summary of Design Treatments

Treatments	Shock Information	Shock	Participants
Positive	Firms and Workers	$R = 12 \rightarrow R = 16$	56
Negative	Firms and Workers	$R = 12 \rightarrow R = 8$	66
Pos. Asymmetric	Only Firms	$R = 12 \rightarrow R = 16$	56
Neg. Asymmetric	Only Firms	$R = 12 \rightarrow R = 8$	72

We elicit the firm’s beliefs of her own worker’s effort response, and her worker’s corresponding effort response function by implementing the strategy method in periods 5, 10, 11, and 15. This allows us to understand how beliefs evolve as a function of experience during baseline play, how beliefs respond to shocks, and how the structure of information surrounding the shock affects beliefs. We

¹³In the positive asymmetric treatment, we do not provide the worker with the firm’s payoff information as this information will reveal the shock. We do not find any significant differences in pre-shock behavior across information conditions, suggesting that this feature did not impact effort choices. However, providing full payoff information in gift-exchange games leads to effort choices that yield more equitable payoff distributions. Thus, if present, this effect attenuates our main results.

¹⁴We provide screenshots of all relevant screens in appendix E.

¹⁵We screen out confused subjects using results from this quiz. We find no differences in confusion across treatment conditions (6 subjects in positive shock and 4 in negative shock, p.value=0.267).

do this by asking what effort the participant playing the role of firm expects from the worker at each possible wage.

In these same periods, we also elicit the worker’s wage expectation for the current period and use the strategy method to elicit the worker’s corresponding effort response function after first asking her wage expectation in that period. We provide example screenshots for both tasks in appendix E.

We incentivize the worker during elicitation periods by implementing her effort response function and paying her \$5 for a correct wage belief. We incentivize the firm’s beliefs by paying \$5 if the effort guess of a randomly selected wage from the wage distribution is within .25 units of the actual effort response for that wage.

During elicitation periods, both the firm and the worker can explore all hypothetical choices before providing a response. Similar to how the worker chooses effort in non-elicitation periods, both the firm and the worker can use a slider to understand how a potential effort level for each wage translate into payoffs. After the first elicitation period, we remind each subject of their own choices in the previous elicitation period. Thus, any changes in beliefs or effort reflect actual updates and not a lack of recollection. We provide instructions on screen for subjects during all elicitations.

Before moving to results, we briefly address two possible design concerns. First, we circumvent hedging in elicitation periods by randomly paying subjects for either the accuracy of beliefs or for choices.¹⁶ Second, one may wonder if employing the strategy method during elicitation periods induces an artificially high degree of monotonicity in effort responses. However, Maximiano et al. (2007) shows in a multi-worker gift-exchange game that the strategy method has a negligible effect, if any, on subject behavior. This finding is especially true in low-complexity environments.¹⁷

Second, we consider our specific choice of information structure. Under no circumstance do we provide subjects false information or omit information necessary for subjects, regardless of role, to correctly compute their own payoffs. Rather, we provide factual but incomplete information to workers, which does not constitute deception according to the long-standing convention about information omission in experiments (Hey, 1998; Hertwig and Ortmann, 2008; Charness et al.,

¹⁶For example, a firm that suspects a worker will not reciprocate but wants to offer a high wage with the hope of reciprocation may guess that the worker will provide low effort at this wage.

¹⁷See Cason and Mui (1998); Brandts and Charness (2000); Oxoby and McLeish (2004); Bosch-Domènech and Silvestre (2005).

2022). An alternative design could explicitly reveal to workers that endowments will change during the experiment or that endowments might change during the experiment. However, this alternative introduces a role for higher-order beliefs to influence wage and effort dynamics in subtle ways that confound inference in our experimental problem. For example, a firm could exploit this alternative design by introducing a discrete wage cut hoping the worker rationalizes the wage cut as the result of an endowment shock. While such behavior could be interesting to study, it is not the focus of our experiment where we aim to understand how strict information frictions influence principle-agent behavior across the business cycle.

4.1 Procedures and Implementation

We recruited a total of 250 undergraduate student subjects from Texas A&M University via the recruitment system ORSEE (Greiner (2015)). We programmed all experimental software using oTree (Chen et al. (2016)).

Each session began by reading experimental instructions aloud and administering comprehension quizzes. We deliver instructions in two parts. First, we provided subjects a brief set of instructions outlining basic components of the game like experimental length, formation of pairs, and anonymity (see D.1), and then administered a first comprehension quiz. We then provided a second set of instructions detailing game play and payoffs (see D.2) followed by a second comprehension quiz.

Following the second quiz, we randomly assign participants to the role of either firm or worker and form firm-worker pairs and familiarize them with the experiment via three unpaid practice periods. Following practice periods, we randomly form new firm-worker pairs that remain stable for the subsequent 20 paid periods.

Subjects completed a short socio-demographic survey and the end of the experiment. Following this survey, we released subjects and paid them privately. The average payment in our sessions was \$25 and each session lasted approximately 90 minutes.

5 Results

We find that information frictions play a fundamental role in determining the allocation of exogenous economic shocks in our experimental labor markets. Under full information, shocks are shared almost equally between firms and their counterparts, while information frictions produce an asym-

metric response, with uninformed workers retaliating against wage cuts. A key outcome is that the more-informed party does not always benefit from information frictions.

Firms' beliefs are highly accurate in all treatments and they rapidly adjust to economic shocks. Workers' wage expectations also adjust to information about economic shocks. However, in the absence of information and relying only on experience, we find a sluggish and asymmetric adjustment in expectations following economic shocks.

5.1 Wage-Effort Dynamics in Full Information

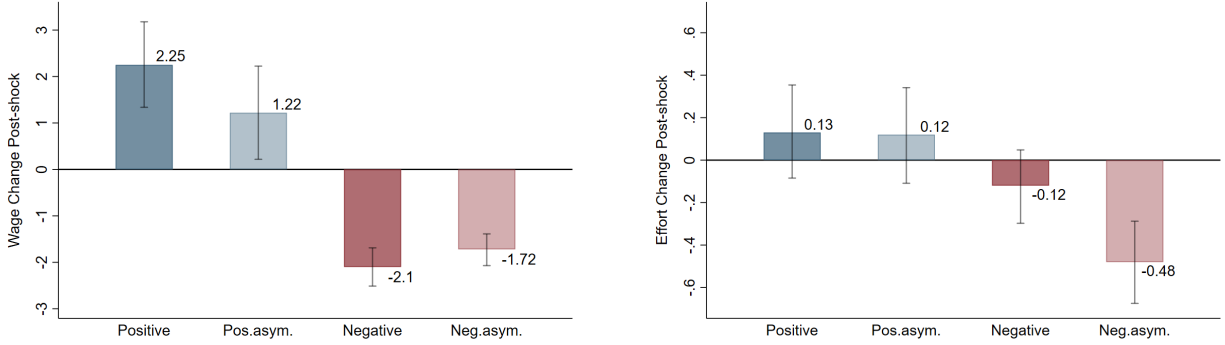
We first consider wage-effort dynamics. Figure 2 show that both wages and effort adjust as a consequence of the endowment shocks. Under full information, average wages increase by about 2.25 units following a positive exogenous economic shock. This wage increase – slightly more than half of the shock – yields a small, albeit statistically insignificant, response in effort (p.value = 0.229). Negative shocks induce an average wage cut of 2.1 units, which again prompts a small, statistically insignificant decrease in effort (p.value = 0.157). Both wage changes are highly significant (p.values < 0.001), in line with Hypothesis 1, and of similar magnitudes, indicating a symmetric response to shocks.

Result 1: *Under full information, wage adjustments are positively correlated with endowment shocks but do not induce significant changes in effort.*

These changes in wages and effort are consistent with firm-level beliefs about workers' effort response functions. To see this, consider figures 2a and 2b, which shows how endowment shocks reshape firm's beliefs about worker's responses. Firms' choices reveal that, under full information, firms' beliefs move in the opposite direction of the endowment shock: they expect less effort for a given wage after a positive shock, indicated by a downward slope in the pre/post beliefs, and more effort following a negative shock, which causes the upward slope. Put another way, firms in our full-information treatments are obligated to share a positive shock to maintain effort levels and are allowed to share a negative shock without reprisal from the worker.

Beliefs about how shocks reshape effort responses are quite accurate, which we see by comparing shock responses in figures A and B in the appendix. This suggests that subjects sorted randomly

Figure 1: Wages and Effort Responses to Shocks



Notes: This figure depicts the average change in wages and effort following endowment shocks in each of our four treatments (bars) surrounded by 95% confidence intervals estimated using a series of random-effects linear regressions that group pre- and post-shock data. We control for the last round, gender, if the pair played the Nash equilibrium strategy (defined as the worker selecting effort equal to 0 for all possible wages in at least one elicitation) and for the corresponding average wage offered during the trial rounds. We excluded pairs where the firm did not pass the asymmetric info check. Clustered standard errors at the individual level. We report the full output in Tables A1 and A2 in the appendix.

into the role of a firm in our experiment correctly predicted that their worker counterparts cared about intentions underlying a wage choice. This is true despite firms predicting changes in effort at wages they have not paid their worker.

Result 2: *Under full information, firms' beliefs reflect workers' expectations of sharing the consequences of exogenous economic shocks, regardless of direction. These beliefs are accurate.*

The fact that the effort-response function adjusts (2b) following these shocks is consistent with our theoretical framework and supports Hypothesis 2. This suggests that workers consider more than just the level wage when making effort decisions. Instead, our results suggest that workers care about the wage relative to the firm's endowment. Firms anticipate this and adjust wages accordingly following endowment shocks, which supports the assumption of accurate contingent reasoning in both classical and behavioral models of principle-agent interactions.

Result 3: *Workers' effort responses to a given wage account for the economic conditions of the firm. This is reflected across the full wage schedule.*

5.2 Wage-Effort Dynamics in Asymmetric Information

Introducing information frictions moderates the reaction of wages to endowment shocks and also impacts how workers respond to wage cuts. These results provide support for Hypothesis 3. Wages increase by only 1.22 (p.value = 0.017) units on average following the positive shock, which is a bit less than half of the wage hike following an equivalent endowment shock under full information (diff. 1.13, p.value = 0.092).

Workers do not exhibit a significant response to this muted wage hike. Following a negative shock, firms cut wages by 1.7 units, which is about 20% less severe than the wage cut under full information, although it is statistically similar (p.value = 0.258). Despite this small wage cut, workers exhibit a large and highly significant reduction in effort of .48 units (p.value < 0.001). This effort cut is four times larger than the average effort cut under full information.

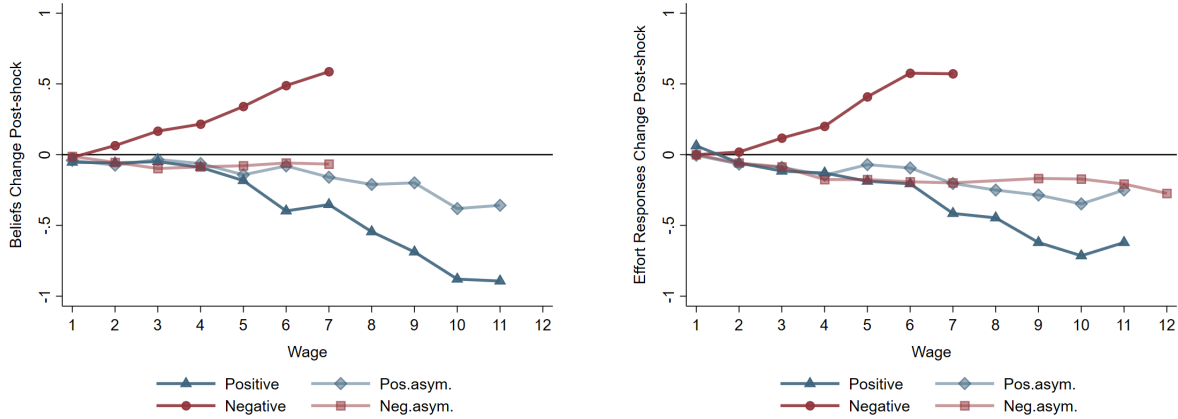
Hypothesis 4 states that workers would be more responsive to wage changes under information frictions. This is clearly true following negative shocks, where effort cuts are four times as large under information frictions even though wages fall by 20% less. The positive shock case is more nuanced. In the positive treatments, although wage increases are half as large, they induce the same effort change from the workers. In other words, firms can increase wages by half as much to induce a similar effort response under information frictions.

Result 4: *Information frictions moderate wage dynamics but amplify the wage elasticity of effort following shocks. This amplification is asymmetric; effort responds much more strongly to wage cuts than hikes.*

Firm beliefs about effort response in [2a](#) reflect a clear understanding that information frictions conceal shocks from workers. Whereas firms expect shocks to reshape the effort response function under full information, firms correctly predict a static effort response function under information frictions. This difference in beliefs, coupled with choice data, gives critical insight into the motives underlying firm behavior.

What we see is that firms facing full-information conditions correctly believe that workers will demand higher wages. Perhaps coincidentally, they pay higher wages. We then see that firms facing information frictions believe that uninformed workers will not demand higher wages following the

Figure 2: Beliefs and Effort Responses to Shocks



Notes: This figure depicts the average change in firms’ beliefs and workers’ effort responses between pre and post-shock periods in each of our four treatments. Pre-shocks elicitation are pooled together, similarly with post-shocks elicitation. A positive (negative) slope indicates an increase (decrease) in expected effort with respect to the pre-shock period. We excluded pairs in the asymmetric information conditions where the firm did not pass the asymmetric info check. For more details, refer to Table A3 and A4 in the appendix. In addition, we report non-pooled beliefs and effort responses in Figures A and B in the appendix.

positive endowment shock. If firms were truly other regarding then we would expect equivalently high wage hikes following a positive shock under both information conditions. Instead, we see that the firms who believe workers will not demand higher wages significantly reduce the pass through of positive endowment shocks. Taken together, this suggests a sophisticated form of self-interested firm that increases wages under full information only because they know the worker will demand higher wages.

Result 5: *Firms do not share positive shocks because of other-regarding motives. Instead, they only share positive shocks whenever they face a fully-informed worker and believe they must in order to maximize profits.*

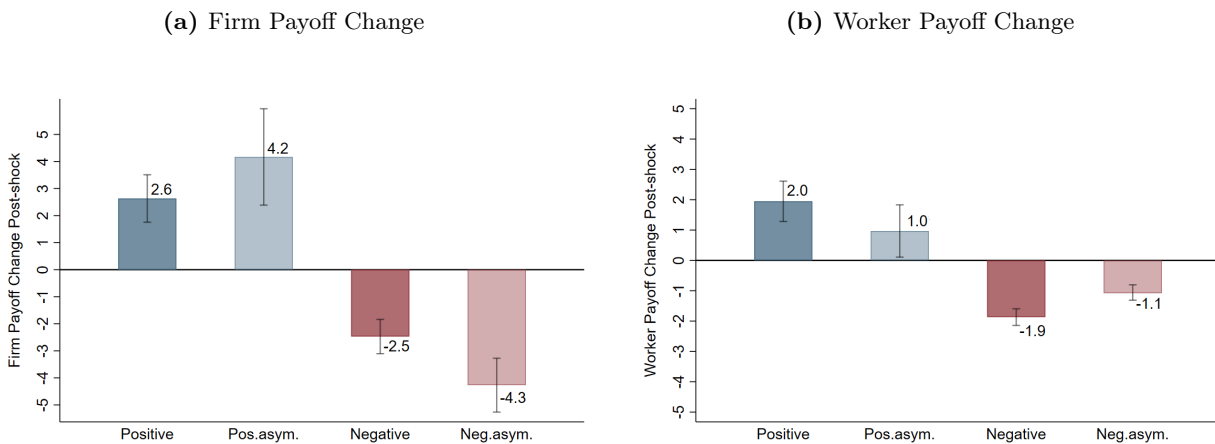
5.3 Payoffs and the Distribution of Endowment Shocks

Our primary finding in this subsection is that information structure matters for determining allocations of shocks. Interestingly, it isn’t always the more informed party who benefits from information frictions in our experiment. To see this, consider figure 3, which show two things. First, information frictions benefit firms following a positive shock and harm firms following a negative shock. Second, the opposite is true for workers, whose payoffs increase less following positive shocks but fall less

following negative shocks whenever information is asymmetric.

Under symmetric information, firms and workers split endowment shocks almost equally. Because of this, positive shocks increase payoffs for both firms and workers by a similar amount (2.6 vs 2 units), and negative endowment shocks decrease payoffs by comparable magnitudes (2.5 vs 1.9 units).

Figure 3: Firms and Workers Payoffs Changes to Shocks



Notes: This figure depicts the average payoffs for firms and workers in each of our four treatments (bars) surrounded by 95% confidence intervals estimated using a series of random-effects linear regressions that group pre- and post-shock data. We control for the last round, gender and if the pair played the Nash equilibrium strategy (defined as the worker selecting effort equal to 0 for all possible wages in at least one elicitation). We excluded pairs where the firm did not pass the asymmetric info check. Clustered standard errors at the individual level. We report the full output in Tables A5 and A6 in the appendix.

Making information about shocks asymmetric greatly benefits firms following positive endowment shocks. Information frictions allow firms to capture a much larger share of the shock without negatively impacting worker effort. This is because workers in asymmetric information treatments do not adjust their reference wage following the shock, which implies that their effort response functions remain unchanged (figure B).

Firms correctly predict this (figure 2a), and significantly reduce pass-thru of the positive endowment shock. Though wages increase less when information is asymmetric, effort responses are equivalent to the full information setting. This causes firm profits, on average, to increase by about twice as much relative to the full information setting (1.85 units increase, p.value = 0.063). In contrast,

workers' payoffs increase little - if at all - when information is asymmetric. Taken together, this means firms increase their profits by about four times as much as workers following a positive shock. Information frictions harm firms following negative endowment shocks. The average firm's payoff falls by about 72% more under asymmetric information (1.77 units decrease, p.value = 0.003). Though firms correctly infer that the worker's stated effort response function is static across the shock due to asymmetric information (figure 2a), they share the shock nonetheless.¹⁸ Wage cuts cause wages to fall significantly below the worker's reference wage, which were also static due to asymmetric information. This leads to drastic and punitive effort cuts that severely impact firm profits.

On the other hand, workers benefit from information frictions following a negative shock. Although they are the less informed party, the average worker payoff falls by only about 57% of what it does under full information (0.73 units increase, p.value < 0.001). This happens because punitive effort cuts greatly reduce the cost of effort. Coupled with a slightly higher average wage, this leads to a higher payoff relative to the full information setting. However, asymmetric information is less beneficial to workers when the endowment shock is positive; average payoffs increase by about half of what they do under full information (1.09 units decrease, p.value = 0.044).

Result 6: *Under full information, profits adjust equally for firms and workers regardless of shock direction. Under asymmetric information, it is not always the more informed party that benefits from information frictions. Firms capture significantly more profit following a positive shock but experience larger profit losses following a negative shock.*

5.4 Optimal Wages and Beliefs Accuracy

After studying wage-effort dynamics, we next look at whether firms form accurate beliefs about optimal wages and if they act on these beliefs. Overall, we find that firms act as profit maximizers: they do form accurate beliefs and make beliefs-consistent decisions. This provides suggestive support that people adhere to the sort of best-response analysis commonly used to solve principle-agent problems in theory.

Table 2 reports three key pieces of information. We report in column 1 the wage that maximizes

¹⁸This aligns with Equation 4 where wages always adjust in the direction of endowment shocks.

firm profits based on firms' beliefs about workers' effort response functions. Column 2 reports the wage that will actually optimize firm profits based on workers' elicited effort responses. Finally, column 3 reports the wage that a firm actually offers.

Firms' beliefs are mostly accurate: optimal wages based on firms' beliefs (column 1) closely match optimal wages based on workers' effort responses (column 2) in all treatments prior to any endowment shock. And although endowment shocks shift effort responses, firms anticipate this and adjust wages accordingly so that offers never diverge significantly from the actual optimal wage.¹⁹ The one exception we observe comes in our negative asymmetric information treatment, where firms do not anticipate workers retaliating for unexpected wage cuts with punitive effort cuts. Thus, the average firm's offer is too low relative to the actual average profit-maximizing wage.

Firms' actions are consistent with their beliefs. Comparing columns 1 and 3 of Table 2 confirms that firms offer wages that are optimal according to their beliefs. Differences between these columns are never statistically significant. This is true even in our one treatment (negative asymmetric) where the firm holds incorrect post-shock beliefs about the profit-maximizing wage.

Result 7: *Firms typically form highly-accurate beliefs. However, firm beliefs are misspecified following negative asymmetric shocks. Firms act on their beliefs, including their misspecified beliefs. This leads to a belief-driven failure in profit maximization.*

5.5 Dynamic Reference Dependence and Information Frictions

We now consider how workers' wage expectations adjust following endowment shocks.²⁰ Two key insights emerge. First, we find that wage expectations adjust instantaneously and accurately in response to information about economic shocks, which aligns with [Abeler et al. \(2011\)](#).²¹ Second, when information is asymmetric, wage expectations can still adjust based on post-shock experience (in line with [Thakral and Tô \(2021\)](#)). However, adjustment is sluggish relative to a full-information setting and adjustment dynamics depend on the direction of wage surprises.

¹⁹Note that even if beliefs and effort responses do not change, optimal wages are still impacted by changes in endowment, as seen in equation 4.

²⁰One can think of wage expectations as a reference point, akin to [Kőszegi and Rabin \(2006\)](#).

²¹[Abeler et al. \(2011\)](#) manipulate the rational expectations of subjects and show this impacts wage-effort dynamics via a reference wage. We show that information about changes in economic conditions, coupled with previous worker-firm experience, is enough to instantly shift wage expectations.

Table 2: Expectations and wage optimality

	(1)	(2)	(3)	(1) - (3)	(2) - (3)
	Optimal wage wrt beliefs	Optimal wage wrt responses	Wage offer	<i>T-test</i>	<i>T-test</i>
Pre (+)	6.35	6.25	6.66	0.48	0.22
Post (+)	8.53	8.62	8.89	0.50	0.65
Pre (+Asym.)	6.04	6.40	5.97	0.88	0.38
Post (+Asym.)	6.61	7.06	7.31	0.15	0.75
Pre (-)	6.81	7.46	6.81	1.0	0.12
Post (-)	4.56	4.96	4.59	0.91	0.12
Pre (-Asym.)	5.54	6.23	5.68	0.70	0.18
Post (-Asym.)	3.89	4.95	3.93	0.87	0.04

Notes: Optimal wage with respect to beliefs is the average of optimal wages according to firms beliefs. Similarly, Optimal wage with respect to responses is the average of the optimal wages based on workers response function. Wage offer is the wage offered by the firm in the elicitation rounds. We exclude pairs where the firm did not pass the asymmetric test. Pre-shock and post-shock rounds are pooled respectively. Columns 4 and 5 report paired t-test for the equality of columns 1-3 and 2-3 respectively.

Under full information, workers' wage expectations are accurate in both pre- and post-shock periods. These expectations are stable on either side of the shock but adjust between periods 10 and 11. We show this in Table 3, which reports average wages, average wage expectations, and their difference for each elicitation period in all treatments. This is true even though workers have not experienced any post-shock wage offers, which highlights the importance of information about the firm's endowment in establishing wage expectations and effort responses. The stability of wages and expectations between rounds 5 and 10 allay any concern that the updating in wage expectations between rounds 10 and 11 are a continuation of pre-shock trends.

Discrepancies occur in asymmetric information treatments because information frictions prevent wage expectations from adjusting on impact of the shock. Since wages adjust in the direction of endowment shocks, workers receive an unexpected wage hike following a positive shock and an unexpected wage cut following a negative shock.

We find that experience alone in the positive asymmetric treatment eventually leads workers to form accurate expectations about wage offers. Immediately following the shock, average wages adjust by more than one point (from 6.13 to 7.36, column 1) while wage expectations remain relatively constant. Thus, average wage expectations are significantly below average wages (p.value = 0.042). However, experiencing higher wages for several periods causes expectations to adjust upward so that by round 15 average wages (7.27, column 1) and wage expectations (7.04, column 2) are no longer significantly different (p.value = 0.701). This demonstrates the ability of expectations to adjust via experience alone following economic shocks despite workers' complete lack of information regarding the shock.

We do not observe this same adjustment following wage surprises in negative shock sessions. Average wages (4.03, column 4) and wage expectations (5.4, column 5) are significantly different following a negative shock (p.value < 0.001). Despite workers and firms interacting for several post-shock periods together, and workers consistently receiving wages below their expectations, we find that significant differences between wages and wage expectations persist through round 15 (p.value < 0.01). Importantly, average wages in this treatment are stable across post-shock rounds. This means that the difference between wages and wage expectations is driven by the failure of expectations to adjust rather than by an adjustment of wages.

Overall, this constitutes strong evidence that expectations adjustment is not symmetric in the presence of information frictions. People are willing to adjust expectations upward to meet unexpected wage surprises but expectations are more strongly anchored and sluggish to adjust whenever wage surprises are negative. This asymmetric adjustment aligns with [Bewley \(1999, 2007\)](#), who show via survey evidence that a primary component of downward nominal wage rigidity is an expressed concern from managers that lowering wages will destroy worker morale and reduce effort.

Result 8: *Announcing endowment shocks instantly shifts workers' wage expectations while information frictions lead to a sluggish and asymmetric adjustment; wage expectations and actual wages eventually converge following positive shocks but do not following negative shocks. Instead, the wage expectations of workers remain significantly higher than the actual wage*

Table 3: Average wage offers and wage expectations [in elicitation rounds]

	Positive Asymmetric			Negative Asymmetric		
	(1)	(2)	(1) - (2)	(4)	(5)	(4) - (5)
	Wage Offer	Expected Wage	<i>T-test</i>	Wage Offer	Expected Wage	<i>T-test</i>
Round 5	5.81	5.54	0.610	5.68	5.87	0.612
Round 10	6.13	5.59	0.248	5.68	6.18	0.283
Round 11	7.36	6.04	0.042	4.03	5.4	0.000
Round 15	7.27	7.04	0.701	3.84	5	0.000
<i>Pairs</i>	22	22	-	32	32	-
	Positive Full Info.			Negative Full Info.		
	(1)	(2)	(1) - (2)	(4)	(5)	(4) - (5)
	Wage Offer	Expected Wage	<i>T-test</i>	Wage Offer	Expected Wage	<i>T-test</i>
Round 5	6.64	6.71	0.787	6.78	6.42	0.402
Round 10	6.67	6.75	0.871	6.84	7.21	0.360
Round 11	8.57	8.5	0.911	4.39	4.81	0.080
Round 15	9.21	8.78	0.312	4.78	4.72	0.839
<i>Pairs</i>	28	28	-	33	33	-

Notes: Wage offer is the wage offered by the firm in the elicitation rounds. Expected wage is the wage that workers expect to receive in each elicitation rounds. We exclude pairs where the firm did not pass the asymmetric test. We report the paired t-test for the the equality of means.

Similarly, our evidence is consistent with the idea of wage ratcheting observed in [Kaur \(2019\)](#), where positive shocks generate persistently higher nominal wages but negative shocks do not lead to nominal wage cuts. In her setting, individuals believe nominal wage cuts are unfair and lead to effort reductions. Our evidence on expectation adjustment shows that wage hikes lead to quick upward updating while the opposite is not true for wage cuts under information frictions. Arguably, this rapid updating might anchor workers expectations and reduce tolerance for wage cuts in the future.

Table 4: Effort responses and wage expectations in round 11

	(1)	(2)	(3)	(4)
	Effort Choice	Effort Choice	Effort Choice	Effort Choice
	(pos. shock)	(pos. asym. shock)	(neg. shock)	(neg. asym. shock)
Mean of dep. var.	1.440 (0.242)	1.402 (0.326)	1.330 (0.120)	1.274 (0.179)
Post	0.559 (0.093)	-0.737 (0.263)	-0.253 (0.127)	-0.099 (0.115)
Post×Above	0.023 (0.186)	1.137 (0.325)	0.138 (0.209)	0.082 (0.447)
Post×Below	-1.266 (0.178)	0.319 (0.330)	-0.176 (0.223)	-0.446 (0.146)
Male	0.222 (0.283)	0.133 (0.465)	0.183 (0.201)	0.292 (0.224)
Nash eq.	0.536 (0.152)	-0.678 (0.449)	-0.876 (0.324)	-0.726 (0.248)
<i>Observations</i>	308	242	363	352

Notes: Results from random-effects linear regressions that include controls indicating gender and if a worker ever played Nash equilibrium in an elicitation period. *Above* indicates wage offers above, *Below* wage offers below and *Equal* corresponds to pairs with offers equal to workers' expectation in round 11. Standard errors clustered at the individual level in parentheses.

We next explore how the misalignment of wages and expectations impact effort choices. To do this, we first classify firm-worker pairs into three groups (Above, Below, or Equal) according to their wage offers relative to wage expectations in round 11. Using these classifications, we look for heterogeneous effects in effort choices using the same specification as in our previous analysis. We report results from this exercise in Table 4 where our main coefficients of interest are Post×Above and Post×Below, which report how effort responds to the surprise component of wages that are above or below the worker's wage expectation. We first consider results from our positive shock treatments. Whenever workers do not expect wage hikes following a positive shock, they strongly reciprocate wage increases (1.137 units, column 2). This effect is not present under full information where workers expect wage increases following positive shocks. Instead, we see that workers strongly

punish wages that fall short of their new, higher wage expectations whenever they know of the positive endowment shock (-1.266 units, column 1). This suggests that a rationale for firms to increase wages under full information is avoiding retaliatory effort cuts when expectations are not met, rather than to elicit a higher effort via reciprocal motives. In contrast, when information frictions mask firm’s intentions, workers who receive a wage above expectations elicit a higher effort response.

In the negative shock treatments, we find that workers strongly punish wage cuts if they are unexpected and lead to shortfalls relative to expectations (-0.446 , column 4). However, this same effect is not present in the negative, full information treatment (-0.176 , column 3). This suggests that workers are more lenient with wage short falls whenever they expect (and can rationalize) wage cuts. It’s worth remembering that the average wage is indeed quite similar in the post-shock rounds of both negative shock treatments. We can see that the large decrease in effort following the endowment shock in our negative asymmetric information treatment (-0.48 , figure 1b) is driven largely by workers retaliating against unexpected wage cuts (-0.44).

Taken together, our analysis in this section suggests that information frictions are more costly in terms of efficiency following negative shocks because sluggish adjustment of expectations leads to prolonged bouts of punitively low effort.

6 Estimating the Model and Evaluation

In simple structural estimation exercise, we quantify the out-of-sample predictive power of our model (equations (1) and (2)) relative to a baseline model that incorporates a static reference wage and does not respond to economic shocks:

$$e^*(w) = \alpha \left(\frac{w - a}{b} \right)^\beta \tag{5}$$

We first use data from both pre-shock elicitation rounds to structurally estimate the parameters of both models. Next, we predict out-of-sample post-shock effort levels and wages using our previous estimates. Finally, we compare these predictions to actual wage and effort choices and compute a mean squared predicted error (MSPE) for each subject. Although our model has an additional

degree of freedom due to the dynamic reference wage, it is worth mentioning that prediction improvements are not mechanical, as we impose a functional form on the reference wage.²² If our functional form is misspecified, that would cause lower predictive power for our suggested model.

We perform this estimation exercise using only subjects from full information treatments. This is because the two models make almost identical predictions under asymmetric information - a prediction fully supported by our data - since the endowment remains unchanged from the worker's perspective following the endowment shock.²³ For details on the structural estimation identification and procedure, refer to appendix section C.

6.1 Post-Shock Effort Predictions

We summarize results of effort predictions in figure 4, which displays cumulative distribution functions (CDFs) of individual-level MSPEs for workers (a and b) and firms (c and d) using the benchmark model (red solid line) and our model (blue solid line). The corresponding vertical lines denote the medians of the two distributions.²⁴

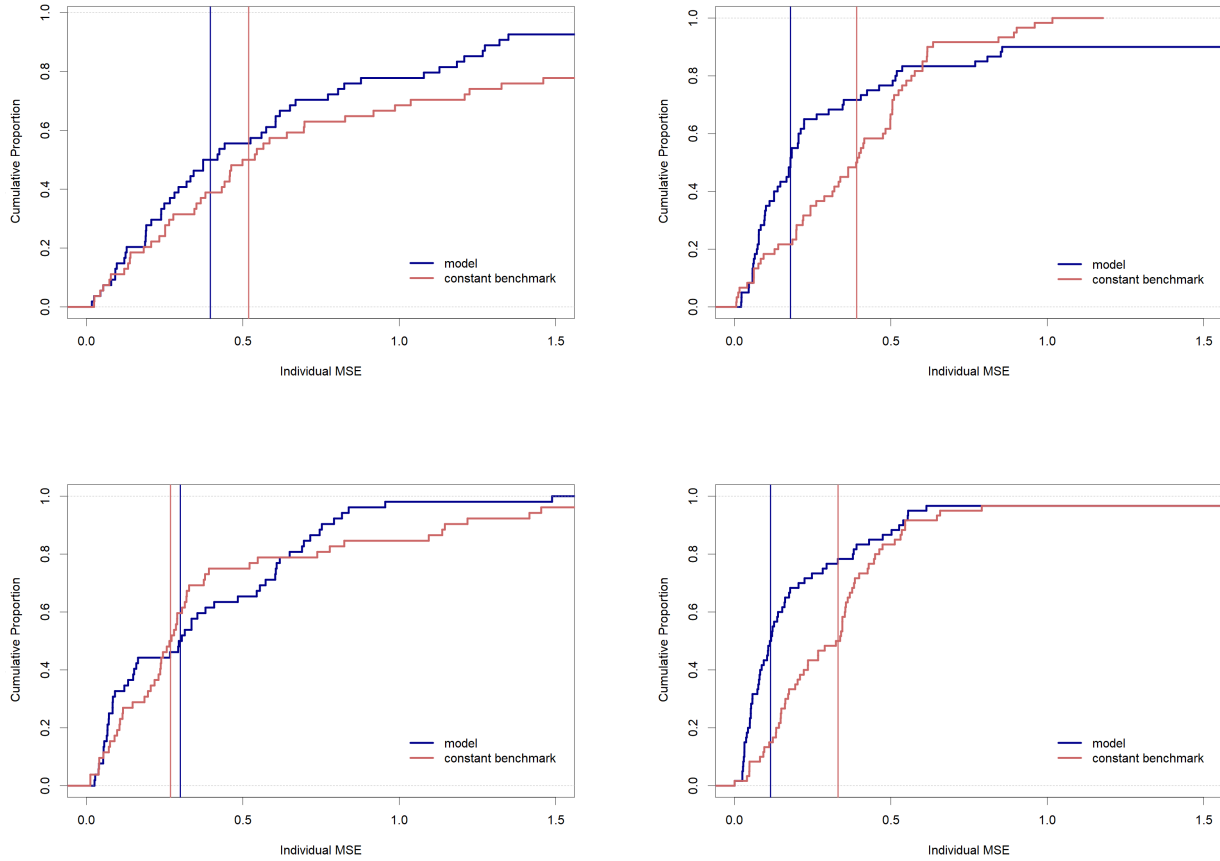
Figure 4 provides compelling evidence that our model outperforms the benchmark model in predicting both firms' beliefs about worker effort and workers' actual effort response functions. Our model reduces the median individual MSPE of effort response predictions by 24% following a positive endowment shock (4a) and by 54% following a negative shock (4b) relative to the benchmark model (one-sided Wilcox test p.values are 0.078 and 0.012 respectively). Likewise, our model reduces the median individual MSPE of predictions about firm beliefs by 65% after a negative shock (4d) relative to the benchmark model (one-sided Wilcox test p.values is <0.001). However, we find that both models predict firm beliefs equally well following a positive endowment shock (4c, one-sided Wilcox test p.value is 0.409).

²²In particular, we assume the reference wage is a constant fraction of the firm's endowment.

²³The only differences arise from two pairs in the positive asymmetric condition that chose to reveal the shock to their counterpart by offering a wage larger than 12.

²⁴We evaluate medians rather than means to ensure that a few extreme outliers are not driving our results.

Figure 4: Individual Mean Squared Prediction Error (MPSE) for Effort Choices



Notes This figure shows CDFs of mean squared prediction errors (MSPEs) in rounds 11 and 15 for workers (panels a and b) and firms (panels c and d). Red dashed CDFs correspond to the benchmark model. Solid blue CDFs correspond to our relative wage model. Red vertical lines show the median of the MSPEs from the benchmark model and the blue vertical line the median of the MSPEs from the relative wage model.

6.1.1 Post-Shock Wage Prediction

Next, we use our estimates for the firms in the pre-shock periods to obtain a prediction for wage offers in the post-shock periods and compare this to observed wage offers. Table 5 shows that our model does remarkably well in predicting shifts in wage offers – there is no significant difference between observed wages (column 1) and wages predicted by our model (column 2) in any of our four treatments.

Table 5: Predicted wage comparison [in post-shock rounds]

	(1)	(2)	(1) - (2)	(4)	(1) - (4)
	Wage	Model	Model	Benchmark	Benchmark
	offer	prediction	deviation	prediction	deviation
Positive	9.06	9.08	0.980	8.47	0.215
Positive asym.	7.86	7.41	0.544	-	-
Negative	4.74	4.78	0.909	5.45	0.063
Negative asym.	4.06	4.26	0.495	-	-

Notes: This table compares predicted wages for our model (2) and a benchmark model (4) to actual wage offers (1) in all the post-shock rounds but the last period. Columns (3) and (5) report p.values of the difference between wage offers and model predictions respectively.

Figure 4 shows that accounting for changes in economic conditions matters for two reasons. First, our model allows reference wages to adjust when economic conditions change whereas the benchmark model does not. Intuitively, we account for the idea that workers will share shortfalls and expect to share windfalls whenever they are exogenous. Second, effort accounts for wages relative to the firm’s endowment. This captures the idea that a person’s degree of altruism can depend on the perceived wealth of an firm and hence, why information about that wealth matters.

We find that firms correctly predict both of these channels, which is why our model better predicts firm’s beliefs about effort response functions. Because firms act on these beliefs, our model also outperforms the benchmark model in predicting wages. More subtly, what we learn from figure 4 is that information structure helps determine *how* changes in economic conditions impact wage-effort dynamics.

Finally, we want to emphasize that there is no tradeoff for using our model instead of the benchmark model. Out-of-sample predictions from our model are always at least as good as those from the benchmark model – usually, they are much better. More generally, it likely always makes sense to adapt behavioral models of the labor market to account for changes in economic conditions and relative information sets.

7 Conclusion

This paper explores the role of information frictions in a labor market setting. We first build intuition using a toy model about how information frictions can significantly impact wage-effort dynamics. Our key insight is that workers evaluate wages relative to a reference wage, which itself depends on economic conditions. Because of this relationship, information frictions regarding economic conditions play a significant role in determining how wage-effort dynamics evolve in response to economic shocks. We then incorporate permanent endowment shocks, information frictions, and belief elicitation into a gift-exchange game to demonstrate these insights empirically.

Under full information, endowment shocks are shared almost equally between agents. Following a positive endowment shock, workers demand higher wages but do not increase their average effort and when the endowment decreases, workers are willing to accept wage cuts and keep effort constant. Firms anticipate this, forming highly accurate beliefs and adjusting wages accordingly in the same direction as the endowment shock. This leads to an equitable sharing of shocks - whether positive or negative - and roughly equivalent changes in payoffs.

Introducing information frictions significantly moderates the pass through of endowment shocks. Despite smaller wage cuts, workers reduce effort four times more than under full information. In this particular case, the less-informed party (i.e., the workers) benefit from information frictions.

Our results suggest workers evaluate wages according to a state-contingent reference wage. These adjust instantaneously in response to news about endowment shocks so that subsequent wage changes are not a surprise and lead to little, if any, changes in effort. However, this dynamic reverses whenever endowment shocks and wage changes surprise uninformed workers. When surprises are positive, the uninformed worker's effort responds about twice as strong as the informed workers. If the surprise is negative, the uninformed worker cuts effort four times more than the informed worker.

Experience alone can remove the wedge between wage expectations and wages. However, adjustment depends critically on the direction of wage surprises. Expectations fully adjust by our second post-shock elicitation in round 15 following positive wage surprises. In contrast, workers are more reluctant to adjust their reference wage in response to negative wage surprises. Because of this,

wages and wage expectations still remain highly significantly different in our second post-shock elicitation round. This is true despite the fact that, in both instances, average wages remain relatively stable across post-shock elicitation rounds. This asymmetric adjustment helps rationalize both wage ratcheting and downward nominal wage rigidity as empirical regularities.

Accounting for economic shocks and information frictions almost always improves the out-of-sample predictive power of the analogous behavioral labor market model. An implication is that models of reference dependence should allow for information frictions, especially when concerned with the dynamics of reference dependence.

An implication of our results is that differences in institutional features that create firm-level heterogeneity in information frictions may themselves lead to differences in wage frictions. For example, wage dynamics might differ between public and private firms, since the latter retain discretion and the former are compelled to reveal information. These features may also be cultural and lead to peer-to-peer information gaps. For example, recent work documents the reluctance to discuss wages between coworkers (Cullen and Perez-Truglia, 2018). Our results on the asymmetric adjustment of reference wages rationalizes this reluctance since only low-paid workers will likely revise their reference wages. This aligns with evidence on pay secrecy and effort provision from Nosenzo (2013) and Cullen and Perez-Truglia (2022).²⁵ Our results are also consistent with Kline et al. (2019), who show that workers capture about 30 percent of patent-induced productivity shocks but that this share is roughly double for workers who were with a firm when they originally filed for the patent and that wages for new entrants do not respond to these shocks. To some extent, employees familiar with the patent filing and decision, or who participated in its development, have more information about the potential impact of the patent decision on firm profitability.

Though our results shed light on the allocation of surplus resulting from exogenous economic shocks, it is often true that real-world surplus is endogenous. This can obviously influence both the workers information set and the firm's outlook on welfare distribution. A meaningful extension then of our work might be to endogenize economic volatility while revealing different amounts of information to workers about output and how output relates to their own effort provision.

Importantly, the asymmetric adjustment of wage expectations that we observe suggests that even

²⁵Charness and Kuhn (2007) provide evidence that revealing wages may not lead to lower effort.

short-lived economic fluctuations can yield long-term effects on wages. The fact that informed workers will tolerate wage cuts while uninformed workers will not highlight the importance of the economic context underpinning a firm's wage decisions.

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Appendix (for online publication)

A Additional Tables and Figures

Table A1: Wage offers pre/post shock

	(1)	(2)	(3)	(4)
	Wage offer	Wage offer	Wage offer	Wage offer
	(pos. shock)	(asym.pos. shock)	(neg. shock)	(asym.neg. shock)
Mean of dep.var	6.874	6.932	6.670	6.015
Post	2.258*** (0.470)	1.221** (0.512)	-2.100*** (0.210)	-1.729*** (0.174)
Last Round	0.631 (0.574)	-0.394 (0.743)	-0.091 (0.293)	-0.708** (0.298)
Male	-0.948** (0.481)	-0.258 (0.421)	0.553* (0.310)	-0.525 (0.488)
Nash Eq.	2.572*** (0.492)	-2.307*** (0.581)	-1.172 (1.017)	-0.351 (0.496)
Trial Round Avg.	0.256 (0.176)	0.463*** (0.147)	-0.140 (0.103)	0.206 (0.191)
<i>Observations</i>	560	440	660	640

Notes: Results from a random-effects linear regression. We control for the last round, gender, if the pair played the Nash equilibrium strategy (defined as the worker selecting effort equal to 0 for all possible wages in at least one elicitation) and for the corresponding average wage offered during the trial rounds. We exclude pairs where the firm did not pass the asymmetric test. Clustered standard errors at the individual level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A2: Effort Choices pre/post shock

	(1)	(2)	(3)	(4)
	Effort Choice (pos. shock)	Effort Choice (asym.pos. shock)	Effort Choice (neg. shock)	Effort Choice (asym.neg. shock)
Mean of dep.var	1.179**	0.809	1.440***	1.617***
Post	0.135 (0.112)	0.116 (0.115)	-0.125 (0.088)	-0.481*** (0.099)
Last Round	-0.240 (0.214)	-0.049 (0.141)	-0.238* (0.126)	-0.275*** (0.097)
Male	0.127 (0.181)	-0.418 (0.424)	0.343** (0.156)	0.086 (0.208)
Nash Eq.	0.335** (0.157)	-0.976** (0.461)	-0.687** (0.311)	-0.610*** (0.213)
Trial Round Avg.	0.050 (0.089)	0.150 (0.097)	-0.030 (0.057)	-0.046 (0.068)
<i>Observations</i>	560	440	660	640

Notes: Results from a random-effects linear regression. We control for the last round, gender, if the pair played the Nash equilibrium strategy (defined as the worker selecting effort equal to 0 for all possible wages in at least one elicitation) and for the corresponding average wage offered during the trial rounds. We exclude pairs where the firm did not pass the asymmetric test. Clustered standard errors at the individual level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A3: Beliefs and effort response changes in post-shock periods (full information)

	(1)	(2)	(3)	(4)
	Beliefs diff. (pos. shock)	Beliefs diff. (neg. shock)	Effort Resp. diff. (pos. shock)	Effort Resp. diff. (neg. shock)
Mean of dep. var.	0.215 *	-0.100	0.180	-0.155 *
Wage	-0.087 *** (0.013)	0.106 *** (0.021)	-0.066*** (0.016)	0.118*** (0.019)
<i>Observations</i>	228	264	228	264

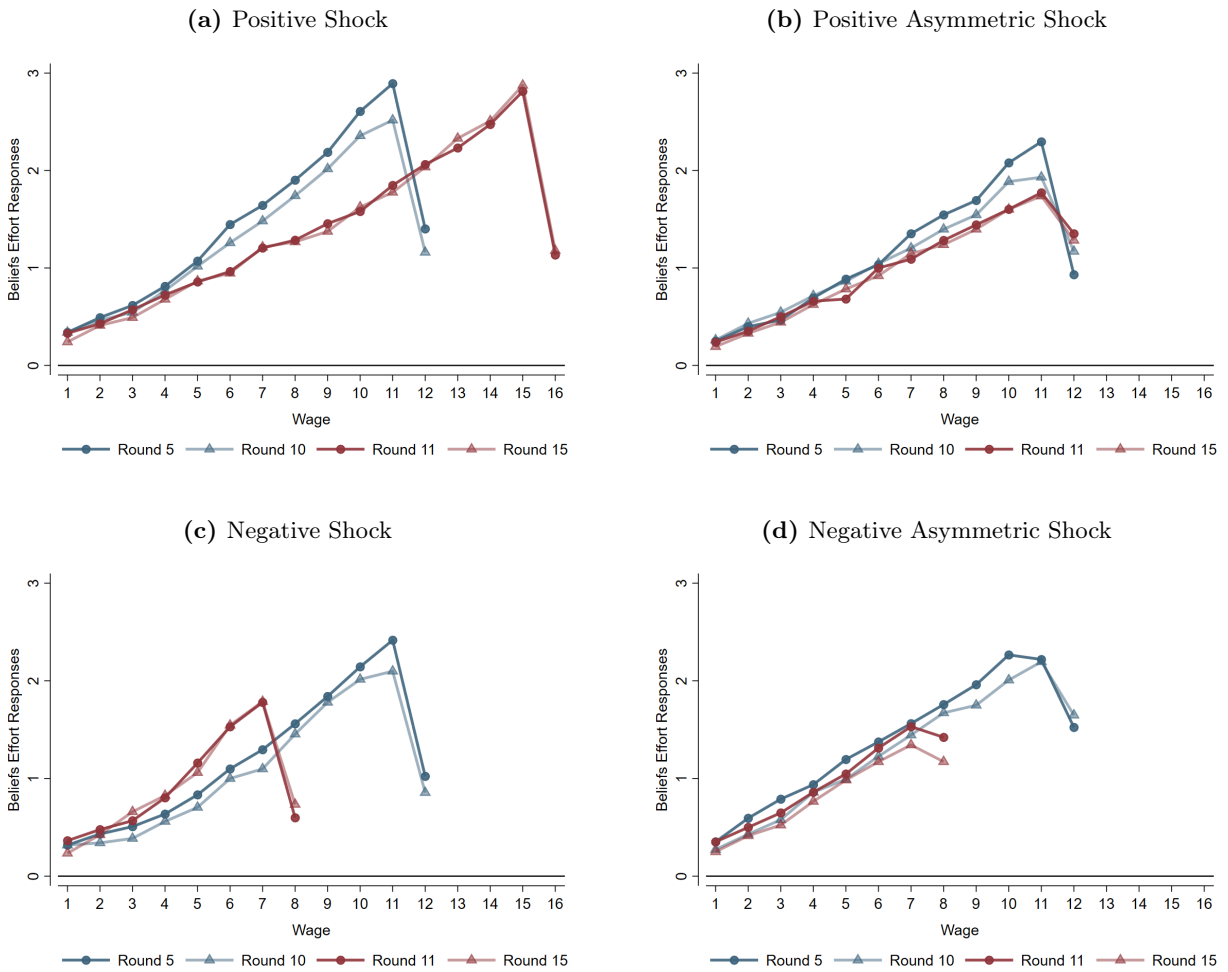
Notes: Results from a random-effects linear regression. Rounds 5 and 10 are pooled together, similarly with rounds 11 and 15. We control for the maximum wage (the one that exhausts the endowment), gender, if the pair played the Nash equilibrium strategy (defined as the worker selecting effort equal to 0 for all possible wages in at least one elicitation), and for the corresponding average wage offered during the trial rounds. Clustered standard errors at the individual level in parentheses. * $p < 0.10$, *** $p < 0.05$, **** $p < 0.01$.

Table A4: Beliefs and effort response changes in post-shock periods (asymmetric information)

	(1)	(2)	(3)	(4)
	Beliefs diff. (asym.pos.shock)	Beliefs diff. (asym.neg.shock)	Effort Resp. diff. (asym.pos.shock)	Effort Resp. diff. (asym.neg.shock)
Mean of dep.var.	0.038	0.082	0.044	0.028
Wage	-0.016* (0.009)	-0.003 (0.014)	-0.007 (0.010)	-0.009 (0.006)
<i>Observations</i>	216	288	216	432

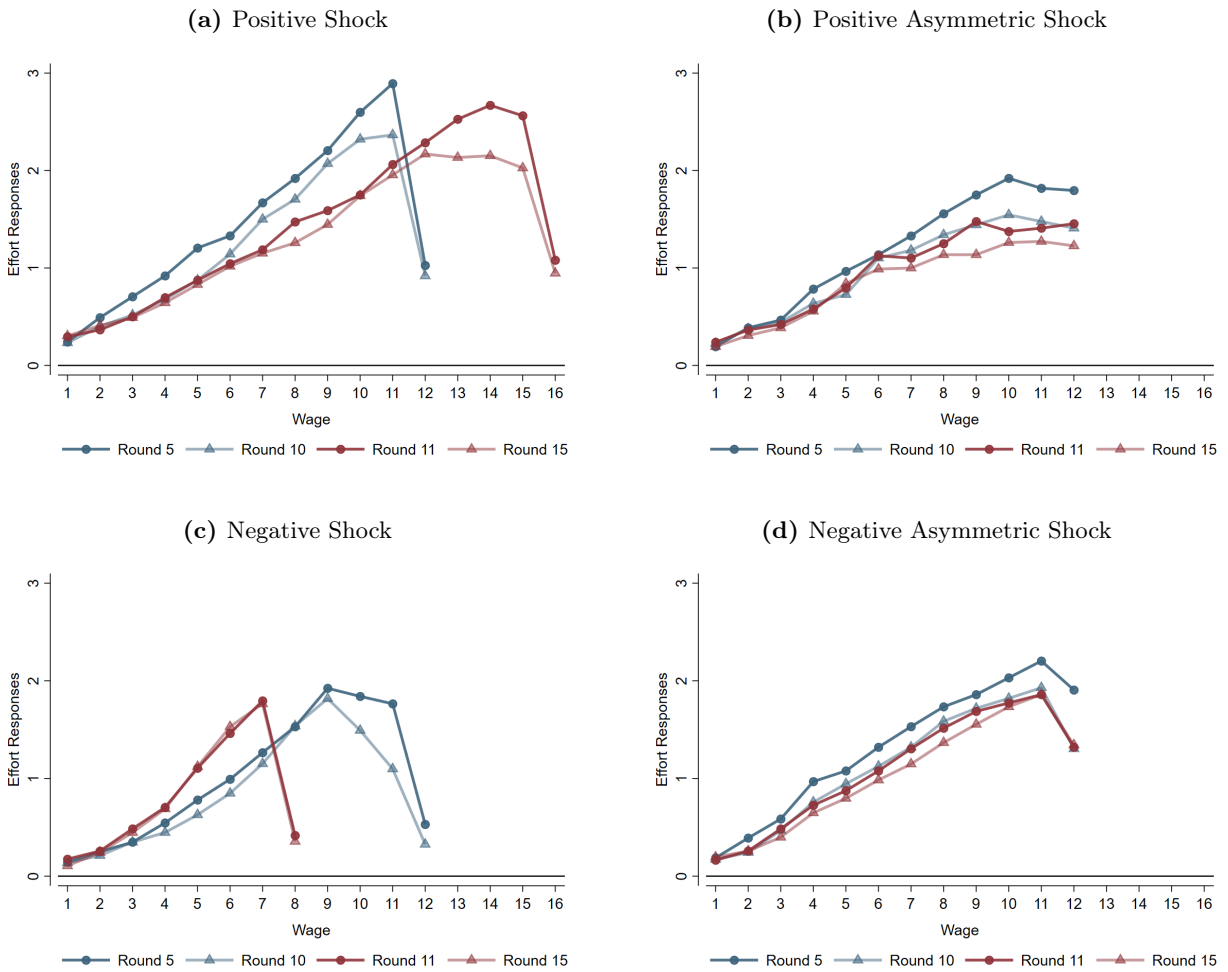
Notes: Results from a random-effects linear regression. Rounds 5 and 10 are pooled together, similarly with rounds 11 and 15. We control for the maximum wage (the one that exhausts the endowment), gender, if the pair played the Nash equilibrium strategy (defined as the worker selecting effort equal to 0 for all possible wages in at least one elicitation), and for the corresponding average wage offered during the trial rounds.. We exclude pairs where the firm did not pass the asymmetric test. Clustered standard errors at the individual level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Figure A: Firms' beliefs about effort responses by elicitation round



Notes: This figure shows the average belief about effort responses for each possible wage. Drops corresponds to wage offers that exhaust the firm's endowment. We exclude two firms that chose to reveal the shock in the positive asymmetric condition.

Figure B: Workers' effort responses by elicitation round



Notes: This figure shows the average effort response for each possible wage. Drops corresponds to wage offers that exhaust the firm's endowment. We exclude two workers for which the firm chose to reveal the shock in the positive asymmetric condition.

Table A5: Firms Payoffs Pre/Post Shock

	(1)	(2)	(3)	(4)
	Firm payoff (pos. shock)	Firm payoff (asym.pos. shock)	Firm payoff (neg. shock)	Firm payoff (asym.neg. shock)
Mean of dep.var	6.145	8.918	5.566	6.890
Post	2.633*** (0.448)	4.169*** (0.911)	-2.471*** (0.324)	-4.269*** (0.508)
Last Round	-2.356** (1.098)	0.784 (1.063)	-0.899*** (0.308)	-0.663** (0.335)
Male	2.019** (0.860)	-2.342 (3.027)	0.838** (0.428)	1.241 (0.868)
Nash Eq.	-1.214 (0.861)	-4.965 (3.239)	-2.722*** (0.884)	-2.921*** (1.025)
Trial Round Avg.	-0.162 (0.414)	0.197 (0.522)	0.010 (0.167)	-0.444* (0.238)
<i>Observations</i>	560	440	660	640

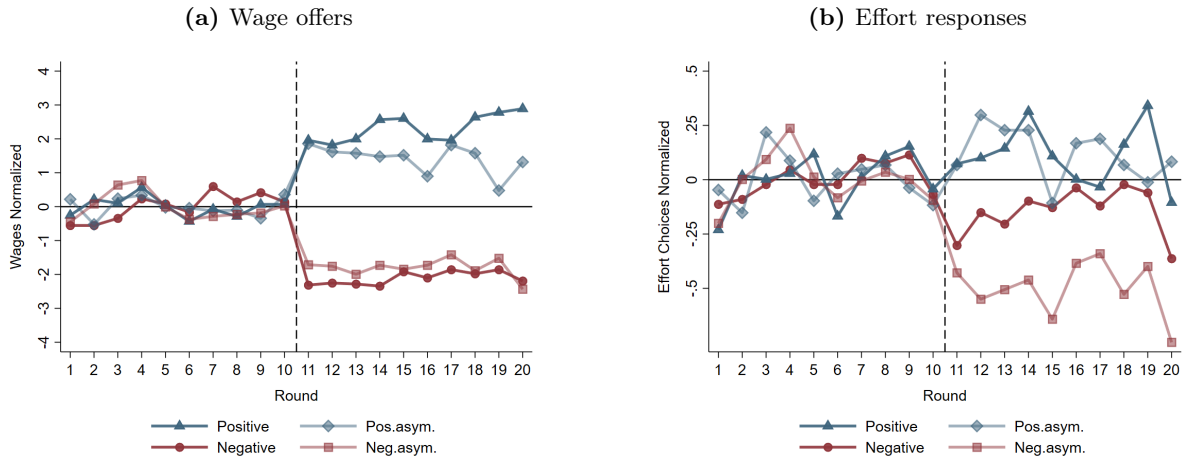
Notes: Results from a random-effects linear regression. We control for the last round, gender, if the pair played the Nash equilibrium strategy (defined as the worker selecting effort equal to 0 for all possible wages in at least one elicitation) and for the corresponding average wage offered during the trial rounds. We exclude pairs where the firm did not pass the asymmetric test. Clustered standard errors at the individual level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A6: Workers Payoffs Pre/Post Shock

	(1)	(2)	(3)	(4)
	Worker payoff (pos. shock)	Worker payoff (asym.pos. shock)	Worker payoff (neg. shock)	Worker payoff (asym.neg. shock)
Mean of dep.var	4.304***	3.034***	6.296***	3.174***
Post	1.948*** (0.339)	0.970** (0.440)	-1.870*** (0.140)	-1.081*** (0.142)
Last Round	0.886* (0.489)	-0.287 (0.721)	0.070 (0.251)	-0.510* (0.281)
Male	-1.223*** (0.450)	0.644 (0.685)	0.029 (0.231)	-0.693* (0.415)
Nash Eq.	2.285*** (0.466)	-0.850 (0.708)	-0.578 (0.744)	0.322 (0.433)
Trial Round Avg.	0.178 (0.153)	0.191* (0.114)	-0.118 (0.086)	0.286* (0.150)
<i>Observations</i>	560	440	660	640

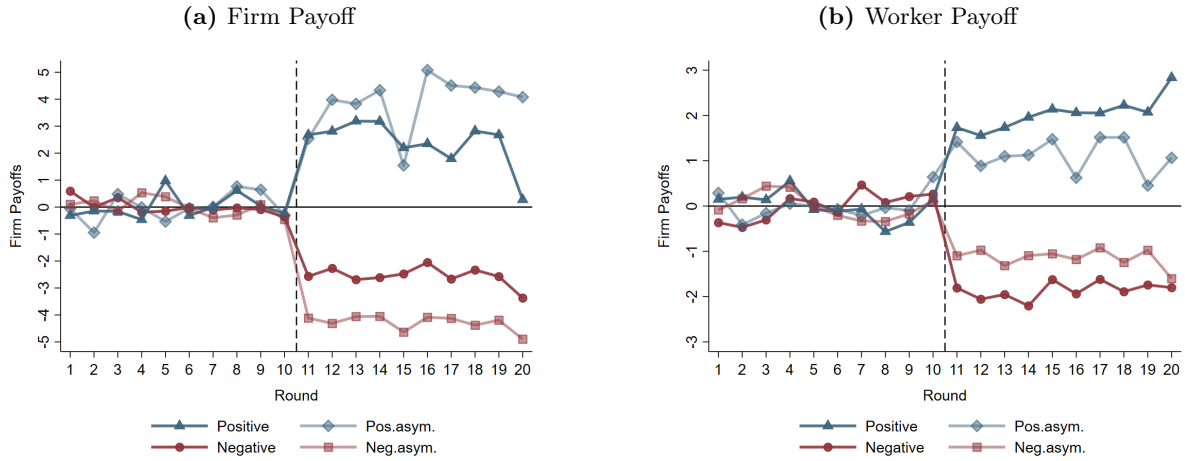
Notes: Results from a random-effects linear regression. We control for the last round, gender, if the pair played the Nash equilibrium strategy (defined as the worker selecting effort equal to 0 for all possible wages in at least one elicitation) and for the corresponding average wage offered during the trial rounds. We exclude pairs where the firm did not pass the asymmetric test. Clustered standard errors at the individual level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Figure C: Average wage offer and effort response by treatment



Notes: This figure shows the average wage (a) and effort choice (b) for each round. We normalize each variable by subtracting the pre-shock average and exclude pairs where the firm did not pass the asymmetric test.

Figure D: Average payoffs by treatment



Notes: This figure shows the average payoff for firms (a) and workers (b) for each round. We normalize each variable by subtracting the pre-shock average and exclude pairs where the firm did not pass the asymmetric test.

Table A7: Firms profits and wage expectations

	(1)	(2)	(3)	(4)
	Firm Payoff	Firm Payoff	Firm Payoff	Firm Payoff
	(pos. shock)	(pos. asym. shock)	(neg. shock)	(neg. asym. shock)
Mean of dep. var.	6.801**	8.512*	5.475***	9.338***
Post	3.369*** (0.831)	6.003*** (2.255)	-2.576*** (0.501)	-4.339*** (1.229)
Post × Above	0.054 (0.948)	-1.113 (2.435)	0.216 (0.716)	-0.565 (1.624)
Post × Below	-1.936 (1.187)	-6.193** (3.054)	0.076 (0.591)	0.172 (1.328)
Last Round	-2.356** (1.100)	0.784 (1.065)	-0.899*** (0.309)	-0.663** (0.336)
Male	2.195*** (0.806)	-2.563 (2.727)	0.848* (0.440)	1.177 (0.884)
Nash eq.	-1.760** (0.773)	-4.881* (2.923)	-2.734*** (0.898)	-2.867** (1.139)
Trial Round Avg.	-0.123 (0.383)	0.046 (0.476)	0.015 (0.174)	-0.446* (0.246)
<i>Observations</i>	560	440	660	640

Notes: Results from a random-effects linear regression. We control for the last round, gender, if the pair played the Nash equilibrium strategy (defined as the worker selecting effort equal to 0 for all possible wages in at least one elicitation) and for the corresponding average wage offered during the trial rounds. We excluded pairs where the firm did not pass the asymmetric test. Type *Above* is a dummy that corresponds to pairs with wage offers above workers' expectation in round 11. Type *Below* to those with wage offers below and *Equal* corresponds to pairs with offers equal to expectations. Clustered standard errors at the individual level in parentheses. * $p < 0.10$, *** $p < 0.05$, *** $p < 0.01$.

Type Classification [as a percentage of pairs]							
	Round 11			Round 15			
	Above	Below	Equal	Above	Below	Equal	#Pairs
Positive	46.4	39.3	14.3	32.1	17.9	50.0	28
Positive asymmetric	63.6	18.2	18.2	45.5	27.3	27.3	22
Negative	30.3	51.5	18.2	24.2	30.3	45.5	33
Negative Asymmetric	9.4	71.9	18.8	12.0	62.5	25.0	32

Notes: This table shows the percentage of pairs in each treatment where the firm offers a wage above, below, or equal to the worker's expected wage in rounds 11 and 15.

B Details for Theoretical Section

In this section of the appendix, we provide additional details on the derivation of optimal wage and effort functions with both symmetric and asymmetric information. Additionally, we consider hypotheses under two alternative specifications for the firm's profit function.

B.1 Solving our stylized model

We solve the model via best response analysis. Under the assumption that $c(e)$ is strictly convex, $U(\cdot)$ is strictly concave in e and the worker can always find a utility-maximizing level of effort e for any offered wage. Assuming the cost function $c(e) = 0.5e^2$, the worker's optimal effort response to a wage w and some reference wage $w_0(R)$ is:

$$e_i^*(w, R, w_0(R)) = \alpha_j \left(\frac{\mu + w - w_0(R)}{R} \right)^{\beta_j} \quad (6)$$

which is increasing in wages, decreasing in the reference wage, and decreasing in beliefs about the firm's endowment.²⁶

Substituting $e_i^*(w, R)$ into the firm's profit function $(R - w)e$ and solving for the optimal wage yields the firm's best-response function:²⁷

²⁶We assume $\mu \geq w_0(R) - \underline{w}$ to ensure non-negative effort responses.

²⁷Our experimental results suggest that firms do form accurate beliefs about the effort response function, understand how a change in the endowment reshapes the effort response function, and form accurate beliefs about the worker's expected wage.

$$w^*(e^*) = \frac{\beta_j R + w_0(\tilde{R}) - \mu}{1 + \beta_j} \quad (7)$$

Notice first that Equation 4 is decreasing in μ . This is because, all else equal, higher values of μ yield a larger effort response for any wage w . Second, Equation 4 is increasing in the firm's endowment R and the worker's belief about the endowment \tilde{R} through $w_0(\cdot)$. Intuitively, this says wages will always adjust in the direction of the endowment shock. Firms share positive shocks in order to elicit a reciprocal effort response from workers and share negative shocks expecting only a proportional decrease in effort. Further, firms understand that $w_0(R)$ is order preserving – the worker will expect a wage increase following a positive shock ($w_0(R)$ shifts up) but will tolerate a wage cut following a negative shock ($w_0(R)$ shifts down). These two channels highlight the relevance of information – or absence thereof – regarding economic conditions in determining optimal wages.

B.2 Alternative profit functions

Firms in our experiment face an induced utility function of the form $\pi = (R - w)e$. Though this functional form was and remains common in relevant pieces of literature, researchers have begun to consider alternative functional forms to address the concern that our chosen functional form implies the marginal product of effort is declining in wages.

If one re-frames our chosen functional form in terms of a Cobb-Douglas function where effort and the firm's endowment are complementary then the idea that the marginal product of effort declines in wages is not problematic. This is because allocating capital stock to the worker as payment before production reduces the firm's capital stock that interacts with worker effort.

There are at least two other functional forms suggested to us by reviewers, and conference and seminar participants. First, we could have considered a functional form where only the wage is multiplied by effort so that $\pi = R - we$. Second, we could have considered a functional form where effort scales only the endowment so that $\pi = Re - w$. The former addresses any concerns about effort multiplying the endowment while the second addresses the concern that the marginal product of the effort is declining in the wage.

Considering $\pi = R - we$

Suppose the firm's profit function is $\pi = R - we$ and the firm's goal is to maximize profits with respect to wage. Clearly, the optimal wage in this setting is $w = 0$, which yields $\pi = R$. This is because effort no longer scales endowment and so the firm has no incentive to induce positive effort. In fact, this functional form implies that firm profits are declining in effort. Further, subjects in our experiment could coordinate on $w = R$, $e = 0$ so that the firm earns $\pi = R - R * 0 = R$ and the worker earns $U(w, e) = w - c(e) = R - 0 = R$. Intuitively, this means the worker and firm could magically double and split the endowment without any labor input. For these two reasons, we chose not to adopt this functional form for firm profits.

Considering $\pi = Re - w$

Suppose instead that the firm's profit function is $\pi = Re - w$ and again the firm wants to maximize profits with respect to wage. If the firm accounts for the worker's optimal effort response $e_i^*(w, \tilde{R}) = \alpha_j \left(\frac{\mu + w - w_0(\tilde{R})}{\tilde{R}} \right)^{\beta_j}$, then the profit-maximizing wage is

$$w^*(w, R, w_o(R)) = \left(\frac{1}{\alpha\beta} \right)^{\frac{1}{\beta-1}} R + w_o(R) - \mu$$

The concern is whether behavior ought to be qualitatively different when we assume alternative specifications for firm profits. This is equivalent to asking whether our hypotheses would change qualitatively if we assume $\pi = Re - w$ (rather than $\pi = (R - w)e$). Since hypotheses 2 and 4 concern worker effort, we can ignore them. Thus, we focus here on hypotheses 1 and 3.

We first consider Hypothesis 1, which says that wage changes are positively correlated with changes in the firm's endowment when information is symmetric. Since α , β are both strictly positive, we have that changes in w^* and R are positively correlated. Thus, hypothesis 1 is qualitatively equivalent under this alternative specification.

Next, we consider Hypothesis 3, which says that information frictions moderate wage changes following an endowment shock. Assume a firm's endowment changes from $R, R', R' > R$. The difference in the corresponding wage change for fully-informed workers is given by

$$\begin{aligned}
w^*(w, R', w_o(R')) - w^*(w, R, w_o(R)) &= \left(\frac{1}{\alpha\beta}\right)^{\frac{1}{\beta-1}} R' + w_o(R') - \mu - \left[\left(\frac{1}{\alpha\beta}\right)^{\frac{1}{\beta-1}} R + w_o(R) - \mu\right] \\
&= \left(\frac{1}{\alpha\beta}\right)^{\frac{1}{\beta-1}} (R' - R) + (w_o(R') - w_o(R))
\end{aligned}$$

With asymmetric information, we would have

$$\begin{aligned}
w^*(w, R', w_o(R)) - w^*(w, R, w_o(R)) &= \left(\frac{1}{\alpha\beta}\right)^{\frac{1}{\beta-1}} R' + w_o(R') - \mu - \left[\left(\frac{1}{\alpha\beta}\right)^{\frac{1}{\beta-1}} R + w_o(R) - \mu\right] \\
&= \left(\frac{1}{\alpha\beta}\right)^{\frac{1}{\beta-1}} (R' - R) + w_o(R) - w_o(R) \\
&= \left(\frac{1}{\alpha\beta}\right)^{\frac{1}{\beta-1}} (R' - R)
\end{aligned}$$

Since we assume that $w_o(R)$ is strictly increasing in R , we have that the wage increase following a positive endowment shock is strictly smaller with asymmetric information by the amount $-(w_o(R') - w_o(R)) < 0$. By similar logic, we would predict that wages fall by less following a negative endowment shock if workers are uninformed. For example, if the endowment changes from R to R' , $R' < R$ then $-(w_o(R') - w_o(R)) > 0$.

C Structural Estimation

This section provides details on our structural estimation.

C.1 Identification and Estimation

We first focus on the worker's problem. Log-linearization of equation (3) yields the following equation:

$$\ln(e^*(w, R)) = \ln(\alpha) + \beta \ln\left(\frac{\mu + w - w_0(\tilde{R})}{\tilde{R}}\right) \tag{8}$$

Because we directly observe w and \tilde{R} , to be able to estimate α , β in equation (8) via ordinary least squares (OLS) we need measures of both μ and $w_0(\tilde{R})$. Since neither of those is directly observable, we first assume $\mu = 0$. This assumption biases our estimates of α (i.e. the intercept) but it does

not affect β (i.e. the slope) since μ is a constant that shifts the effort response function but does not impact its curvature. Biasing α does not reduce the goodness of fit of either model and we can still estimate wage offers since the optimal wage does not depend on α . This leaves only the issue that we do not directly observe $w_0(\tilde{R})$.

One possibly solution is to proxy $w_0(\tilde{R})$ using wage expectations gathered from workers during elicitation rounds. However, this proxy leads to many instances in our data where $w - w_0(\tilde{R}) < 0$ for which the log of the ratio is undefined in \mathbb{R} . To circumvent this issue, we instead proxy $w_0(\tilde{R})$ using the wage $\bar{w}_0(\tilde{R})$ such that $e^*(w, R) = 0$ whenever $w \leq \bar{w}_0(\tilde{R})$. For $\bar{w}_0(\tilde{R})$ to be a valid proxy, it should react to endowment shocks in a way consistent with our theoretical assumptions about $w_0(\tilde{R})$. We provide evidence of this in table C8, which shows that our proxy measure reacts to endowment shocks in the same direction as fair wages under full information and does not change under asymmetric information.

Table C8: Reference wage proxy [in elicitation rounds]

	(1)	(2)	(2)-(1)
	Pre-shock proxy	Post-shock proxy	Diff.
Positive	1.24	2.13	0.88
Positive asymmetric	1.38	1.47	0.08
Negative	1.50	0.92	-0.58
Negative Asymmetric	1.04	1.21	0.16

Notes: This table shows the average wage for which workers choose a zero effort level in the elicitation rounds. $\bar{w}_0(R)$ is defined as the wage such that $e^*(w, R) = 0$ whenever $w \leq \bar{w}_0(R)$. Rounds 5 and rounds 10 are pooled together. Similarly for rounds 11 and 15. As in the remaining of our structural exercise, we exclude pairs with an all-zero effort elicitation.

While we obtain $\bar{w}_0(\tilde{R})$ directly from pre-shock data, we need to be able to estimate this value following an endowment shock. This means we must assume a functional form for $\bar{w}_0(\tilde{R})$ in order to produce post-shock estimates of wages, beliefs, and effort that do not rely on post-shock data. Thus, we further assume $\bar{w}_0(\tilde{R}) = \gamma\tilde{R}$, which says that our proxy of the reference wage is simply

a constant fraction of the endowment. Note that if this is a misspecification of $\bar{w}_0(\tilde{R})$ then it will penalize our model while leaving unaffected the benchmark model.

In our benchmark model the worker’s effort response function does not react to endowment shocks or incorporate information frictions. We model this by replacing $w_0(\tilde{R})$ and \tilde{R} with two constants. For simplicity, we let these two constants match the pre-shock values of $\bar{w}_0(\tilde{R})$ and \tilde{R} , respectively.²⁸

$$\ln(e^*(w, R)) = \ln(\alpha) + \beta \ln\left(\frac{w - a}{b}\right) \quad (9)$$

Intuitively, this benchmark model implies that neither changes in the endowment nor information regarding those changes impact a worker’s effort response function. The models are otherwise identical.

We start by estimating individual-level values of α and β using pre-shock elicitation data for workers (from effort response function) and firms (from belief elicitation) separately.²⁹ We then predict out-of-sample post-shock values for wages, beliefs, and effort with both models using these parameter estimates. Comparing the resulting distributions of individual-level MSPEs determines which model provides better out-of-sample predictions.

C.1.1 Post-Shock Wage Prediction

Next, we use our estimates for the firms in the pre-shock periods to obtain a prediction for wage offers in the post-shock periods and compare this to observed wage offers. Our proxy $\bar{w}_0(\tilde{R})$ almost certainly introduces downward bias in our wage predictions since the levels are likely lower than actual reference wages. However, we can recover firm’s actual beliefs of worker’s reference wage $\hat{w}_0(\tilde{R})$ if we assume that the firm set wages optimally given their beliefs (this is supported by evidence in section 5.4). Given this assumption, we can then use our estimates of β and pre-shock wage offers to recover the firm’s beliefs from equation (1) and its benchmark analog.³⁰ Finally, we

²⁸Though the values of a, b do not influence the out-of-sample predictive power of this benchmark model, this approach to selecting their values ensures that pre-shock values of α, β are consistent across the two models that we consider.

²⁹In many instances, all effort responses or beliefs are 0 in a given elicitation. We drop these observations from the estimation since logs are undefined. In addition, we do not take into account the responses for when the wage offer exhausts the endowment for the same reason. For a discussion about how to deal with logs and zeros in regression models see [Young and Young \(1975\)](#) and [Bellego et al. \(2021\)](#).

³⁰The benchmark equation only differs in that $w_0(\cdot)$ is substituted by a constant.

assume the same functional form as before $\hat{w}_0(\tilde{R}) = \gamma\tilde{R}$ so we can do out-of-sample predictions for changes to the endowment.

D Instructions

This subsection of the appendix provides the instructions used in our experiment. There was one minor difference in the instructions used for symmetric and asymmetric information sessions. This difference - where we change what information workers receive at the end of a Decision Period - is highlighted in red text. This difference, which corresponds to a difference in end-of-period information for workers across information conditions, was necessary to create our desired information frictions. Importantly, our baseline periods of play across information conditions confirm that this difference did not meaningfully affect workers' effort decisions.

We provided instructions in two phases. First, we provided subjects with a one-page document meant to outline the basics of the game they would play, how their decisions would affect their earnings, and how we would construct their final payoffs. We followed this with a basic comprehension quiz, delivered on-screen. Subjects could not proceed without answering all questions in the comprehension quiz correctly. Next, we provided subjects with more detailed information the the two types of periods they would experience. We again followed this set of instructions with an on-screen comprehension quiz.

D.1 Instructions - Basic Information Sheet

Basic Information

Formation of Pairs:

We will randomly assign you to one of two roles for this experiment: employer or worker. You will be informed about your role at the beginning of this experiment. Once we assign you to one of these two roles we will then randomly form employer-worker pairs. Your role (employer or worker) will not change during this experiment. Additionally, the composition of worker-employer pairs will not change during the paid portion of this experiment. That means that you will always make decisions

with the same worker/employer during the paid portion of this experiment

Anonymity:

This is an anonymous game. No other participant will know your identity during this experiment. Your counterpart will know your role (whether you are an employer or worker) and will see your decisions. However, your counterpart cannot link these decisions to you personally. No other participant (other than your counterpart) will know your role or be able to view your decisions.

Experiment Length:

- This experiment lasts for 20 paid periods. A period ends after both players (worker and employer) make all relevant choices.
- However, you will play 3 additional trial periods to get used to the game. Trial periods are not paid. It is important that you take these seriously so that you understand the game. This will help you maximize your earnings during paid periods. After the 3 trial periods, the 20 paid periods will begin automatically

Description of the 20 periods

There are two types of periods during the paid portion of this experiment:

- *Decision Periods:* workers and employers make some decisions.
- *Questionnaire Periods:* first, players will respond to some questions; then, they will proceed to making their decisions. You will start the experiment by playing a Decision Period and you will be notified when you are playing a Questionnaire Period.

Payment for this experiment:

- We will pay you in cash at the end of this experiment.
- The computer will randomly select one Decision Period and one Questionnaire Period out of the 20 periods. We will pay you for these two randomly selected periods. This is in addition to your \$10 show-up fee.
- Thus, your final payment will include your earnings for the two randomly selected periods and the show-up fee.

D.2 Instructions - Description of Periods

1. Description of a Decision Period

Steps

Each *Decision Period* proceeds as follows:

1. The employer receives an endowment and then sets a wage for the worker
2. The worker learns the wage offered and then selects a level of effort in response
3. Both subjects learn their payoff for that period
4. The game proceeds to either another Decision Period or to a Questionnaire Period

Roles and Actions

- **Employer:**

- A subject assigned to the role of employer' initially receives an endowment of \$12. The employer will use the per-period endowment to pay a wage to the worker for that period.
- The wage must be some number between \$1 and the total endowment in increments of \$1. Thus, an employer could pay a wage of \$1,\$2,\$3, , etc.
- Whatever portion of the endowment the employer keeps is multiplied by the effort provided by the worker and then paid to the employer.
- Formally, the employer will earn:

$$\text{Employer's payoff} = (\text{Endowment} - \text{Wage}) * \text{Effort}$$

- **An Example:** Suppose that the employer decides to pay the worker a wage of \$4. Further, suppose that the worker selects effort of 1.5. With these hypothetical values, the employer earns $(12 - 4) * 1.5 = 8 * 1.5 = \12 .
- Note that only what is left of the initial endowment is multiplied by the level of effort chosen by the worker. Thus, paying the whole endowment as a wage would yield a payoff of zero for the employer no matter the level of effort the worker selects in response.
- At the end of each period, the employer will learn both the worker's effort level and his/her own payoff.

- The employer cannot accumulate money throughout periods. This means the employer can use only his/her endowment to set a wage in each period.

- **Worker:**

- A subject assigned to the role of 'worker' will receive a wage offer in each period from the employer.
- In each period, after receiving the employer's wage offer, the worker will select a level of costly effort for that period. The higher the effort, the higher is the cost of effort.
- The level of effort can be: [0, 0.25, 0.5, 1, 1.25, 1.50,..., max effort]. Note that a worker cannot select a level of effort that will cause a negative payoff.
- Workers have the following payoff function:

$$\text{Worker's payoff} = \text{Wage} - \text{Cost of Effort}$$

The cost of effort is computed according to the following function and displayed before confirming the effort choice:

$$\text{Cost of effort} = .5 * e^2$$

- Suppose an employer offers a wage of \$6 and the worker exerts an effort level of 2 in response. Then the worker earns $6 - (0.5 * 2^2) = 6 - 2 = \4
- At the end of each period, the worker will learn his/her own payoff. Note: For symmetric information treatments, subjects also learned the employers payoff, which we informed them of here.
- The worker cannot accumulate money throughout periods. That is, each period the worker will receive a wage offer and go through the steps described above.

2. Description of a Questionnaire Period

Steps

Each *Questionnaire Period* proceeds as follows:

1. Both the worker and the employer respond to some questions
2. Both the worker and the employer make their Decisions

3. Payoffs of the worker and the employer for that period are displayed
4. The game proceeds to either another Questionnaire Period or to a Decision Period.

Further details on points 1 and 2 will be given during the game and displayed on screens. Instructions are role specific. We display these instructions during each questionnaire period. However, the instructions for a questionnaire period are the same for all questionnaire periods.

The software will notify you when you are playing a Questionnaire Period. You will start the game by playing a Decision Period.

3. Final remarks:

If you have any further questions, please raise your hand and an experimenter will visit your station to answer your question privately.

4. Summary of Basic Instructions:

- We will randomly assign you to one of two roles: employer or worker. Your role will not change during the experiment.
- We randomly assign one worker to one employer. This is the employer-worker pair. These pairs do not change during the experiment.
- The game lasts for 20 periods (plus 3 trial periods) and they are distinguished into Decision Periods and Questionnaire Periods.
- In Each Decision period, the employer receives an endowment and uses this endowment to pay a wage to the worker.
- Once the worker receives a wage offer, the worker will respond by selecting a level of costly effort.
- Employer earnings for each period are $(\text{Endowment} - \text{Wage}) * \text{Effort}$. -Worker earnings for each period are $(\text{Wage} - \text{Cost of Effort})$.
- The employer receives a new endowment in each period, and the employer and the worker cannot accumulate money across periods.
- The employer selects a new wage each Decision Period. The worker selects a new level of

costly effort each Decision Period.

- During Questionnaire Periods, both players respond to some questions displayed on their respective screens. The software will always notify you when you are playing a Questionnaire Period.
- 1 Decision Period and 1 Questionnaire Period will be randomly chosen and the payoffs in these periods, plus your show-up fee, form your final payment.

E Screen Shots

Comprehension Quiz

Please, respond to the following questions concerning the instructions that you just read.

• **Question 1. :**

How many period types are there?	<input type="text" value="0"/>	
---	--------------------------------	--

• **Question 2. :**

How many <i>Decisional Periods</i> will be paid?	<input type="text" value="0"/>	
How many <i>Questionnaire Periods</i> will be paid?	<input type="text" value="0"/>	
How many periods will be paid overall?	<input type="text" value="0"/>	

Number of right answers: 0

(c) First comprehension quiz

Comprehension Quiz

Please, respond to the following questions concerning the instructions that you just read.

• **Question 3. :**

What is the initial endowment of the employer?	<input type="text"/>	
What is the payoff of the employer for a wage = 12 and effort = 4?	<input type="text"/>	
What is the payoff of the employer for a wage = 12 and effort = 0?	<input type="text"/>	
What is the payoff of the employer for a wage = 0 and effort = 0?	<input type="text"/>	
What is the payoff of the worker for a wage = 12 and effort = 4?	<input type="text"/>	
What is the payoff of the worker for a wage = 12 and effort = 0?	<input type="text"/>	

Number of right answers: 0

(d) Second comprehension quiz

Figure E: Beliefs and Effort Responses to Shocks

Decisional Period

round 1/20

The employer has offered you the following wage: \$10

Please, select an effort level

Note: negative payoffs are not allowed. You can proceed only if your payoff is non-negative

Effort:



You will earn :

$$\text{Wage} - \text{Cost of Effort} = \$10 - 0.5 * 3^2 = \$5.5$$

The employer will earn:

$$(\text{Endowment} - \text{Wage}) * \text{Effort} = (\$12 - \$10) * 3 = \$6$$

Next

Figure F: Worker's effort selection screen

Decisional Period

round 1/20

You have to make a wage offer to the worker.

Please, select a wage level to send between \$1 and \$12.

Wage:

Next

Figure G: Worker's effort selection screen

Results

round 1

The employer you are paired with offered the wage:	10
You chose the effort:	2,5
Your payoff in this round is:	\$6,9
The employer's payoff is:	\$5,0

Next

(a) Firm's end-of-period information

Results

round 1

You offered the wage:	10
The worker you are paired with chose the effort:	2,5
Your payoff in this round is:	\$5,0
The worker's payoff is:	\$6,9

Next

(b) Worker's end-of-period information

Figure H: End-of-period information

Change in Employer's Endowment

The employers' per-period endowment has changed from \$12 to \$8.

This change will last for the remainder of this experiment!

Please, note:

- The employer's payoff is now $(\$8 - \text{Wage}) * \text{Effort}$.
- Therefore, the **highest** wage offer possible is now \$8 rather than \$12.
- This screen is being displayed **only** to **employers** in this experiment.
- Workers **do not learn** about this change.

Click on the button below to proceed.

Next

(a) Negative shock under asymmetric information

Change in Employer's Endowment

The employers per-period endowment has changed from \$12 to \$8.

This change will last for the remainder of this experiment!

Please, note:

- The employer's payoff is now $(\$8 - \text{Wage}) * \text{Effort}$.
- Therefore, the **highest** wage offer possible is now \$8 rather than \$12.
- This screen is being displayed to all employers and workers in this experiment.

Click on the button below to proceed.

Next

(b) Negative shock under full information

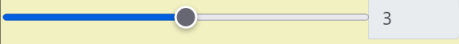
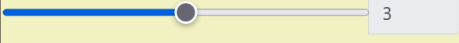
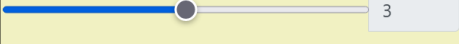
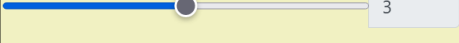
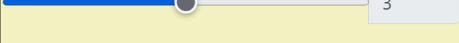




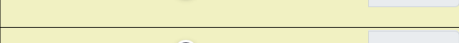
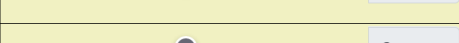
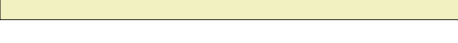
Figure I: Examples of endowment shock announcement

1. Guess Task:

Please use the table below to complete the Guess Task by moving the sliders.

There is a summary of Guess Task instructions at the bottom of this page should you need to remind yourself of how to complete the Guess Task and/or how you are paid for completing the Guess Task.

Note: negative payoffs are not allowed.

Wages	Guess on Effort	Worker's payoff	Your payoff
1	 3	-3.5	33
2	 3	-2.5	30
3	 3	-1.5	27
4	 3	-0.5	24
5	 3	0.5	21
6	 3	1.5	18
7	 3	2.5	15
8	 3	3.5	12
9	 3	4.5	9
10	 3	5.5	6
11	 3	6.5	3
12	 3	7.5	0

Negative payoff not allowed. You cannot proceed

Figure J: Example of the belief elicitation screen seen by subjects sorted into the role of employer in periods 5,10,11 and 16

Figure K: Example of the effort function elicitation seen by subjects sorted into the role of worker in periods 5,10,11 and 16

2. Strategy Task:

You will use the table below to provide your effort choice for each possible wage the employer could send you in this round. Note that in this task you will not know in advance the offered wage (as in previous Decisional Periods). That is:

- The employer will make a wage offer as usual, but this time it will not be displayed until the end of this task. You will learn the wage offer only after completing this task.
- You have to complete the table below with your effort response for each hypothetical wage level

How you earn money for the Effort Provision Task

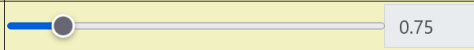
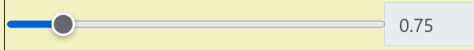
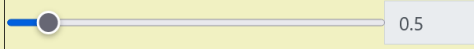
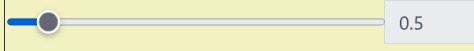
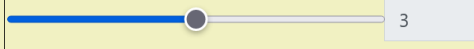
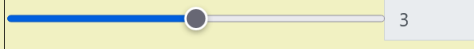
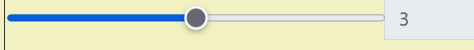
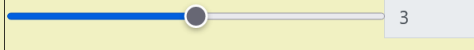
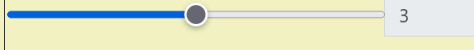
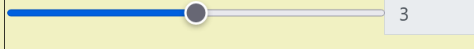
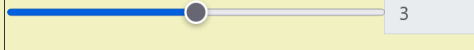
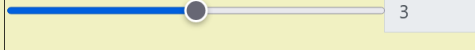
- To compute your payoff for this task, the effort level corresponding to the wage offered by the employer will be chosen as effort response.

Example

- suppose you have completed the table below.
- Now, suppose that the employer offers a wage of \$6 and that you agreed previously to provide effort 1.5 for a wage offer of \$6 (that is the line 6 of table).
- Your payoff is computed as usual : Wage - Cost of Effort = $(\$6 - 0.5 * 1.5^2) = \4.9 in this example.

----- Please, indicate your effort choices in the table below by moving the sliders.-----

Note: negative payoffs are not allowed. You can proceed only if your payoff is non-negative

Hypothetical Wages	Your Effort	Your payoff	Employer's payoff
1	 0.75	0.7	8.3
2	 0.75	1.7	7.5
3	 0.5	2.9	4.5
4	 0.5	3.9	4
5	 3	0.5	21
6	 3	1.5	18
7	 3	2.5	15
8	 3	3.5	12
9	 3	4.5	9
10	 3	5.5	6
11	 3	6.5	3
12	 3	7.5	0