Information Acquisition and Learning from Prices Over the Business Cycle

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Abstract

We study firms' incentives to acquire costly information in booms and recessions to investigate the role of endogenous information in accounting for business cycles. Our model predicts that, for a wide range of parameter values, firms have a stronger incentive to acquire information when the economy has been in a recession and a pessimistic belief about the state of the economy prevails than after a boom when firms share an optimistic belief. The equilibrium price system, which features endogenous information transmission, dampens aggregate fluctuations by discouraging information acquisition. Our welfare analysis reveals that information acquisition in the decentralized economy is not efficient. This is due to inefficient employment dispersion, arising from information heterogeneity in equilibrium. Time series data for the U.S. economy support the model's prediction of wages being more informative about total factor productivity after recessions than following booms.

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1. Introduction

In macroeconomics, the literature on informational frictions and the business cycle has a long history, stretching back to Phelps (1969), Lucas (1972), Barro (1976) and Townsend (1983). In the early 2000s, Mankiw and Reis (2002), Reis (2006) and Sims (2003) not only revived interest in models of imperfect information in macroeconomics, but also refined the concept of informational rigidities by developing models of (i) sticky information, (ii) inattentiveness, and (iii) rational inattention, apt for business cycle analysis.[1] While the focus of this literature has been largely on developing microfounded models of incomplete price adjustment to explain real effects of nominal disturbances in environments with imperfect information, the related question whether agents' learning efforts to alleviate such informational imperfections exhibit any systematic pattern over the business cycle has not been investigated. In contrast, cyclicality of agents' learning plays a prominent role in the closely related literature that employs models of imperfect information to provide an explanation for observed asymmetries in business cycle dynamics and financial time series. Chalkley and Lee (1998)'s partial equilibrium analysis of asymmetric investment behavior due to the presence of more noise traders in recessions than in booms marks a starting point for this literature. In a more recent contribution, Van Nieuwerburgh and Veldkamp (2006) examine the qualitative and quantitative implications of procyclical learning in a real business cycle model. Similarly, Veldkamp (2005) and subsequently Ordoñez (2013) build models that rely on procyclical learning in order to generate slow booms and sudden crashes in asset markets. The unifying idea in papers on procyclical learning is that in an

[1] A large literature has emerged since then. See, e.g. Amador and Weill (2010, 2012), Amato and Shin (2006), Angeletos and La'O (2009, 2010, 2012, 2013b), Angeletos and Pavan (2004, 2007a,b), Lorenzoni (2009, 2010), Maćkowiak and Wiederholt (2009, 2011), Moscarini (2004), Nimark (2008), Van Nieuwerburgh and Veldkamp (2006), Woodford (2003) and the references therein. The two chapters by Mankiw and Reis (2010) and Sims (2010) provide an overview of models with informational frictions in monetary economics.

environment where agents hold only imperfect information about the current state of the economy, upon a state change, procyclical learning induces only small upward revisions in agents' beliefs during recessions, but large downward revisions during booms. This pattern of learning triggers a quick response on part of the agents when the state transits from a boom to a recession, but only a slow response when the economy moves from a recession to a boom. Despite the explanation's intuitive appeal, two, so far unanswered, questions remain. First, is procyclical learning optimal when firms are allowed to choose their information?[2] Second, how does information contained in equilibrium prices affect individual agents' incentives for information acquisition, and ultimately the pattern of aggregate fluctuations? To answer these questions, in this paper we develop a general equilibrium model of firms' information acquisition decision in booms and recessions. Our contribution is to demonstrate that firms' information demand exhibits countercyclicality, and that the equilibrium price system moderates aggregate fluctuations by disincentivizing information acquisition.

A further contribution of our paper is to offer a model based explanation of the empirical finding that the degree of informational rigidities varies over the business cycle, as documented in Coibion and Gorodnichenko (2010). They investigate survey data on forecasts of various macroeconomic variables and reject the null hypothesis of full-information rational expectations. Their analysis suggests that this rejection stems from information rigidities, as measured by the predictability of forecast errors. Moreover, they find that recessions are characterized by a lower degree of information rigidity than booms. Our analysis shows how such state dependence in expectation formation can arise when firms optimally acquire costly information. It is noteworthy that we obtain this result in our baseline model where firms' uncertainty about the state of the economy exhibits no exogenous cyclicality.

[2] See Veldkamp (2011) for a comprehensive survey on models of information choice in macroeconomics and finance.

In our model, firms initially hold imperfect information about the aggregate technology level that varies randomly between a high level in a boom and a low level in a recession. Prior to hiring labor in a perfectly competitive market, firms choose whether to acquire an informative signal about the economy's true state at some fixed cost. An additional signal arises endogenously in the form of the labor market clearing wage. As the rational expectations equilibrium wage reflects firms' employment decisions, and ultimately the information they hold, it transmits information from firms that have bought the informative signal to those that have not. In our model information acquisition is a strategic substitute: an individual firm's expected gain from acquiring the costly signal decreases as the fraction of informed firms increases. Demand for information and hence the fraction of informed firms differ across the two states of the business cycle. For a wide range of parameter values, the demand for information is countercyclical. That is, when the economy has been in a recession in the previous period, and consequently firms enter the current period with a pessimistic belief, the incentive to acquire information is stronger than when the economy has been in a boom and firms share an optimistic belief.[3] We identify the following mechanisms rendering information demand countercyclical. First, the expected gain from acquiring the costly signal is decreasing in the equilibrium wage. Due to the procyclicality of wages, the incentives for information acquisition are weaker in booms. Second, for a wide range of parameter values the slope of firms' expected profit function is concave in their belief about the state of the economy. This leads to the costly signal being less valuable when firms are more optimistic about the state. Third, the informative signal has a stronger effect on informed firms' demand when the prior belief is high. As a result, *for a given fraction of informed firms*, equi-

[3]The determination of firms' prior belief is directly linked to previous period's realized technology level, which firms can deduce perfectly from their own output. A low technology level during a recession in the previous period renders firms' belief pessimistic, whereas a high technology level during a boom in the previous period gives firms an optimistic belief.

librium wages are more informative in booms, lowering firms' incentives to acquire information. Moreover, for empirically plausible transition probabilities, firms' uncertainty about the state of the economy exhibits countercyclicality. This strengthens the incentive to acquire information in recessions. The equilibrium price system, transmitting information from the informed to the uninformed firms, weakens firms' incentives to acquire costly information. As a result, in equilibrium, firms are less well informed about the state of the economy, which makes employment less responsive to changes in the state. Hence, learning from wages dampens aggregate fluctuations. Finally, a welfare analysis reveals that information acquisition in the decentralized economy is not efficient. This arises from inefficient employment dispersion, which itself is due to information heterogeneity in equilibrium.

Our paper is most closely related to the works of Chalkley and Lee (1998), Veldkamp (2005) and Van Nieuwerburgh and Veldkamp (2006), whose models feature procyclical learning to generate asymmetric business cycle dynamics. Chalkley and Lee (1998) study a binary state, binary action model of capital utilization with imperfect information about the economy's state. In their model, due to risk aversion, investors require more precise information to choose the high than the low action, the latter constructed to be the safer choice. Hence, noise investors, whose actions are independent of their belief about the economy's state, are more numerous relative to investors changing their action upon a state change in recessions than in booms. This, in turn, renders signals about the economy's state noisier in recessions than in booms. As a consequence, the dynamics of beliefs and aggregate activity are characterized by fast declines and slow recoveries. In Veldkamp (2005) asymmetric movements in lending rates are the result of more investment projects being undertaken in good than in bad times which generates a procyclical number of public signals about the unknown probability of a positive return. Similar to the idea of a larger number of signals in good than in bad times in Veldkamp (2005), the explanation for asymmetric movements in macroeconomic aggregates in Van Nieuwerburgh and Veldkamp (2006) relies on procyclical learning as a consequence of higher precision signals in booms than in recessions. In their model, an additional additive shock to aggregate technology ensures that the signal-to-noise ratio and thus learning is procyclical. All aforementioned papers, featuring procyclical learning as an explanation for asymmetric business cycle dynamics, share three model features that separate them from our analysis. First, agents in the three models are passive learners whereas we allow them to choose whether to become informed, i.e. they are active learners. Second, we allow for an informational role of prices, that arises naturally in equilibrium with asymmetrically informed agents, a channel that is however absent in the three papers since agents are symmetrically informed.[4] Third, public signals about aggregate activity are more informative in booms than in recession in the three models. In Chalkley and Lee (1998) the high action, which firms choose when being sufficiently confident that the economy is in the good state, is chosen by few firms upon a state change, generating noisy information in a recession. Similarly, in Veldkamp (2005) the precision of the public signal moves procyclically as the number of investment projects is, by construction, greater in booms than in recessions. In Van Nieuwerburgh and Veldkamp (2006), in turn, the variance of the aggregate statistic is smaller in booms than in recessions due to the combination of an additive and a multiplicative shock to aggregate technology. In equilibrium, our model features no procyclically informative aggregate statistic. Moreover, we find that optimal information acquisition by firms gives rise to a countercyclical aggregate learning outcome. We contribute to the literature on learning and business cycles by examining information demand and showing that countercyclical learning can arise when information acquisition is endogenous and the price system transmits information. Thus, our paper can be viewed as complementing the

[4]It is an important and well known result that with asymmetric information at least some agents will wish to reoptimize their plans if learning from equilibrium prices is suppressed, see e.g. the discussions in Grossman (1981) and in chapter 9 of Laffont (1989).

analyses of information supply by Chalkley and Lee (1998), Veldkamp (2005) and Van Nieuwerburgh and Veldkamp (2006).

In finance, the literature assessing to what extent mutual fund managers have skill has recently also turned to the idea of countercyclical incentives for information acquisition.[5] Most notably, Kacperczyk et al. (2014a) develop a theoretic model to provide an answer to why fund managers alter their investment behavior over the business cycle.[6] They argue that learning features countercyclicality in that acquiring information about aggregate shocks is more valuable in recessions than in booms. In their framework this countercyclicality can result from either aggregate volatility being higher in recessions than in booms or the price of risk, i.e. investors' risk aversion, being countercyclical. It is noteworthy that our baseline model does not hinge on countercyclicality of the price of risk or the quantity of risk. Instead, the three mechanisms underlying countercyclical information demand in the baseline model are the procyclicality of wages, the concavity of the slope of firms' expected profit function and the procyclical informativeness of equilibrium wages for a given fraction of informed firms.

Our paper is related in focus and methodology to Hahm (1987) which builds on the seminal works of Lucas (1972) and Phelps (1969). Lucas (1972), formalizing Phelps (1969), demonstrates how nominal disturbances can have real effects in the presence of incomplete information. Hahm (1987) augments Lucas (1972) by allowing traders to acquire information on aggregate variables. He finds that the output-inflation tradeoff can vanish faster when increasing the variance of the monetary shock than without information acquisition. Despite both Hahm (1987) and our analysis acknowledging the importance of modeling agents' incentives for acquiring information, there remain three important differences. First, in our environment, the real shock hitting the econ-

[5]We thank an anonymous referee for suggesting to us this strand of literature.

[6]The empirical finding that skilled fund managers successfully pick stocks in booms and time the market well in recessions is established in Kacperczyk et al. (2014b).

omy is persistent, allowing for state-dependence in information acquisition. Second, our main interest revolves around how learning from prices affects real aggregate fluctuations whereas Hahm (1987) is concerned with the inflation-output tradeoff. Third, our environment permits us to find the exact equilibrium price functional while Hahm (1987) derives an approximate equilibrium price functional by guess-and-verify.

The more recent imperfect information models of business cycles differ from our analysis in that they do not consider information transmission via the price system.[7] Woodford (2003), applying the idea of rational inattention proposed by Sims (2003), considers an imperfect information environment where firms' pricing decisions are strategic complements. When firms receive private signals about aggregate demand, higher-order expectations enter pricing decisions as firms need to forecast each others' forecasts.[8] Due to private signals being less informative about other firms' signals than about the aggregate state, the aggregate price level responds to a nominal disturbance only slowly and gradually. Mankiw and Reis (2002) obtain similar aggregate price level dynamics by assuming that firms obtain information about the state of the economy only sporadically. Reis (2006) shows that such stochastic updating is optimal when firms are allowed to acquire costly information. In Maćkowiak and Wiederholt (2009), on the other hand, rationally inattentive firms decide how much attention to allocate to idiosyncratic and to aggregate shocks. Due to idiosyncratic conditions being relatively more variable, firms find it optimal to attend more closely to idiosyncratic than aggregate conditions. We show that learning from prices constitutes an endogenous channel which discourages firms from acquiring information about aggregate shocks. Thus, our analysis suggests that in a rational inattention model à la Maćkowiak and Wiederholt (2009), introducing learning from prices would further dampen incentives to

[7] Lorenzoni (2009) is an exception but his analysis pertains to an exogenous information structure and concerns the effects of shocks to expectations.

[8] The study of the problem of forecasting the forecasts of others goes back to Townsend (1983).

attend to aggregate conditions. More generally, our contribution to the literature on imperfect information and business cycles is a methodological one: we connect the earlier literature on the informational role of the price system with the more recent literature on information choice in macroeconomics and finance.

The results from our welfare analysis can be related to the literature on the social value of public information. In a seminal paper, Hirshleifer (1971) shows that the revelation of public information can reduce welfare by destroying risk-sharing opportunities in insurance markets. Morris and Shin (2002) propose an alternative mechanism through which the release of public information can decrease welfare. In a setting where agents have access also to private information, and the existence of a payoff externality gives rise to a coordination motive, more precise public information can lower welfare since agents, attempting to coordinate actions, put more weight on public information than what is socially optimal. Angeletos and Pavan (2007a) find conditions under which the dissemination of public information causes welfare losses in a setting with quadratic preferences. They demonstrate that the kind of externality assumed in the payoff structure is relevant for the resulting negative welfare effects. Angeletos and La'O (2012) study a business cycle model with a Dixit-Stiglitz demand structure and show that the endogeneity of learning through the equilibrium price system causes inefficiently little learning and too much noise in the business cycle. In comparison to the decentralized economy, a social planner would find it optimal to increase the sensitivity of allocations to private information and lower the sensitivity of allocations to public information. Amador and Weill (2010) use a micro-founded macroeconomic model to explore the effects of releasing public information in a setting with learning from prices and also private information. They show that the release of public information can lower welfare by negatively affecting the informational efficiency of the equilibrium price system. Amador and Weill (2012), building on Vives (1993, 1997), analyze a dynamic model of information diffusion where agents can learn from a public and a private channel. They show that more initial public information can reduce welfare in a setting where both channels are present, and agents are sufficiently patient. Our paper relates to this literature by illustrating another source of welfare losses in the presence of more information. In our model, an increase in the fraction of informed firms does not necessarily lead to higher welfare. The potential welfare loss arises from an increase in employment dispersion, which is inefficient as firms are ex ante identical.

Finally, our paper is also related to the recent literature on the sources of inefficiencies in information acquisition. We elaborate on this connection in detail in Section 6.2.2, after having discussed the mechanisms rendering information acquisition inefficient in our environment.

The rest of the paper is organized as follows. In the next section, we lay out the model environment, describe the information structure and the ordering of events. Section 3 defines and analyzes equilibrium of the model. In Section 4 we present our main results: countercyclicality of both demand for information and the informativeness of the price system. Section 5 studies the robustness of our results for different model specifications. Section 6 examines the role of learning from equilibrium wages, discusses welfare and examines whether U.S. data support an empirical implication of the model. Section 7 concludes.

2. Environment

Time is discrete and periods are indexed by $t \in \{0, 1, 2, \ldots\}$. In each period the state of the economy is described by $z_t \in \mathscr{Z} = \{\underline{z}, \overline{z}\}$, with $0 < \underline{z} < \overline{z}$.[9] The two possible states $\underline{z}$ and $\overline{z}$ reflect a low and a high level of aggregate technology and can be interpreted as a recession and a boom, respectively.[10] The evolu-

[9] Section 5.4 considers the case of a continuous state variable z_t.

[10] Although our environment also features an aggregate taste shock, we will restrict our attention to parameter values for which fluctuations in aggregate output are primarily driven by the

tion of the state z_t is governed by a Markov chain with time invariant transition probabilities. Let $\overline{\rho} = \mathbb{P}(z_{t+1} = \overline{z} \,|\, z_t = \overline{z})$ and $\underline{\rho} = \mathbb{P}(z_{t+1} = \underline{z} \,|\, z_t = \underline{z})$ denote the conditional probabilities of the economy prevailing in a boom and a recession, respectively, for two consecutive periods. Throughout the text we assume that the persistence parameters satisfy $(\underline{\rho}, \overline{\rho}) \in (\frac{1}{2}, 1)^2$, implying that given the previous period's state, the economy is more likely to remain in that same state than to transit to the other state.[11]

There is a measure-one continuum of ex ante identical firms, indexed by $i \in [0,1]$. Firm i produces output y_{it} employing labor h_{it}, taking as given the wage rate w_t. The firm's real profits in period t are given by

$$\Pi_{it} = y_{it} - w_t h_{it}. \tag{1}$$

The production technology of the firm exhibits diminishing returns to labor and is hit by an aggregate technology shock that depends on the state of the economy

$$y_{it} = z_t h_{it}^{\alpha}, \tag{2}$$

where $\alpha \in (0,1)$.

We introduce a representative household with preferences represented by the following period utility function defined over consumption and leisure

$$U(c_t, \ell_t) = c_t + \frac{\phi_t^{\gamma} \ell_t^{1-\gamma}}{1-\gamma}, \tag{3}$$

where $\phi_t \in \Phi = \left[\underline{\phi}, \overline{\phi}\right]$, features a positive-valued taste shock that is independent of the state z_t.[12] The distribution of ϕ is characterized by a log-concave

aggregate technology shock.

[11]This assumption is consistent with data for the U.S. economy. For NBER monthly data on business cycle expansions and contractions in the period from 1946:01 to 2013:12, maximum likelihood estimation of the conditional transition probabilities gives $\widehat{\overline{\rho}} = 0.9839$ and $\widehat{\underline{\rho}} = 0.9173$.

[12]We show in Section 5.4 that our main results do not hinge on the boundedness of the taste shock.

probability density $f(\phi)$.[13] The role of this aggregate supply shock, whose realization is known to the household but unknown to firms, is to introduce noise in the information revealed by the labor market clearing wage.[14] This is motivated by the fact that in the absence of unobservable noise in labor supply, a competitive rational expectations equilibrium with costly information acquisition would fail to exist.[15] Moreover, as we wish to concentrate on how equilibrium wages transmit information held by the firms rather than that of the household, we assume that consumption enters linearly in (3). Under that assumption, the household's labor supply schedule varies with the shock ϕ_t but remains unaffected by its belief about the state.[16] The household's endowment of time is normalized to unity, that is $\ell_t + h_t \leq 1$. Finally, the representative household owns all firms and finances its consumption expenditures from labor income and aggregate profits. The budget constraint therefore reads

$$c_t \leq w_t h_t + \int_0^1 \Pi_{it}\, \mathrm{d}i. \tag{4}$$

This concludes the description of the physical environment of the model. We now lay out the information structure of the economy and describe firms' learning rule together with the ordering of events.

[13]Log-concavity delivers monotonicity of learning from equilibrium wages. Many commonly used distributions, including the uniform, the normal and the negative exponential are log-concave.

[14]Technically, the introduction of unobservable noise in labor supply in our model serves the same purpose as the random asset supply assumption in Grossman and Stiglitz (1980) and many closely related papers, for instance Hellwig (1980), Diamond and Verrecchia (1981), Verrecchia (1982), Admati (1985), and more recently in Ganguli and Yang (2009) and Van Nieuwerburgh and Veldkamp (2009).

[15]Grossman and Stiglitz (1976) were the first to establish this insight in the context of a financial market.

[16]As we demonstrate in Section 5.5, our main findings obtain also in an environment where the household's utility is concave in consumption.

Information structure, learning, and ordering of events

In our model, the true state is a priori unknown to all firms by assumption.[17] However, firms are allowed to acquire a costly signal about the state prior to choosing their profit maximizing employment level. In addition to this costly and exogenous signal, the labor market clearing wage provides firms with another costless and endogenous signal about the current state. Whenever firms learn a new piece of information about the state, they update their belief in a Bayesian fashion. Since firms will hold different beliefs about the state within a single period, we distinguish between the following three stages.

Stage 1: Costly information acquisition. At the beginning of each period, before the opening of markets, the state $z_t \in \mathscr{Z}$ is drawn according to the Markov chain. Firms do not learn the true state. Instead, they enter the period with a common prior belief μ_t about the economy being in a boom, where $\mathbb{P}(z_t = \overline{z} \,|\, z_{t-1}) = \mu_t$ derives from the Markov chain.[18] Firms choose individually and simultaneously whether to refine their belief about the state by acquiring a symmetric binary signal $s_t \in \mathscr{S} = \{\underline{s}, \overline{s}\}$ with precision $q \in (1/2, 1]$, i.e.

$$q = \mathbb{P}(s_t = \underline{s} \,|\, z_t = \underline{z}) = \mathbb{P}(s_t = \overline{s} \,|\, z_t = \overline{z}). \tag{5}$$

The signal realization is the same for all firms.[19] Acquiring the signal involves a fixed cost $\kappa > 0$ that is equal across all firms and periods. Re-

[17]As alluded to, in the model we subject firms to imperfect information but maintain the assumption of a perfectly informed representative household. This approach is in line with the recent literature on informational frictions in macroeconomics, which also employs this assumption, see e.g. Mankiw and Reis (2002), Woodford (2003), Maćkowiak and Wiederholt (2009), and Angeletos and La'O (2012).

[18]The fact that firms share a common prior is not an assumption. At the end of each period they learn the true state perfectly by observing their own output in (2) and form a prior belief about the next period's state using their knowledge of the transition probabilities. This yields a common prior belief at the beginning of each period $t > 0$.

[19]Section 5.6 solves the model when the signals are drawn independently and firms can choose the precision of their signal.

selling purchased information is not permissible. Firms that pay κ to observe signal s_t update their belief to

$$\tilde{\mu}_t^I = \begin{cases} \frac{q\mu_t}{q\mu_t+(1-q)(1-\mu_t)} & \text{if } s_t = \overline{s}, \\ \frac{(1-q)\mu_t}{(1-q)\mu_t+q(1-\mu_t)} & \text{if } s_t = \underline{s}, \end{cases} \tag{6}$$

where the superscript I identifies firms that become informed. We let $\lambda_t \in [0,1]$ denote the fraction of firms that acquire the costly signal in stage 1 and hold the updated belief $\tilde{\mu}_t^I$. Accordingly, fraction $1-\lambda_t$ of firms choose not to observe signal s_t and keep their initial prior belief μ_t.[20]

Stage 2: Learning from the equilibrium wage. The labor market opens and firms enter with their belief about the state from stage 1. They maximize expected profits by choosing the optimal level of employment h_{it}. Firms take as given the real wage rate w_t and account for any information contained in the equilibrium wage about the state in their optimal labor demand. In particular, uninformed firms revise their stage 1 belief μ_t about the state to $\hat{\mu}_t^U$ upon observing the equilibrium real wage w_t. On the contrary, informed firms do not revise their belief $\tilde{\mu}_t^I$ from stage 1 as the equilibrium wage conveys information already held by the informed firms. The representative household privately learns the realization of the taste shock ϕ_t and forms its labor supply h_t^S to maximize expected period utility. The labor market clears.

Stage 3: End-of-period learning. Informed and uninformed firms produce outputs y_t^I and y_t^U according to their employment decisions from stage

[20]In the following, we will repeatedly refer to firms that acquire the costly signal as informed firms, and those firms refraining from costly information acquisition as uninformed firms. We use this terminology even though the equilibrium wage can contain information about the state and thus potentially allows also those firms that do not acquire the costly signal to become further informed.

2, and given the realized technology level from stage 1. The representative household chooses consumption, and the goods market clears. From observing their own output, firms can infer the true z_t perfectly. Next period's common prior belief μ_{t+1} obtains from perfect knowledge of z_t and the transition probabilities of the Markov chain

$$\mu_{t+1} = \begin{cases} \overline{\rho} & \text{if } z_t = \overline{z}, \\ 1-\underline{\rho} & \text{if } z_t = \underline{z}. \end{cases} \tag{7}$$

For notational convenience we define the set of possible prior beliefs as $\mathscr{M} = \{1-\underline{\rho}, \overline{\rho}\}$. As a consequence of perfect end-of-period learning, information in the form of the costly signal has value only in the current period. The information acquisition problem in stage 1 is therefore static, as are the household's and firms' optimization problems in stages 2 and 3.[21] To economize on notation we drop the time subscripts from the next section on.

3. Equilibrium

We solve the model backwards, starting from equilibrium in the labor market in stage 2, for a given fraction of informed firms.[22] Then, we solve the stage 1 information acquisition problem taking as given the distribution of equilibrium outcomes in the labor market.

We solve for the labor market equilibrium using rational expectations equilibrium (REE) under asymmetric information, based on the pioneering work of

[21] For reasons of tractability, the majority of models employed in the pertinent literature on informational frictions in macroeconomics, and in the closely related literature on the social value of public information feature a single-period learning problem. A notable exception is Amador and Weill (2012) whose continuous time baseline model builds on the discrete time environments in Vives (1993, 1997).

[22] Given that the household does not have access to a storage technology, goods market equilibrium in stage 3 is given by $\int y_i \, \mathrm{d}i - \lambda\kappa = c$.

Lucas (1972) and Green (1973).[23] This equilibrium concept accounts for learning from prices by imposing a consistency requirement on equilibrium beliefs. Namely, beliefs are required to be in line with the information contained in the observed equilibrium wage. We first characterize rational expectations equilibrium à la Lucas and Green in our model. Then, we explicitly solve for equilibrium under a parameter restriction, allowing us, in the next section, to analytically illustrate all the mechanisms present in our environment.

3.1. Labor market equilibrium

Labor demand and supply schedules are found by solving the household's and firms' maximization problems. The household solves its static utility maximization in two steps. First, in stage 2, it chooses how much labor to supply for a given wage and realization of taste shock, $h^S(w,\phi)$. Then, in stage 3, when labor income and profits are realized, it chooses consumption.

For $\lambda > 0$, the equilibrium wage can contain information about the signal s the informed firms acquired. Hence, uninformed firms update their belief using the information that may be contained in the equilibrium wage they observe. Letting $\hat{\mu}^U(w,\mu)$ to stand for this updated belief, an uninformed firm's profit maximization problem reads

$$\max_{h^U\geq 0}\left\{\hat{\mu}^U(w,\mu)\Pi(w,\overline{z},h^U)+(1-\hat{\mu}^U(w,\mu))\Pi(w,\underline{z},h^U)\right\}. \tag{8}$$

The resulting labor demand of an uninformed firm is denoted by $h^U(w,\hat{\mu}^U)$.

Informed firms maximize expected profits for a given wage, forming expectations with belief $\hat{\mu}^I(w,\mu,s)$.[24] That is, they solve

$$\max_{h^I\geq 0}\left\{\hat{\mu}^I(w,\mu,s)\Pi(w,\overline{z},h^I)+(1-\hat{\mu}^I(w,\mu,s))\Pi(w,\underline{z},h^I)\right\}, \tag{9}$$

[23] For surveys on extensions of rational expectations equilibrium to asymmetric information see Radner (1979) and Grossman (1981).

[24] Informed firms do not learn anything new from the equilibrium wage, but we still write their belief as a function of the wage to indicate that their belief is equally required to be consistent with the equilibrium wage as stated in (11). Moreover, this formulation allows us to use Definition 1 also in the extension with independently drawn signals.

yielding $h^I(w,\hat{\mu}^I)$, the labor demand of an informed firm. Having laid out the maximization problems of the agents, we can now define rational expectations equilibrium in the labor market.

Definition 1 (Rational expectations equilibrium in the labor market)**.** *Given a fraction of informed firms, $\lambda \in [0,1]$, rational expectations equilibrium in the labor market is a pair of demand schedules $h^U(w,\hat{\mu}^U)$ and $h^I(w,\hat{\mu}^I)$, a supply schedule $h^S(w,\phi)$ and a wage functional $\mathscr{W}_\lambda(\phi,\mu,s)$ such that for all $(\phi,\mu,s) \in \Phi \times \mathscr{M} \times \mathscr{S}$ and $w = \mathscr{W}_\lambda(\phi,\mu,s)$*

1. *$h^U(w,\hat{\mu}^U)$ and $h^I(w,\hat{\mu}^I)$ solve the uninformed and informed firm's profit maximization problem in* (8) *and* (9)*, respectively;*
2. *beliefs are consistent with the realized wage w*

$$\hat{\mu}^U(w,\mu) = \mathbb{P}(z = \overline{z} \mid w = \mathscr{W}_\lambda(\phi,\mu,s),\mu) \tag{10}$$

$$\hat{\mu}^I(w,\mu,s) = \mathbb{P}(z = \overline{z} \mid w = \mathscr{W}_\lambda(\phi,\mu,s),\mu,s) \tag{11}$$

3. *$h^S(w,\phi)$ solves the household's stage 2 problem;*
4. *labor market clears*

$$(1-\lambda)\,h^U(w,\hat{\mu}^U) + \lambda\, h^I(w,\hat{\mu}^I) = h^S(w,\phi). \tag{12}$$

Note that we impose the plausible restriction that the equilibrium wage cannot contain information about the state of the economy beyond the signal received by the informed firms. The following lemma establishes a noteworthy characteristic of the labor market equilibrium. Namely, due to the combination of bounded taste shocks and binary noisy signals, an equilibrium wage can fully reveal the signal of the informed firms.[25]

Lemma 1 (Fully revealing wages)**.** *A rational expectations wage in the labor market can fully reveal the signal s of the informed firms.*

[25] The conditions under which an equilibrium wage is fully revealing are provided by (A.6) and (A.7) in the proof of Lemma 1.

Proof. See Appendix A, page A-1. □

The proof of Lemma 1 reveals that, for $\lambda = 1$ and $q = 1$, aggregate output is higher for all realizations of the taste shock when $z_t = \overline{z}$ than when $z_t = \underline{z}$ if the following inequality holds[26]

$$\overline{z}\left(\frac{\overline{z}}{\mathscr{W}_{\lambda=1}(\overline{\phi},\overline{s})}\right)^{\frac{\alpha}{1-\alpha}} > \underline{z}\left(\frac{\underline{z}}{\mathscr{W}_{\lambda=1}(\underline{\phi},\underline{s})}\right)^{\frac{\alpha}{1-\alpha}}. \tag{13}$$

We confine attention to parameters satisfying this restriction, allowing us to interpret periods when the aggregate technology shock is high as booms and periods of low aggregate technology shock as recessions. This restriction ensures that the two shocks in the model serve different purposes. On the one hand, fluctuations in output are primarily accounted for by changes in productivity, as in a standard real business cycle model. On the other hand, the taste shock introduces noise to equilibrium wages, rather than driving the business cycle. We formulate the restriction under the condition that all firms obtain a perfectly revealing signal as we wish to separate the technology shock from the taste shock regarding its impact on changes in aggregate output, while at the same time abstracting from fluctuations arising from the noisiness of the informative signal and from learning from wages. Alternatively, imposing the stronger restriction that requires output to be higher for $z_t = \overline{z}$ than for $z_t = \underline{z}$ not only for all realizations of the taste shock but also for all realizations of the informative signal and any fraction of informed firms is feasible, but would further limit the support of the taste shock.

To further characterize labor market equilibrium, we next state the consistency requirement of the belief of the uninformed firms for non-fully revealing

[26]We state this restriction in terms of the equilibrium wage for the reason that the wage does not generally admit a closed-form solution. However, note that to check this condition, one does not need to solve for the belief of the uninformed firms as $\lambda = 1$. Similarly, the prior belief μ does not feature in the restriction and has been suppressed as an argument of the wage functional due to $q = 1$.

wages.[27]

Lemma 2 (Belief of uninformed firms for non-fully revealing wages)**.** *For non-fully revealing wages, the belief of the uninformed firms satisfies*

$$\frac{q\hat{\mu}^U(w)+(1-q)(1-\hat{\mu}^U(w))}{(1-q)\hat{\mu}^U(w)+q(1-\hat{\mu}^U(w))}=\frac{|\phi_w(w,\overline{s})|f(\phi(w,\overline{s}))}{|\phi_w(w,\underline{s})|f(\phi(w,\underline{s}))}\frac{q\mu+(1-q)(1-\mu)}{(1-q)\mu+q(1-\mu)}, \quad (14)$$

where

$$\phi(w,s)=w^{\frac{1}{\gamma}}-w^{\frac{1-\alpha-\gamma}{(1-\alpha)\gamma}}\alpha^{\frac{1}{1-\alpha}}\left[(1-\lambda)\mathbb{E}[z\mid w]^{\frac{1}{1-\alpha}}+\lambda\mathbb{E}[z\mid s]^{\frac{1}{1-\alpha}}\right], \quad (15)$$

$$\phi_w(w,s)=\frac{1}{\gamma}w^{\frac{1-\gamma}{\gamma}}-\frac{1-\alpha-\gamma}{(1-\alpha)\gamma}w^{\frac{(1-\alpha)(1-\gamma)-\gamma}{(1-\alpha)\gamma}}\alpha^{\frac{1}{1-\alpha}}\left[(1-\lambda)\mathbb{E}[z\mid w]^{\frac{1}{1-\alpha}}+\lambda\mathbb{E}[z\mid s]^{\frac{1}{1-\alpha}}\right]$$
$$-\hat{\mu}^U_w(w)(\overline{z}-\underline{z})(1-\lambda)\mathbb{E}[z\mid w]^{\frac{\alpha}{1-\alpha}}w^{\frac{1-\alpha-\gamma}{(1-\alpha)\gamma}}\frac{\alpha^{\frac{1}{1-\alpha}}}{1-\alpha} \quad (16)$$

Proof. See Appendix A, page A-2. □

Note from the characterization in Lemma 2 that for $\gamma=1-\alpha$, the belief of the uninformed firms does not depend on $\hat{\mu}^U_w(w)$. Therefore, in this case, one can solve for $\hat{\mu}^U$ from (14). Given that imposing the restriction $\gamma=1-\alpha$ does not suppress any mechanism present in our environment, we will proceed by characterizing equilibrium in this case.

Under the parameter restriction $\gamma=1-\alpha$, Lemmas 1 and 2 enable us to arrive at the equilibrium wage functional constructively. Here, our model differs from Grossman-Stiglitz type models, which typically rely on guess-and-verify. Moreover, we can establish the uniqueness of equilibrium.

Proposition 1 (Unique labor market equilibrium)**.** *For $\gamma=1-\alpha$, the unique*

[27]The taste shock ϕ is written to be a function of the wage and the informative signal as ϕ is unknown to the uninformed firms when they form their equilibrium belief. Consequently, the uninformed firms need to compute the possible realizations of the taste shock which can support a given equilibrium wage.

equilibrium wage functional is given by

$$\mathscr{W}_\lambda(\phi,\mu,\underline{s}) = \begin{cases} \left(\phi + \alpha^{\frac{1}{1-\alpha}}\mathbb{E}[z\,|\,\underline{s}]^{\frac{1}{1-\alpha}}\right)^{1-\alpha} & \textit{if } \phi < \phi^* \\ \left(\phi + \alpha^{\frac{1}{1-\alpha}}\left[(1-\lambda)\mathbb{E}[z\,|\,\hat{\mu}^U(\phi,\underline{s})]^{\frac{1}{1-\alpha}} + \lambda\mathbb{E}[z\,|\,\underline{s}]^{\frac{1}{1-\alpha}}\right]\right)^{1-\alpha} & \textit{if } \phi \geq \phi^* \end{cases} \tag{17}$$

$$\mathscr{W}_\lambda(\phi,\mu,\overline{s}) = \begin{cases} \left(\phi + \alpha^{\frac{1}{1-\alpha}}\left[(1-\lambda)\mathbb{E}[z\,|\,\hat{\mu}^U(\phi,\overline{s})]^{\frac{1}{1-\alpha}} + \lambda\mathbb{E}[z\,|\,\overline{s}]^{\frac{1}{1-\alpha}}\right]\right)^{1-\alpha} & \textit{if } \phi \leq \phi^{**} \\ \left(\phi + \alpha^{\frac{1}{1-\alpha}}\mathbb{E}[z\,|\,\overline{s}]^{\frac{1}{1-\alpha}}\right)^{1-\alpha} & \textit{if } \phi > \phi^{**}, \end{cases} \tag{18}$$

where

$$\phi^* = \underline{\phi} + \alpha^{\frac{1}{1-\alpha}}\lambda\left(\mathbb{E}[z\,|\,\overline{s}]^{\frac{1}{1-\alpha}} - \mathbb{E}[z\,|\,\underline{s}]^{\frac{1}{1-\alpha}}\right) \tag{19}$$

$$\phi^{**} = \overline{\phi} - \alpha^{\frac{1}{1-\alpha}}\lambda\left(\mathbb{E}[z\,|\,\overline{s}]^{\frac{1}{1-\alpha}} - \mathbb{E}[z\,|\,\underline{s}]^{\frac{1}{1-\alpha}}\right). \tag{20}$$

and $\hat{\mu}^U(\phi,s)$ *satisfy* (A.13), (A.14), (A.15) *and* (A.16) *in Appendix A.*

Proof. See Appendix A, page A-2. □

The taste shock ϕ^* is the lowest taste shock for which a non-fully revealing wage obtains when the signal realization is low. Similarly, ϕ^{**} is the highest taste shock supporting a non-fully revealing wage for the high signal realization. Given that the equilibrium wage is increasing in the taste shock and in the informed firms' belief about the state, a sufficiently low taste shock yields an equilibrium wage which can only obtain when the signal is low. Hence, such a wage reveals the realization of the signal. Analogously, when the signal realization is high, for a sufficiently high taste shock, the equilibrium wage exceeds the highest non-fully revealing wage $\mathscr{W}_\lambda(\overline{\phi},\mu,\underline{s})$, also supported by the low signal realisation. Thus, the highest and the lowest equilibrium wages are fully revealing. It is also worth noting that when $\phi^* \geq \overline{\phi}$ and $\phi^{**} \leq \underline{\phi}$, all equilibrium wages are fully revealing.

Equations (19) and (20) show that the set of taste shocks for which a non-fully revealing wage obtains shrinks when the fraction of informed firms λ increases. This is due to the stronger dependence of the equilibrium wage on the demand of the informed firms, increasing the distance between the two taste shocks for which a given wage can obtain for both of the signal realizations. Consequently, as we demonstrate in the next section, an increase in the fraction of informed firms raises the probability of observing a fully revealing wage.

3.2. Information acquisition equilibrium

Equipped with a REE wage functional, we can solve a firm's information acquisition problem in stage 1. A firm will acquire information at cost κ if the expected profit of an informed firm exceeds that of an uninformed firm by more than κ. Letting $G(\lambda) = \mathbb{E}[\Pi^I(w,\lambda)|\mu] - \kappa - \mathbb{E}[\Pi^U(w,\lambda)|\mu]$[28] to denote the expected gain from becoming informed, we define stage 1 equilibrium as follows.

Definition 2 (Information acquisition equilibrium)**.** *Information acquisition equilibrium is a fraction of informed firms λ^* such that*

$$\lambda^* = \begin{cases} 0 & \text{if } G(0) < 0 \\ 1 & \text{if } G(1) > 0 \\ \lambda^* \in [0,1] & \text{if } G(\lambda^*) = 0. \end{cases} \tag{21}$$

A sufficient condition for the equilibrium fraction of informed firms to be unique is that the expected gain from becoming informed, $G(\lambda)$, is strictly decreasing in λ, i.e. information acquisition exhibits strategic substitutability.

4. Demand for information and learning from prices

In this section, we exhibit the main mechanisms operating in our environment. We do so by considering a baseline model which can be solved analytically.

[28] $\Pi(\cdot,\cdot)$ represents labor market equilibrium profit.

Definition 3 (Baseline model)**.** *The baseline model satisfies*

$$\gamma = 1 - \alpha, \forall \alpha \in (0,1) \tag{22}$$

$$\phi \sim \mathscr{U}[\underline{\phi}, \overline{\phi}]. \tag{23}$$

Assuming that $\gamma = 1-\alpha$ ensures that the endogenous signal provided by the equilibrium wage is additively separable in the informed firms' expectation of the state z and in the noise ϕ. On the other hand, uniformly distributed noise renders non-fully revealing wages completely uninformative.[29] In the next section, we show that the mechanisms proved here remain to operate when these assumptions are relaxed. We first show that, as in Grossman and Stiglitz (1980), information acquisition exhibits strategic substitutability. Then, we specify conditions under which demand for information is countercyclical. That is, firms have a stronger incentive to acquire information when the economy has been in a recession in the previous period, and firms hold a pessimistic belief about the economy being in a boom than after a boom when firms share an optimistic belief. Countercyclical information demand, in turn, implies that the price system is more informative when firms have a pessimistic belief than for an optimistic belief.

Before proving strategic substitutability in information acquisition, we show that in the baseline model, non-fully revealing wages are completely uninformative about s.

Lemma 3 ("All-or-nothing" learning from REE wages)**.** *In the baseline model, non-fully revealing wages are completely uninformative about s.*

Proof. See Appendix A, page A-3. □

[29]We thank an anonymous referee for pointing out that the assumption of uniform noise shocks to render equilibrium analysis of information revelation more tractable appears also in Guerrieri and Kondor (2012). In their asset pricing model three possible regimes of information revelation can arise in equilibrium. There are two regimes with fully revealing bond prices, and one in which bond prices do not reveal any information. This is akin to the "All-or-nothing" learning from REE wages in our baseline model, see Lemma 3.

Having solved for the beliefs of the uninformed firms, we can analyze the gain from acquiring the informative signal.

Proposition 2 (Strategic substitutability in information acquisition)**.** *In the baseline model, the expected gain from becoming informed is strictly decreasing in the fraction of informed firms for all $\lambda < \bar{\lambda}$, where*

$$\bar{\lambda} = \frac{\overline{\phi} - \underline{\phi}}{\alpha^{\frac{1}{1-\alpha}} \left(\mathbb{E}[z \mid \overline{s}]^{\frac{1}{1-\alpha}} - \mathbb{E}[z \mid \underline{s}]^{\frac{1}{1-\alpha}} \right)}. \tag{24}$$

Proof. See Appendix A, page A-3. □

In our model, strategic substitutability in information acquisition arises from an information externality due to rational expectations equilibrium wages transmitting information, similar to the information externality arising from the rational expectations equilibrium asset price transmitting information from informed to uninformed investors in Grossman and Stiglitz (1980). As more firms acquire the costly signal and become informed about the economy's state, the price system becomes more informative as measured by the probability of observing an informative wage. As a consequence, an individual firm's incentive to acquire the costly signal is reduced. Hence, the expected gain of becoming informed decreases in the fraction of informed firms as long as not all equilibrium wages are fully revealing. This is guaranteed by the condition $\lambda < \bar{\lambda}$.

We now turn to characterizing firms' information demand, and the informativeness of the price system. In what follows, we consider an environment with symmetric transition probabilities, i.e. $\underline{\rho} = \overline{\rho} = \rho$. This implies that when the economy has been in a boom in the previous period, firms' prior belief μ is equal to ρ. On the other hand, when the economy has been in a recession in the previous period, $\mu = 1 - \rho$. Consequently, firms' uncertainty about the state z, as measured by entropy, exhibits no cyclicality. This allows us to focus on how firms' technology and equilibrium wages affect information demand.

Proposition 3 (Countercyclical information demand)**.** *In the baseline model, when $\alpha < 1/2$, the expected gain from becoming informed is higher for the low prior belief $\mu = 1-\rho$ than for the symmetric high prior belief $\mu = \rho$ for all $\rho \in (1/2, 1)$ and $\lambda < \bar{\lambda}(1-\rho)$, where*

$$\bar{\lambda}(\mu) = \frac{\overline{\phi} - \underline{\phi}}{\alpha^{\frac{1}{1-\alpha}} \left(\mathbb{E}[z \mid \overline{s}, \mu]^{\frac{1}{1-\alpha}} - \mathbb{E}[z \mid \underline{s}, \mu]^{\frac{1}{1-\alpha}} \right)}. \tag{25}$$

Proof. See Appendix A, page A-5. □

To understand the mechanisms behind countercyclical information demand, consider the expected profit of a firm for a given wage,

$$\mathbb{E}[\Pi^J \mid w, \mu] = (1-\alpha)\alpha^{\frac{\alpha}{1-\alpha}} \left(\frac{1}{w}\right)^{\frac{\alpha}{1-\alpha}} \mathbb{E}[z \mid \hat{\mu}^J(\cdot)]^{\frac{1}{1-\alpha}}, \tag{26}$$

where $J \in \{I, U\}$. Integrating $\mathbb{E}[\Pi^I \mid w]$−$\mathbb{E}[\Pi^U \mid w]$−κ over uninformative wages yields the expected gain from becoming informed,[30]

$$G(\lambda) = \overbrace{\alpha^{\frac{\alpha}{1-\alpha}} \left[\mathbb{P}(s = \overline{s})\mathbb{E}[z \mid \overline{s}, \mu]^{\frac{1}{1-\alpha}} + \mathbb{P}(s = \underline{s})\mathbb{E}[z \mid \underline{s}, \mu]^{\frac{1}{1-\alpha}} - \mathbb{E}[z \mid \mu]^{\frac{1}{1-\alpha}} \right]}^{(1)} \overbrace{\left(\frac{\overline{w} - \underline{w}}{\overline{\phi} - \underline{\phi}} \right)}^{(2)} - \kappa, \tag{27}$$

where $\underline{w}$ and $\overline{w}$ denote the lowest and the highest uninformative wage, respectively. The first term in (27) represents the difference in the expected profits of informed and uninformed firms for a given, uninformative wage. This difference is illustrated for two different prior beliefs in Figure 1. The expected gain from acquiring information for a given wage $\mathbb{E}[\Pi^I - \Pi^U \mid w, \mu]$ is lower for the high prior belief μ_h than for the low prior belief μ_l as the curvature of the expected profit function is decreasing in the prior belief. Due to the convexity of the expected profit function, its curvature is decreasing in the prior belief when $\partial^3 \mathbb{E}[\Pi^U \mid w]/\partial \mu^3 < 0$, which holds for $\alpha < 1/2$.

[30] See the proof of Proposition 2, in Appendix A, for a complete derivation.

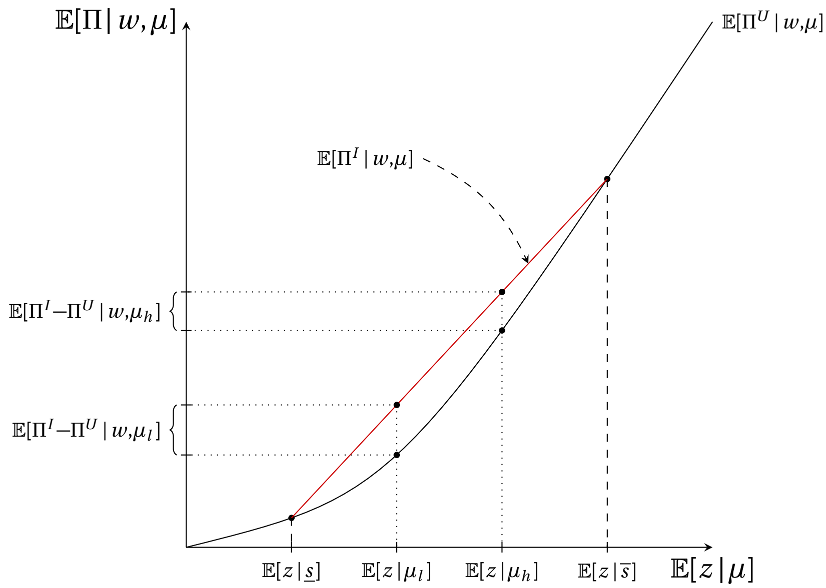

Figure 1: The expected gain for a given wage from acquiring a perfectly revealing signal for two different prior beliefs.

The second term in (27) can be decomposed as follows[31]

$$\frac{\overline{w}-\underline{w}}{\overline{\phi}-\underline{\phi}} = (1-\alpha)\overbrace{\mathbb{E}\left[\left(\frac{1}{w}\right)^{\frac{\alpha}{1-\alpha}} \,\middle|\, w \in [\underline{w}, \overline{w}]\right]}^{(2a)} \overbrace{\mathbb{P}(w \in [\underline{w}, \overline{w}])}^{(2b)}. \tag{28}$$

The term labeled (2a) captures the effect of the equilibrium wage on the expected gain from acquiring information whereas (2b), the probability of observing an uninformative wage, summarizes the information content of equilibrium wages. Appendix A shows that both of these two terms are higher for the low prior belief $1-\rho$ than for the symmetric high prior belief ρ. Equilibrium wages are increasing in the prior belief μ and as a consequence (2a) is decreasing in μ. The probability of observing an uninformative wage, (2b), on the other hand, is lower for the high prior belief due to the effect of the

[31]We thank an anonymous referee for suggesting this decomposition.

prior belief on the demand schedule of the informed firms. As shown in Appendix A, an informed firm's demand is proportional to $\mathbb{E}[z\,|\,s,\mu]^{\frac{1}{1-\alpha}}$. Given that $\mathbb{E}[z\,|\,\overline{s},\mu]^{\frac{1}{1-\alpha}} - \mathbb{E}[z\,|\,\underline{s},\mu]^{\frac{1}{1-\alpha}}$ is higher for the high than the low prior belief, the informed firms' demand schedules for the two signal realizations are further apart from each other when the prior belief is high. Consequently, the equilibrium wages respond more to the signal of the informed firms, lowering the probability of observing an uninformative wage. However, it should be noted that, when the signal is perfectly revealing, (2b) is independent of the prior belief as the informed firms' demand no longer depends on their prior belief.

In sum, countercyclical demand for information in the baseline model arises from three effects. First, when $\alpha < 1/2$, the slope of firms' expected profit function is concave in their belief about the state of the economy. Thus, acquiring the costly signal is less valuable when the prior belief is high. Second, firms' profits and and as a consequence the expected gain from acquiring the costly signal are decreasing in the equilibrium wage. Due to the procyclicality of wages, the incentives for information acquisition are weaker in booms. Third, informed firms' demand responds more strongly to the informative signal when the prior belief is high. Consequently, for a given fraction of informed firms, equilibrium wages are more informative in booms, lowering the expected gain from acquiring information when firms hold the high prior belief.

It is important to note that the condition $\alpha < 1/2$ is not a necessary condition of information demand to be countercyclical. When $\alpha > 1/2$, the effect of the equilibrium wage still favors countercyclical information demand and can dominate the opposing force arising from the shape of firms' expected profit function. As illustrated in the next section, this is indeed the case for a wide range of parameter values.

At this point it is worth relating our finding of countercyclicality of information demand to Vives (2014b), in which it is argued that traders have incentives to purchase less precise information in crises. In Vives (2014b) traders' information demand is decreasing in the correlation of their valuations and in their transaction cost. Due to crises being thought of as a scenario in which the correlations of traders' valuations and their transaction costs increase, one should observe less information acquisition in a crisis situation. In our environment, mechanisms similar to those in Vives (2014b) are at work. More specifically, firms' information demand is decreasing in the equilibrium wage and in the informativeness of equilibrium wages. These two endogenous objects can be seen as comparable to the correlation of traders' valuation and their transaction cost in Vives (2014b) for the following reasons. First, when the correlation of traders' valuation increases in Vives (2014b), the equilibrium price is more informative about a trader's private valuation. This is similar to a more informative equilibrium wage in our setting. Second, a higher transaction cost in Vives (2014b) limits the scope of the traders to increase their profits by acquiring information. Analogously, a higher equilibrium wage in our environment leads to a lower expected gain from acquiring information. Since, for a given fraction of informed firms, equilibrium wages are lower and less informative in recessions than in booms, we find that firms' information demand is countercyclical rather than low in crises as in Vives (2014b).

Countercyclical information demand implies that, given an interior solution for λ^*, the fraction of informed firms is higher for the pessimistic belief than for the optimistic belief. This, in turn, raises the probability of observing a fully revealing wage for the low prior belief relative to that for the high prior belief. Despite wages being more informative for the high than the low prior belief for a given fraction of informed firms, we further find that in equilibrium the probability of observing a fully revealing wage is higher when the low prior belief prevails than when the prior belief is high. That is, measuring the informativeness of equilibrium wages with the probability of observing a fully revealing wage, we have the following.

Corollary 1 (Countercyclical informativeness of equilibrium wages)**.** *At an in-*

terior solution for the equilibrium fraction of informed firms, equilibrium wages in the baseline model with $\alpha < 1/2$ are more informative when the low prior belief $1-\rho$ prevails than when the symmetric high prior belief ρ prevails.

Proof. See Appendix A, page A-5. □

5. Robustness

In this section, we investigate the robustness of the countercyclicality of information demand when departing from the baseline model. To that end, we consider variants of the general model featuring (i) asymmetric transition probabilities, (ii) unrestricted labor supply elasticity, (iii) a non-uniform distribution of taste shocks, (iv) a continuous technology level, (v) a utility function concave in consumption and (vi) independently drawn signals.[32] In addition, we examine the sensitivity of firms' incentives to acquire information to changes in the parameters of the baseline model.

In order to establish a benchmark, we illustrate the countercyclicality of information demand in the baseline model for symmetric transition probabilities. We set $\rho = 0.9233$, obtained by estimating the persistence of U.S. expansions and contractions, as defined by the NBER business cycle dating committee, in the period 1946:01–2013:12 under the restriction that the transition probabilities are symmetric. Moreover, we normalize $\underline{z} = 1$, set $q = 1$ and the other parameters such that average labor input is one third of the unitary time endowment and the variances of productivity and employment match those in the U.S. data.[33] The resulting gross gain functions are plotted in Figure 2.[34]

[32] Appendix B describes how the model can be solved when equilibrium is not characterized by Proposition 1.

[33] We use data on total hours worked from the BLS (HOANBS) and the TFP data described in Section 6.3. The moments are matched when $\alpha = 2/3$ and all firms are uninformed.

[34] The expected gain here and in the subsequent figures is plotted relative to the average per-period profit of an uninformed firm, calculated at $\lambda = 0$ and averaged over the two states using the stationary distribution.

One observes that firms' information demand is countercyclical for $\alpha \leq 1/2$ and essentially acyclical for higher values of α.

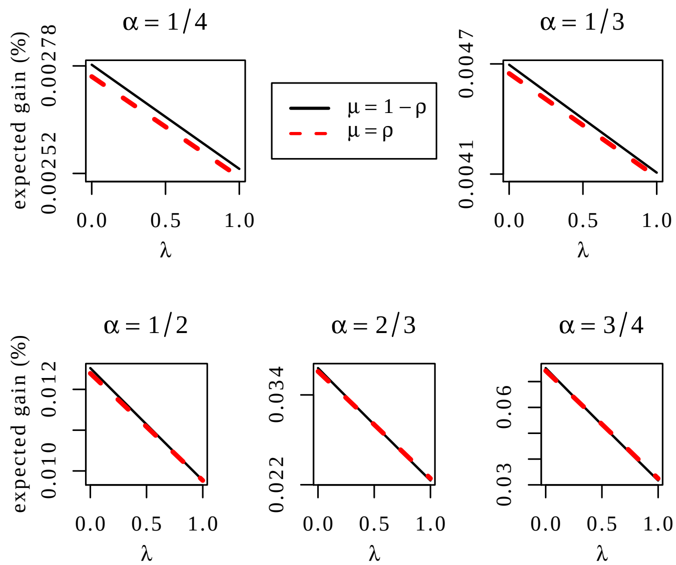

Figure 2: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for symmetric transition probabilities.

5.1. Asymmetric transition probabilities

We first study the baseline model when transition probabilities are asymmetric. More specifically, we consider the empirically plausible case of booms being more persistent than recessions. This implies that firms' prior uncertainty about the state is higher when the economy has been in a recession than when it has been in a boom.

Figure 3 illustrates the expected gain from acquiring information when booms are more persistent than recessions.[35]

[35]The parameter values are the same as in Figure 2 apart from $\underline{\rho} = 0.7719$ and $\overline{\rho} = 0.9525$, matching the persistence of U.S. expansions and contractions in the period 1946:01–2013:12

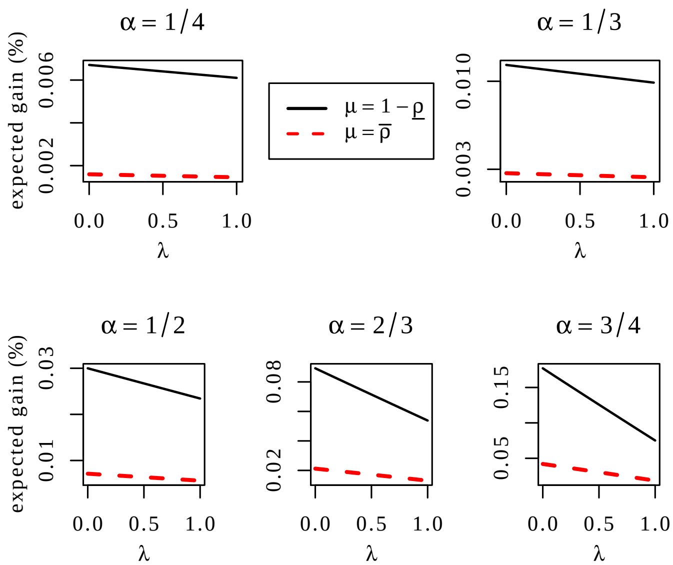

Figure 3: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for asymmetric transition probabilities.

The effect of asymmetric transition probabilities on the expected gain of acquiring information can be seen by comparing Figures 2 and 3. In the model illustrated in Figure 3 booms are more persistent and recessions less persistent than in the model of Figure 2 whereas all the other parameters take identical values. One sees that the demand for information is more countercyclical in the model with asymmetric transition probabilities. Moreover, firms have a stronger incentive to acquire the costly signal in recessions than in booms even for $\alpha > 1/2$. The stronger countercyclicality arises from higher prior uncertainty about the state when the economy has been in a recession than following a boom. This is a mechanism not present in the baseline model with symmetric transition probabilities, which strengthens the countercyclicality of information demand.[36]

5.2. *Unrestricted labor supply elasticity*

Let us next relax the parameter restriction $\gamma = 1 - \alpha$. More specifically, we vary the parameter α while keeping constant the parameter γ, which determines labor supply elasticity. Figures 4 and 5 illustrate the results of this exercise.[37] In the case of high labor supply elasticity, $\gamma = 1/5$, information demand can be procyclical even when $\alpha \leq 1/2$. Inspecting Lemma 2 reveals that this is due the belief of the uninformed firms being lower than the prior belief for all non-fully revealing wages, i.e. $\hat{\mu}^U(w) < \mu$. Consequently, receiving the low signal alters a firm's belief less than in the baseline model. Given that the low signal is more likely to obtain when the prior belief is low, firms have weaker incentives to acquire information in recessions.

A reverse mechanism operates when the elasticity of labor supply is low, illustrated in Figure 5. That is, the belief of the uninformed firms is higher than the prior belief for all non-fully revealing wages. Thus, the difference between the beliefs of an informed and an uninformed firm is lower than in the baseline model when the signal is high. As the informed firms are more likely to receive a high signal when the prior belief is high, firms incentives to acquire information in booms are moderated. For this reason, in the case of low labor supply elasticity, information demand is countercyclical also when $\alpha \geq 1/2$.

5.3. *Non-uniform taste shock*

To explore the implications of departing from the assumption of uniformly distributed taste shock, we let ϕ follow a Beta distribution in Φ. Figure 6 illustrates the expected gain when ϕ follows a Beta(2,2) distribution.[38] The distribution of the taste shock affects the informational content of non-fully re-

[36] Appendix C shows that information demand is countercyclical in all the model variants considered in the rest of this section when booms are more persistent than recessions.

[37] Parameters other than γ take the same values as in Figure 2.

[38] Parameters values are as in Figure 2.

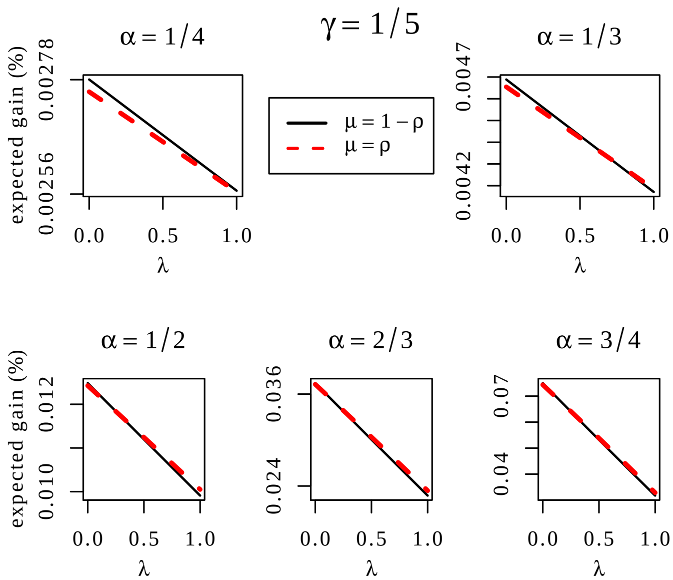

Figure 4: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for high labor supply elasticity.

vealing wages, manifesting itself in the shapes of the expected gain functions. It is also worth noting that information demand is countercyclical under this alternative distribution of taste shocks also for $\alpha \geq 1/2$.

5.4. Continuous technology level

To investigate firms' incentives to acquire information when the aggregate technology level is continuous, we let both z and ϕ follow gamma distributions. Instead of explicitly modeling the evolution of z_t over time, we specify two gamma distributions, one capturing firms' prior uncertainty about z following a recession and the other one after a boom. The parameters of these distributions are set to match the firms' prior expectation and entropy of z in the two states of the baseline model with symmetric transition probabilities. Similarly, the gamma distribution of ϕ is parameterized to have the same mean and entropy as the uniform distribution in the model of Figure 2. The resulting expected gain functions are shown in Figure 7. Compared to the baseline

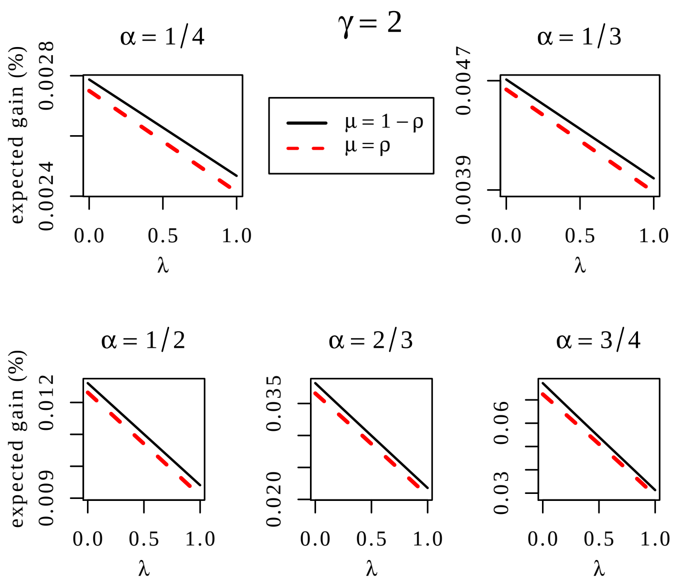

Figure 5: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for low labor supply elasticity.

model, there are two main differences. First, strategic substitutability in information acquisition is stronger than in the baseline model. This arises from the relatively sharply peaked distribution of the noise ϕ, facilitating learning from equilibrium wages. Second, firms value the signal more than in the baseline model. This shows that the modest expected gain from becoming informed in the baseline model partly derives from the aggregate technology level being binary.

5.5. Utility concave in consumption

Let us consider a model variant featuring a utility function concave both in leisure and consumption. More specifically, we let the representative household's preferences be represented by

$$U(c_t, \ell_t) = \log c_t + \phi_t \log \ell_t. \tag{29}$$

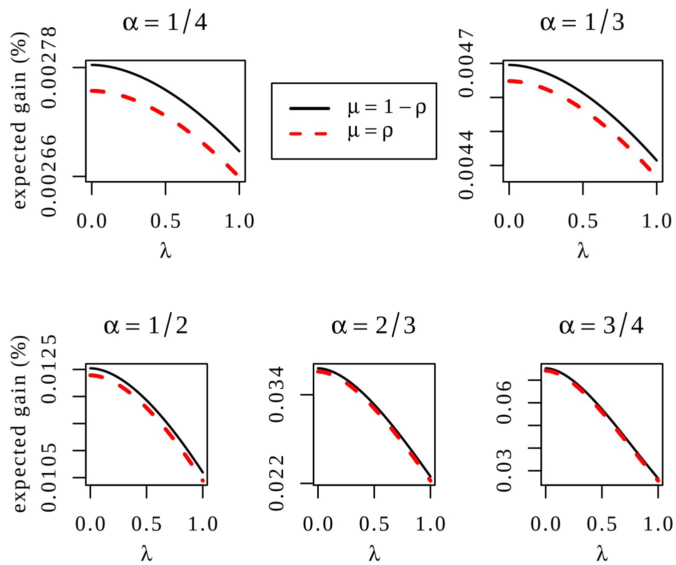

Figure 6: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for non-uniform taste shock.

Under this specification of utility, the household's labor supply also depends on its expectation of the firms' profits. Note however that given that the household knows the realization of the taste shock, it can infer the signal of the informed firms from the equilibrium wage. This in turn implies that the equilibrium wage reflects information about the signal from both the supply schedule of the household and the demand schedules of the informed firms. Figure 8 shows that procyclical information demand can arise in this model variant.[39] This results from two new effects. In booms, when expected consumption is high, the household's labor supply, given by (B.9), varies more with the taste shock. Consequently, the information contained in equilibrium wages is noisier. Moreover, by (B.12), uninformed firms' belief about the state falls when a non-fully revealing equilibrium wages obtains. This lowers the difference be-

[39] Parameters other than γ take the same values as in Figure 2.

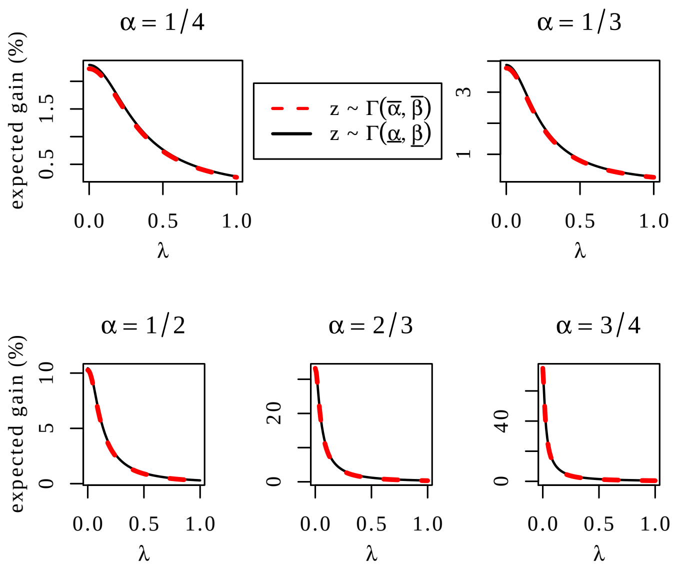

Figure 7: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for continuous technology level.

tween the profit of an informed and an uninformed firm when the prior belief is low but raises it when the prior belief is high, as can be seen from Figure 1. As a result of these two effects, firms' incentives to acquire information become less countercyclical.

Moreover, due to information being imputed to equilibrium wages not only by informed firms but also by the representative household, this variant features stronger strategic substitutability in information acquisition than the baseline model. This can be seen from the expected gain functions having steeper slopes in Figure 8 than in Figure 2.

5.6. Independently drawn signals

Next, we solve the model when firms can choose the precision of their signals and signals are conditionally independent. To facilitate comparison with the other model variants, we consider the expected gain to a firm from acquiring a perfectly revealing signal when all other firms acquire a signal of preci-

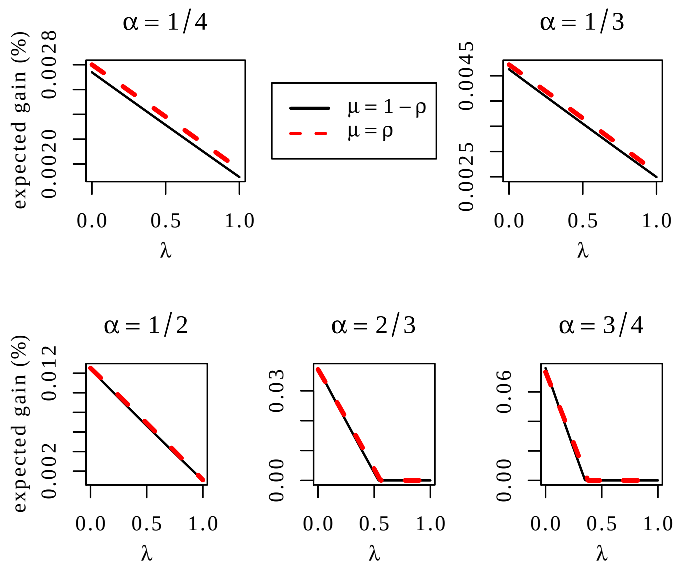

Figure 8: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for utility concave in consumption.

sion q. Then, to illustrate the effect of strategic substitutability, we plot this expected gain as a function of q. That is, in this model variant, the precision of the signal acquired by all other firms q is comparable to the fraction of firms acquiring a perfectly revealing signal λ in the other variants. We obtain the results shown in Figure 9.[40] This variant is characterized by weaker strategic substitutability than the baseline model illustrated in Figure 3. This is due to the fact that the informativeness of equilibrium wages increases faster when a larger fraction of firms acquire perfectly revealing signals than when all firms receive signals of higher precision.

5.7. *Parameters of the baseline model*

Finally, we consider how firms' incentives to acquire information vary with parameters of the baseline model other than the persistence of the two states.

[40]Parameters values are as in Figure 3.

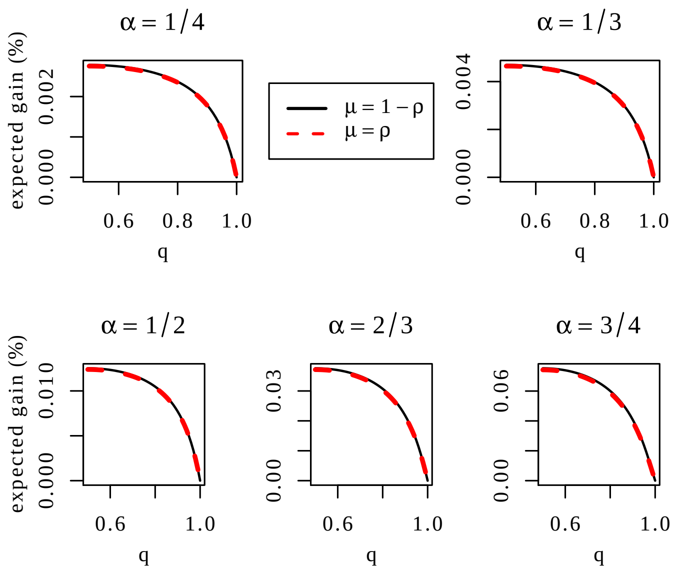

Figure 9: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for independently drawn signals.

First, we study the sensitivity of information demand to a change in the productivity gap between booms and recessions. Second, we investigate the effect of varying the difference between the highest and the lowest taste shock. Third, we discuss how changes in the cost of information influence information demand.

Figure 10 illustrates firms' information demand when the productivity gap between booms and recessions $\overline{z}-\underline{z}$ is higher than in the baseline model in Figure 2.[41] One notes that strategic substitutability in information acquisition is stronger than in the baseline model illustrated in Figure 2. This results from an increase in the variance of productivity. Consequently, informed firms' demand varies more strongly across the two signals, leading to more informative equilibrium wages. Moreover, firms value the informative signal more than in

[41]More specifically, $\overline{z}-\underline{z}$ is 35 per cent higher than in the baseline model in Figure 2.

the model of Figure 2, as evidenced by the higher levels of the expected gain functions in Figure 10.

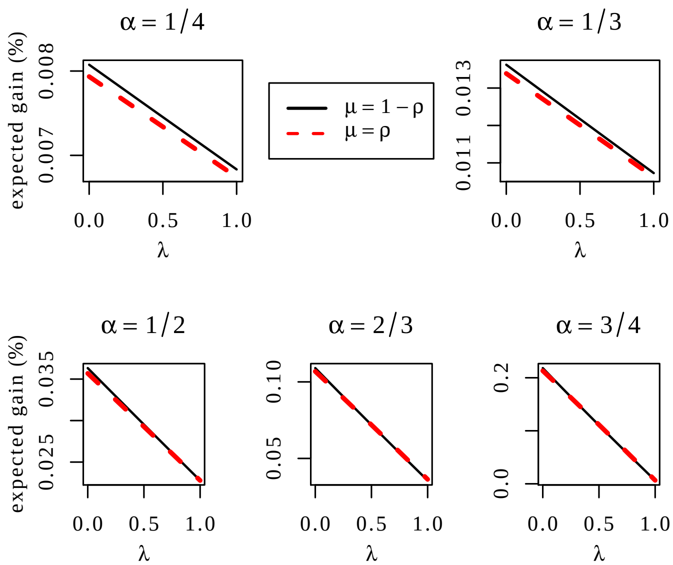

Figure 10: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for high variance of productivity.

Figure 11, on the other hand, shows how firms' incentives to acquire information respond to an increase in the difference between the highest and the lowest taste shock $\overline{\phi} - \underline{\phi}$.[42] In contrast to the preceding exercise, information demand exhibits weaker strategic substitutability than in Figure 2. This is due to an increase in the noise imputed to equilibrium wages by the taste shock.

For completeness, let us briefly discuss a change in the cost of acquiring the signal κ. Note from (27) that the fixed cost of the informative signal does not affect the shape of the expected gain function, but only its intersection with the horizontal axis. Therefore, κ does not affect the cyclicality of the equilibrium fraction of informed firms except in the case when the expected gain functions

[42] More specifically, $\overline{\phi} - \underline{\phi}$ is 35 per cent higher than in the baseline model in Figure 2.

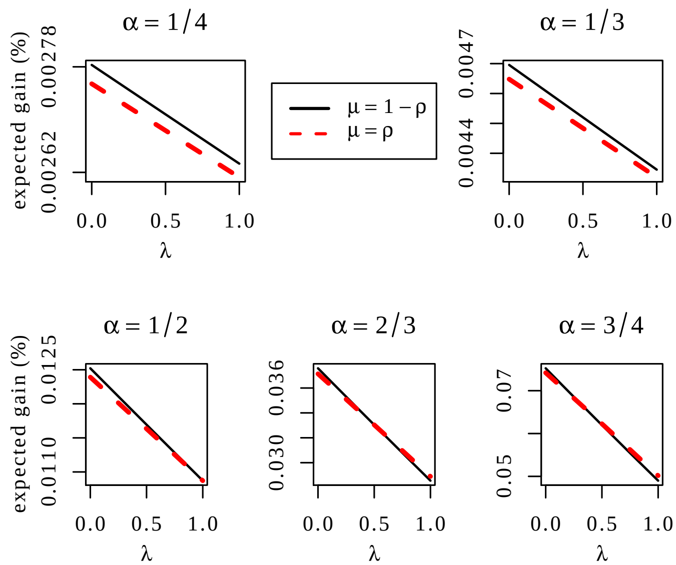

Figure 11: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for high variance of the taste shock.

associated with the two prior beliefs cross at some $\lambda \in (0,1)$.

6. Discussion

In this section we first delve deeper into the role of learning from equilibrium wages and examine how it affects firms' information demand and aggregate fluctuations. To study how firms' incentives to acquire information will change if learning from wages is suppressed, we consider Walrasian equilibrium in the labor market, which does not require firms' beliefs to be consistent with the observed wage.[43] We find that suppressing the informational role of wages strengthens firms' incentives to acquire information.

[43]We follow Grossman (1981) in referring to the solution concept which does not require beliefs to be in line with the observed wage as Walrasian equilibrium. However, note that this solution concept does not constitute an equilibrium as firms have an incentive to reoptimize their plans on observing the wage.

After having examined Walrasian equilibrium, we conduct a welfare analysis to address the efficiency of information acquisition in the decentralized economy. To be more specific, we ask whether there is too little or too much information acquisition from the perspective of the representative household. We find that the level of information acquisition in the decentralized economy is not, in general, efficient. Here, we also identify the determinants of the socially optimal level of information acquisition. Moreover, we study the efficiency of use of information in order to relate our welfare findings to the recent literature on the sources of inefficiencies in information acquisition.

Finally, we confront the empirical implication of our model that wages are more informative about total factor productivity after recessions than following booms (see Corollary 1) with U.S. data. We find that the data support this prediction of the model.

6.1. Role of learning from wages

Let us begin by defining a solution concept which disregards learning from wages, namely Walrasian equilibrium.

Definition 4 (Walrasian equilibrium in the labor market)**.** *Given a fraction of informed firms, $\lambda \in [0,1]$, Walrasian equilibrium in the labor market is a pair of demand schedules $h^U(w,\breve{\mu}^U)$ and $h^I(w,\breve{\mu}^I)$, a supply schedule $h^S(w,\phi)$ and a wage functional $\breve{\mathscr{W}}_\lambda(\phi,\breve{\mu}^U,\breve{\mu}^I)$ such that for all $(\phi,\breve{\mu}^U,\breve{\mu}^I) \in \Psi \times [0,1]^2$ and $w = \breve{\mathscr{W}}_\lambda(\phi,\breve{\mu}^U,\breve{\mu}^I)$*

1. *$h^U(w,\breve{\mu}^U)$ and $h^U(w,\breve{\mu}^I)$ solve*

$$\max_{h^U \geq 0} \left\{ \breve{\mu}^U \, \Pi(w,\overline{z},h^U) + (1-\breve{\mu}^U)\Pi(w,\underline{z},h^U) \right\}, \tag{30}$$

$$\max_{h^I \geq 0} \left\{ \breve{\mu}^I \, \Pi(w,\overline{z},h^I) + (1-\breve{\mu}^I)\Pi(w,\underline{z},h^I) \right\}, \tag{31}$$

   respectively;

2. *$h^S(w,\phi)$ solves the household's stage 2 problem;*
3. *labor market clears*

$$\lambda \, h^I(w,\breve{\mu}^I) + (1-\lambda)\, h^U(w,\breve{\mu}^U) = h^S(w,\phi). \tag{32}$$

To find the expected gain from becoming informed in the baseline model when the stage 2 labor market equilibrium is Walrasian, we proceed as in the proof of Proposition 2. As there is no learning from wages, the expected gain from becoming informed is found by integrating over all possible Walrasian equilibrium wages and accounting for the cost of the signal

$$\breve{G}(\lambda) = \alpha^{\frac{\alpha}{1-\alpha}} \left[\mathbb{P}(s=\overline{s})\mathbb{E}[z\,|\,\overline{s}]^{\frac{1}{1-\alpha}} + \mathbb{P}(s=\underline{s})\mathbb{E}[z\,|\,\underline{s}]^{\frac{1}{1-\alpha}} - \mathbb{E}[z]^{\frac{1}{1-\alpha}} \right] \left(\frac{w_h - w_l}{\overline{\phi} - \underline{\phi}} \right) - \kappa, \tag{33}$$

where w_l and w_h denote the lowest and the highest Walrasian equilibrium wages, respectively, and are given by

$$w_l = \left(\underline{\phi} + \alpha^{\frac{1}{1-\alpha}} \left[(1-\lambda)\mathbb{E}[z]^{\frac{1}{1-\alpha}} + \lambda \mathbb{E}[z\,|\,\underline{s}]^{\frac{1}{1-\alpha}} \right] \right)^{1-\alpha} \tag{34}$$

$$w_h = \left(\overline{\phi} + \alpha^{\frac{1}{1-\alpha}} \left[(1-\lambda)\mathbb{E}[z]^{\frac{1}{1-\alpha}} + \lambda \mathbb{E}[z\,|\,\overline{s}]^{\frac{1}{1-\alpha}} \right] \right)^{1-\alpha}. \tag{35}$$

Comparison of the two expected gain functions in (A.26) and (33) reveals that $G(\lambda) < \breve{G}(\lambda)$ for all $\lambda > 0$. That is, learning from equilibrium wages weakens incentives to acquire costly information. The intuition for this effect comes from the labor market equilibrium wage serving as a costless signal about the unknown state, discouraging firms from acquiring costly information. Consequently, in equilibrium, firms are less well informed about the state of the economy, which in turn makes employment less responsive to changes in the state. Therefore, learning from wages dampens aggregate fluctuations.

6.2. Welfare

To address the efficiency of information acquisition in the decentralized economy, we examine how the expected utility of the representative household varies with the fraction of informed firms. Given that the expected lifetime utility of the household is a weighted sum of its expected utility in a period where the low prior belief prevails and in a period in which the prior belief is high, it is sufficient to analyze the household's expected per-period utility. For a given fraction of informed firms, the household's utility in the baseline model is

$$U = \left(\frac{1}{\alpha}\right)\left(\frac{1}{w}\right)^{\frac{\alpha}{1-\alpha}} \left[\alpha^{\frac{1}{1-\alpha}} \left(\lambda z \mathbb{E}[z\,|\,s]^{\frac{\alpha}{1-\alpha}} + (1-\lambda)\, z \mathbb{E}[z\,|\,w]^{\frac{\alpha}{1-\alpha}} \right) + \phi \right] - \lambda\kappa. \tag{36}$$

Using the law of iterated expectations yields

$$\begin{aligned}\mathbb{E}[U] &= \mathbb{E}[\mathbb{E}[U \mid w]] - \lambda\kappa \\ &= \left(\frac{1}{\alpha}\right)\mathbb{E}[w] - \lambda\kappa.\end{aligned} \tag{37}$$

Differentiating with respect to λ one obtains

$$\frac{\partial \mathbb{E}[U]}{\partial \lambda} = \overbrace{G(\lambda)}^{(1)} \overbrace{+\mathbb{P}(s=\overline{s})(\overline{w}_r - \overline{w})\Delta}^{(2a)} \overbrace{-\mathbb{P}(s=\underline{s})\big(\underline{w} - \underline{w}_r\big)\Delta}^{(2b)}, \tag{38}$$

where

$$\Delta = \left(\frac{\alpha^{\frac{\alpha}{1-\alpha}}}{\overline{\phi} - \underline{\phi}}\right)\Big(\mathbb{E}[z \mid \overline{s}]^{\frac{1}{1-\alpha}} - \mathbb{E}[z \mid \underline{s}]^{\frac{1}{1-\alpha}}\Big) \tag{39}$$

$$\underline{w}_r = \Big(\underline{\phi} + \alpha^{\frac{1}{1-\alpha}}\Big[(1-\lambda)\mathbb{E}[z \mid \underline{s}]^{\frac{1}{1-\alpha}} + \lambda\mathbb{E}[z \mid \overline{s}]^{\frac{1}{1-\alpha}}\Big]\Big)^{1-\alpha} \tag{40}$$

$$\overline{w}_r = \Big(\overline{\phi} + \alpha^{\frac{1}{1-\alpha}}\Big[(1-\lambda)\mathbb{E}[z \mid \overline{s}]^{\frac{1}{1-\alpha}} + \lambda\mathbb{E}[z \mid \underline{s}]^{\frac{1}{1-\alpha}}\Big]\Big)^{1-\alpha}. \tag{41}$$

The decomposition of the derivative in (38) illustrates the two effects of increasing the fraction of informed firms. The first term in (38) is the expected gain to an individual firm from becoming informed, i.e. the private benefit from increased productive efficiency less the cost of acquiring the signal. This coincides with the social benefit from higher productive efficiency when an additional firm becomes informed, ignoring any wage effects. The two other terms (2a and 2b), on the other hand, represent an externality of information acquisition. Namely, they show the welfare consequences of a change in employment dispersion from a higher fraction of informed firms. Given that firms are ex ante identical, cross-sectional dispersion in labor inputs is inefficient. When more firms become informed, uninformative equilibrium wages rise for the high signal and fall for the low signal. Consequently, the difference in labor inputs between informed and uninformed firms decreases when the signal is high. This welfare gain is represented by the term (2a) in (38). On the other hand, when the signal is low, the cross-sectional dispersion in employment increases as equilibrium wages fall. This welfare loss is captured by the term (2b) in (38). To sum up, a higher fraction of informed firms yields a social benefit in terms of productive efficiency, but also alters employment dispersion, which by itself is welfare reducing.

The strength of the dispersion externality depends crucially on labor supply elasticity.[44] Let us look at two extreme cases to demonstrate the idea. First, suppose that the household's labor supply is perfectly inelastic and equal to $\bar{h}$. Then, aggregate output is given by $z\lambda\left(h^I\right)^\alpha + z(1-\lambda)\left(h^U\right)^\alpha$, where $\lambda h^I + (1-\lambda)h^U = \bar{h}$. By Jensen's inequality, aggregate output is maximized when all firms are uninformed. Hence, for perfectly inelastic labor supply, information has no social value since aggregate employment is insensitive to firms' information about the state of the economy. On the other hand, if labor supply were perfectly elastic, the dispersion externality would not be present as a change in informed firms' demand would not affect the equilibrium wage. Consequently, information acquisition in the decentralized economy would be socially efficient were labor supply perfectly elastic.

The household's expected utility as a function of the fraction of informed firms is illustrated in Figure 12. One can conclude from Figure 12 that information acquisition is not, in general, efficient in the decentralized economy. That is, the welfare effect of less dispersed employment for the high signal does not necessarily offset the effect of higher dispersion when the signal is low. For both prior beliefs the equilibrium fraction of informed firms is above 0.7 whereas welfare is maximized when no firm is informed. Figure 12 also shows that the welfare loss from more dispersed labor inputs is higher when the informed and uninformed firms' beliefs differ by more, implying that their labor demand schedules are further apart from each other. When the signal is low and the prior belief is high, informed firms' belief differs from that of the uninformed firms by a larger amount than when the prior belief is low. For this reason, in Figure 12, welfare is monotonically decreasing in the fraction of in-

[44] We thank an anonymous referee for pointing out the importance of labor supply elasticity for efficiency of information acquisition.

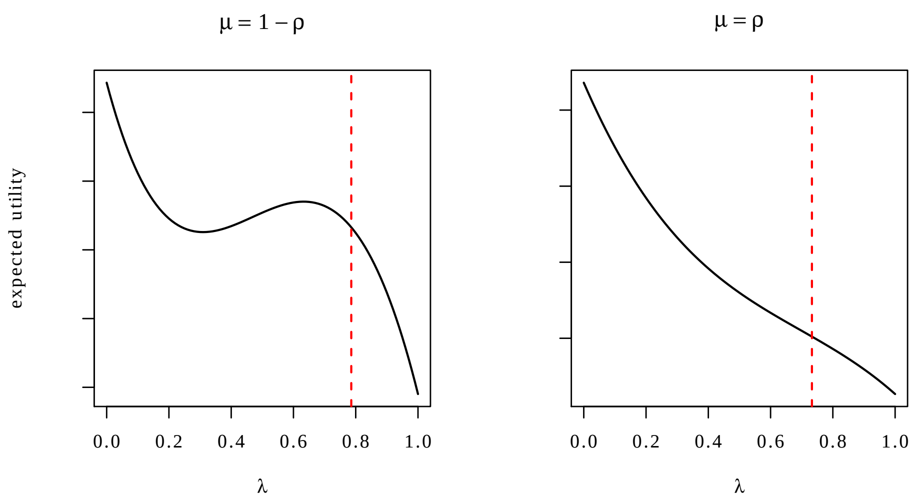

Figure 12: Expected utility as a function of the fraction of informed firms for $\alpha = 1/2$, $\underline{z} = 1$, $\overline{z} = 1.5$, $\underline{\phi} = 0.5$, $\overline{\phi} = 1.5$, $\rho = 0.9$, $q = 1$ and $\kappa = 0.00365$. The dashed line indicates the equilibrium fraction of informed firm in the decentralized economy.

formed firms for the high prior belief but exhibits non-monotonicity for the low prior.

In choosing the optimal level of information acquisition, the social planner balances the gains from efficiency in production against the losses from inefficient dispersion. Figure 13 shows how there can also be less information acquisition in the decentralized economy than what is socially optimal. When productivity in the high state increases in Figure 13, the optimal level of information acquisition eventually exceeds that in the decentralized economy as dispersion decreases more strongly when the signal is high.

6.2.1. *Efficiency of use of information*

To offer a view of our welfare findings through the lens of the literature on the sources of inefficiencies in information acquisition, we proceed by studying the efficiency of use of information in the decentralized economy. That is, we investigate whether, for a given fraction of informed firms, the firms' be-

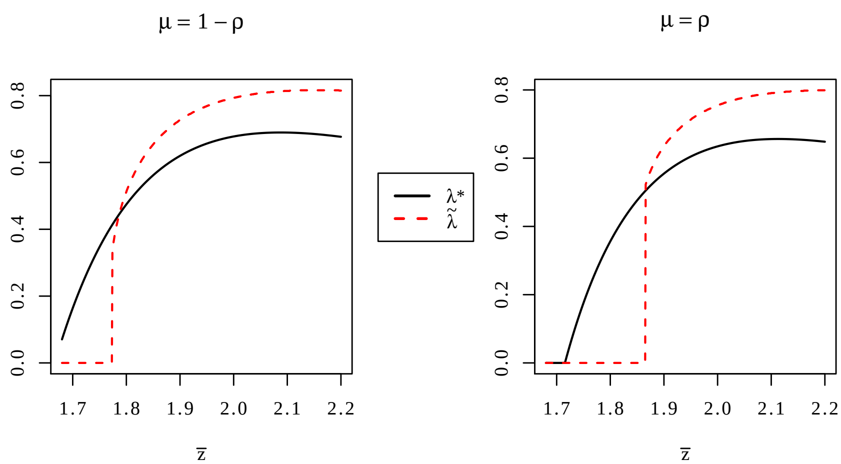

Figure 13: Equilibrium fraction of informed firms λ^* and the socially optimal fraction of informed firms $\tilde{\lambda}$ for $\alpha = 1/2$, $\underline{z} = 1$, $\underline{\phi} = 0.5$, $\overline{\phi} = 1.5$, $\rho = 0.9$ and $\kappa = 0.009$.

lief updating rule maximizes the representative household's expected utility. In other words, we ask whether the firms assign the welfare-maximizing weights to their signal and their prior when forming their posterior beliefs about the state of the economy. To this end, let us revisit the economy considered in Figure 12. To illustrate the welfare implications of alternative uses of information at the firms' disposal, we fix the fraction of informed firms to that in the decentralized economy and vary the weight placed on information available to the firms when they observe the equilibrium wage relative to that put on their prior belief. Namely, the uninformed and the informed firms' posterior expectations of z are altered to[45]

$$\hat{\mathbb{E}}[z \mid w, \mu] = \psi \mathbb{E}[z \mid w, \mu] + (1-\psi)\mathbb{E}[z \mid \mu], \tag{42}$$

$$\hat{\mathbb{E}}[z \mid s, \mu] = \psi \mathbb{E}[z \mid s, \mu] + (1-\psi)\mathbb{E}[z \mid \mu], \tag{43}$$

respectively. Note that the Bayesian belief updating rule, according to which the firms form their expectations in the decentralized economy, obtains when $\psi = 1$. Figure 14 shows how the expected utility of the representative household varies with the weight parameter ψ.[46] It is worth noting that, for both prior beliefs, welfare is maximized when ψ assumes a value strictly less than one. That is, it would be welfare-enhancing if the firms relied less on the signal and more on the prior belief when forming their posterior expectation. This result is a manifestation of the dispersion externality uncovered in the previous section. When increasing ψ, the informed and uninformed firms' expectations diverge from each other for uninformative equilibrium wages. Consequently, cross-sectional dispersion in labor inputs, which by itself is inefficient, rises. On the other hand, an increase in ψ leads to a higher probability of observing a fully revealing wage. Moreover, the informed firms' labor input moves closer to its individually optimal level when ψ increases towards one. If the first (negative) effect dominates the latter two (positive) effects, it is welfare-enhancing to assign a lower weight to the informative signal relative to the prior belief. This is due to the fact that doing so brings the posterior beliefs of the informed and the uninformed firms closer to each other. Finally, it should be pointed out that the use of information can be efficient in the decentralized economy for some parameter values. For instance, when cost of information is such that

[45]Note that that due to the "all-or-nothing" learning from equilibrium wages in the baseline model, the posterior expectation of the uninformed firms differs from their prior expectation only when the equilibrium wage fully reveals the signal of the informed firms. Thus, the uninformed firms' expectation is invariant to the weight parameter ψ for uninformative equilibrium wages.

[46]The range of ψ is chosen to clearly illustrate how welfare varies around the value of ψ which maximizes the household's expected utility.

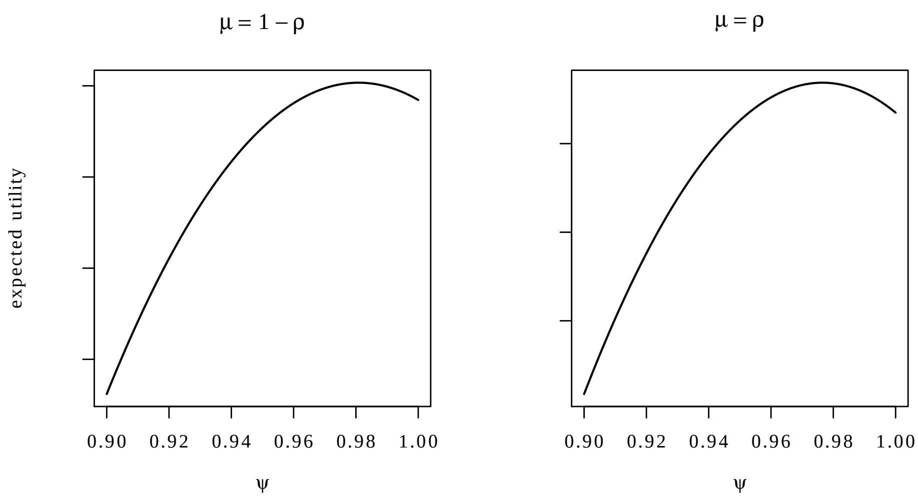

Figure 14: Expected utility as a function of the weight ψ assigned to the signal and the prior belief in the economy considered in Figure 12. The fraction of informed firms is set to that in the decentralized economy.

all firms choose to acquire the signal, the welfare-maximizing belief updating rule coincides with that employed by the firms in the decentralized economy.

6.2.2. Relation to the literature

In light of the preceding discussion, we can relate our welfare results to the recent literature on the origins of inefficiencies in information acquisition. Colombo et al. (2014) study the efficiency of information acquisition in an environment in which agents' payoffs depend not only on an unknown fundamental but also on the average action taken by other agents and the dispersion of individual actions in the population.[47] First, they establish that, in the case of

[47] Pavan (2014) extends the analysis in Colombo et al. (2014) to a more general information structure and considers the case of bounded recall. In a related paper, Llosa and Venkateswaran (2013) compare the equilibrium and efficient level of private information acquisition in three different environments with dispersed information. Like Colombo et al. (2014) and Pavan (2014), they establish that the efficient use of information does not guarantee efficient acqui-

inefficient use of information, the acquisition of private information is inefficiently high when agents' response to their private signal is inefficiently strong. Second, they show that inefficiencies in the equilibrium acquisition of information arise from the discrepancy between the private and the social value of reducing the cross-sectional dispersion of individual actions when agents use their information efficiently. Finally, in an application of their general model to a monetary economy, they demonstrate that whether agents over- or under-invest in information acquisition depends on the curvature of the utility function over consumption. Despite the absence of an endogenous public signal in Colombo et al. (2014), our welfare findings can be related to theirs. More specifically, the payoff relevant variables in our environment that correspond to the average action and the dispersion of individual actions in Colombo et al. (2014) are the equilibrium wage and employment dispersion, respectively. As regards the equilibrium acquisition of information when the use of information is inefficient, the previous section demonstrates that firms can acquire too much information when their labor demands rely too much on information at their disposal, analogously to the result in Colombo et al. (2014). Second, also in our setting the equilibrium acquisition of information can be inefficient even when the use of information is efficient.[48] However, in our setting the discrepancy between the private and the social value of information in this case arises from firms not internalizing the effect of their information acquisition on the equilibrium wage, rather than from changes in the cross-sectional dispersion of actions resulting from more private information. As to the role of the primitive parameters in our environment, we find that inefficiency in information acquisition depends crucially on the curvature of the utility function over leisure. Namely, the more concave is the utility function in leisure, the stronger is the negative dispersion externality relative to the positive effect of information acquisition on productive efficiency. This tends to render information ac-

sition of information.

[48]Results are available from the authors upon request.

quisition in the decentralized economy inefficiently high.

Vives (2014a) analyzes the efficiency of use of private information in a setting in which agents learn from equilibrium prices. He identifies two sources of inefficiency in decentralized strategies: allocative and productive inefficiency. Vives (2014a) shows that agents can put too much weight on private information, leading to excessively informative equilibrium prices. Also in our setting, the sources of inefficiency in use of information are allocative and productive inefficiency as defined in Vives (2014a). That is, welfare losses arise from deviations of aggregate output from its full information level and from a suboptimal distribution of production of a given aggregate output.

Angeletos and La'O (2013a) study how endogeneity of information collection and information aggregation affect the efficiency of the business cycle and the design of optimal policy. They demonstrate that, in the case of agents being insured against any idiosyncratic risk in their consumption and leisure, inefficiency originates solely from the endogeneity of information aggregation. Analogously, we find that the decentralized economy would be efficient were the equilibrium wage invariant to firms' information, which is the case when labor supply is perfectly elastic.

Angeletos et al. (2013), in turn, examine the social value of information in an elementary DGSE model and show that, when fluctuations arise exclusively from technology and preference shocks, welfare increases with the precision of either public or private information. This is due to the fact that the use of information is efficient. Thus, our finding that welfare can decrease with the fraction of informed firms[49] does not conflict with the positive social value of information in Angeletos et al. (2013) as in our environment the use of information is not, in general, efficient.

[49]This can be the case even when the cost of information is set to zero.

6.3. *Empirical test of countercyclically informative wages*

According to Corollary 1 wages are more informative about total factor productivity when the economy has been in a recession in the previous period than after a boom. Here, we wish to investigate whether U.S. data support this empirical implication of our model. To do so, we use the quarterly utilization-adjusted TFP data described in Fernald (2012), private-sector wages and salaries provided by the Bureau of Economic Analysis (A132RC1) and the NBER business cycle dating committee's recession indicator. Our data spans the period 1947:Q1–2013:Q3. In one of our empirical specifications we also control for the standard deviation of TFP to account for TFP volatility as a potential determinant of information acquisition and the informativeness of equilibrium wages, as suggested by the results in Section 5.1. Table 1 summarizes our empirical findings.[50] Estimates obtained from the second specification reveal that wages and TFP are positively correlated when a recession prevailed in the previous quarter while no statistically significant correlation exists after a boom. The third specification shows that this finding is robust to controlling for the volatility of TFP. Hence, the empirical evidence lends support to the model's prediction of wages being more informative about aggregate productivity after a recessionary period than following a boom.

7. Conclusion

We have investigated the implications of firms' acquisition of costly information and the transmission of information via the price system for business cycle dynamics by addressing two so far unanswered questions. Namely, we have studied how firms' incentives to acquire information vary over the business cycle and how learning from prices affects aggregate fluctuations. We find that for a wide range of parameter values firms' information demand is coun-

[50] We consider percentage changes in both TFP and wages as Phillips-Perron tests indicate that the log-level series are integrated of order one.

	Dependent variable: ΔTFP_t		
Explanatory variable	(1)	(2)	(3)
Δw_t	0.0672*	0.0325	0.0478
	(0.0365)	(0.0411)	(0.0456)
$\Delta w_t \times \text{recession}_{t-1}$		0.173*	0.190*
		(0.104)	(0.111)
$\sigma_{\text{TFP},t-1}$			−0.182
			(0.172)
ΔTFP_{t-1}	0.0941	0.108*	0.0766
	(0.0678)	(0.0585)	(0.0565)
ΔTFP_{t-2}	0.119*	0.129**	0.110*
	(0.0652)	(0.0643)	(0.0648)
ΔTFP_{t-3}	−0.00201	−0.00288	−0.00832
	(0.0591)	(0.0576)	(0.0563)
ΔTFP_{t-4}	−0.0857	−0.0853*	−0.0981*
	(0.0539)	(0.0514)	(0.0567)
R^2	0.0389	0.0537	0.0536
observations	262	262	256

Table 1: Newey-West standard errors in parentheses. Coefficient estimates marked with * are significant at the 10 per cent level and those marked with ** at the 5 % level. $\sigma_{\text{TFP},t-1}$ is the standard deviation of $\Delta\text{TFP}_{t-1}, \Delta\text{TFP}_{t-2}, \ldots, \Delta\text{TFP}_{t-10}$.

tercyclical. This arises from the following mechanisms. First, firms' profits and as a consequence the expected gain from acquiring information are decreasing in the equilibrium wage. Thus, firms are less willing to acquire information in booms when they expect the equilibrium wage to be high. Second, for a wide range of parameter values the slope of firms' expected profit function is concave in their belief about the state of the economy. This lowers the value of information when firms hold an optimistic belief about the state. Third, when the prior belief is high, informed firms' demand varies more with the informative signal. Thus, *for a given fraction of informed firms*, equilibrium wages are more informative in booms, lowering information demand. Moreover, in the empirically plausible case in which recessions are less persistent than booms, firms' uncertainty about the state is countercyclical. Consequently, firms value information about the state more in recessions. Learning from prices has a dampening effect on aggregate fluctuations. Given that the price system transmits information from the uninformed to the informed firms, their incentives to acquire information are moderated. As a result, in equilibrium, firms are more imperfectly informed and respond less to changes in the state of the economy.

A welfare analysis reveals that information acquisition in the decentralized economy is not, in general, efficient. This is due to information acquisition leading to information heterogeneity and as a consequence to employment dispersion, which by itself is inefficient as firms are ex ante identical.

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Appendix A. Proofs

Proof of Lemma 1

Solving the representative household's labor supply problem yields

$$h^S(w,\phi)=\begin{cases}1-\phi\left(\frac{1}{w}\right)^{\frac{1}{\gamma}} & \text{if } w^{\frac{1}{\gamma}}>\phi\\ 0 & \text{otherwise.}\end{cases} \tag{A.1}$$

Firm i's labor demand, which solves its profit maximization problem is

$$h_i(w,\mu)=\left(\frac{\alpha\mathbb{E}_i[z\,|\,w]}{w}\right)^{\frac{1}{1-\alpha}} \tag{A.2}$$

where $\mathbb{E}_i[z\,|\,w]$ denotes the expectation with respect to the equilibrium belief $\hat{\mu}_i(\cdot)$. Market clearing in the labor market requires

$$\alpha^{\frac{1}{1-\alpha}}\left[(1-\lambda)\mathbb{E}[z\,|\,w]^{\frac{1}{1-\alpha}}+\lambda\mathbb{E}[z\,|\,w,s]^{\frac{1}{1-\alpha}}\right]=w^{\frac{1}{1-\alpha}}-\phi\, w^{\frac{\gamma-(1-\alpha)}{(1-\alpha)\gamma}}, \tag{A.3}$$

where $\mathbb{E}[z\,|\,w,s]=\mathbb{E}[z\,|\,s]$ due to the fact that the equilibrium wage does not contain information about z beyond s.[51]

To show that an equilibrium wage can fully reveal the signal of the informed firms, first suppose that $s=\underline{s}$ and $\phi=\phi'\in\Phi$. Equilibrium wage $w=\mathscr{W}_\lambda(\phi',\mu,\underline{s})$ is determined by

$$\alpha^{\frac{1}{1-\alpha}}\left[(1-\lambda)\mathbb{E}[z\,|\,w]^{\frac{1}{1-\alpha}}+\lambda\mathbb{E}[z\,|\,\underline{s}]^{\frac{1}{1-\alpha}}\right]=w^{\frac{1}{1-\alpha}}-\phi' w^{\frac{\gamma-(1-\alpha)}{(1-\alpha)\gamma}}. \tag{A.4}$$

Note that if there does not exist $\phi''\in\Phi$ such that

$$\alpha^{\frac{1}{1-\alpha}}\left[(1-\lambda)\mathbb{E}[z\,|\,w]^{\frac{1}{1-\alpha}}+\lambda\mathbb{E}[z\,|\,\overline{s}]^{\frac{1}{1-\alpha}}\right]=w^{\frac{1}{1-\alpha}}-\phi'' w^{\frac{\gamma-(1-\alpha)}{(1-\alpha)\gamma}}, \tag{A.5}$$

then w can only obtain when $s=\underline{s}$, hence fully revealing s. Namely, the wage reveals that $s=\underline{s}$ when

$$\phi'<\underline{\phi}+w^{\frac{1-\alpha-\gamma}{(1-\alpha)\gamma}}\alpha^{\frac{1}{1-\alpha}}\lambda\left(\mathbb{E}[z\,|\,\overline{s}]^{\frac{1}{1-\alpha}}-\mathbb{E}[z\,|\,\underline{s}]^{\frac{1}{1-\alpha}}\right), \tag{A.6}$$

[51] Here and in the rest of this proof, we have suppressed the dependence of the expectation of z on the prior belief μ for conciseness as none of the results depend on the prior belief.

where w solves (A.4).

Analogously, when $s = \overline{s}$ and $\phi = \phi''$, the signal is revealed when

$$\phi'' > \overline{\phi} - w^{\frac{1-\alpha-\gamma}{(1-\alpha)\gamma}} \alpha^{\frac{1}{1-\alpha}} \lambda \Big(\mathbb{E}[z \mid \overline{s}]^{\frac{1}{1-\alpha}} - \mathbb{E}[z \mid \underline{s}]^{\frac{1}{1-\alpha}} \Big), \tag{A.7}$$

where w solves (A.5).

Proof of Lemma 2

By Theorem 2.1.5 in Casella and Berger (2001), the probability density of w conditional on s is given by $|\phi_w(w,s)| f(\phi(w,s))$. Then, (14), (15) and (16) follow from (A.3) and Bayes' rule.

Proof of Proposition 1

Let us first consider the belief of the uninformed firms for non-fully revealing wages. Note from Lemma 2, that under the restriction $\gamma = 1-\alpha$, we have that

$$\phi_w(w,s) = \frac{1}{1-\alpha} w^{\frac{\alpha}{1-\alpha}} - \hat{\mu}^U_w(w)(\overline{z} - \underline{z})(1-\lambda)\mathbb{E}[z \mid w]^{\frac{\alpha}{1-\alpha}} \frac{\alpha^{\frac{1}{1-\alpha}}}{1-\alpha} \tag{A.8}$$

Thus, $\phi_w(w, \underline{s}) = \phi_w(w, \overline{s})$. Therefore, (14) becomes

$$\frac{q\hat{\mu}^U(w) + (1-q)(1-\hat{\mu}^U(w))}{(1-q)\hat{\mu}^U(w) + q(1-\hat{\mu}^U(w))} = \frac{f(\phi(w,\overline{s}))}{f(\phi(w,\underline{s}))} \frac{q\mu + (1-q)(1-\mu)}{(1-q)\mu + q(1-\mu)}, \tag{A.9}$$

where

$$\phi(w,\underline{s}) = \phi(w,\overline{s}) + \alpha^{\frac{1}{1-\alpha}} \lambda \Big(\mathbb{E}[z \mid \overline{s}]^{\frac{1}{1-\alpha}} - \mathbb{E}[z \mid \underline{s}]^{\frac{1}{1-\alpha}} \Big). \tag{A.10}$$

To prove that $\hat{\mu}^U$ is uniquely determined, let us show that the right-hand side of (A.9) is decreasing in $\hat{\mu}^U$. First, note that $\phi(w,s)$ is decreasing in $\hat{\mu}^U$ as $\mathbb{E}[z \mid w]$ is increasing in $\hat{\mu}^U$. Therefore, we wish to show that

$$\frac{\partial}{\partial \phi} \left(\frac{f(\phi)}{f(\phi+\delta)} \right) \geq 0, \tag{A.11}$$

for any $\delta \geq 0$. This is equivalent to

$$\frac{f'(\phi)}{f(\phi)} \geq \frac{f'(\phi+\delta)}{f(\phi+\delta)}, \tag{A.12}$$

which is true by the log-concavity of f. Thus, the right-hand side of (A.9) is decreasing in $\hat{\mu}^U$. As the left-hand side of (A.9), in turn, is strictly increasing in $\hat{\mu}^U$ for all $q > 1/2$, the belief of the uninformed firms is uniquely determined.

Turning to the fully revealing wages, note from (A.10) that ϕ^* and ϕ^{**} are determined independently of the belief of the uninformed firms. Namely,

$$\phi^* = \underline{\phi} + \alpha^{\frac{1}{1-\alpha}} \lambda \Big(\mathbb{E}[z \,|\, \overline{s}]^{\frac{1}{1-\alpha}} - \mathbb{E}[z \,|\, \underline{s}]^{\frac{1}{1-\alpha}} \Big) \tag{A.13}$$

$$\phi^{**} = \overline{\phi} - \alpha^{\frac{1}{1-\alpha}} \lambda \Big(\mathbb{E}[z \,|\, \overline{s}]^{\frac{1}{1-\alpha}} - \mathbb{E}[z \,|\, \underline{s}]^{\frac{1}{1-\alpha}} \Big). \tag{A.14}$$

To solve for non-fully revealing wages, we can proceed in two steps. First, we can find the belief of the uninformed firms for a given realization of (ϕ, s) from

$$\frac{q\hat{\mu}^U(\phi,\underline{s}) + (1-q)(1-\hat{\mu}^U(\phi,\underline{s}))}{(1-q)\hat{\mu}^U(\phi,\underline{s}) + q(1-\hat{\mu}^U(\phi,\underline{s}))} = \frac{f(\phi - \delta(\lambda))}{f(\phi)} \frac{q\mu + (1-q)(1-\mu)}{(1-q)\mu + q(1-\mu)} \tag{A.15}$$

$$\frac{q\hat{\mu}^U(\phi,\overline{s}) + (1-q)(1-\hat{\mu}^U(\phi,\overline{s}))}{(1-q)\hat{\mu}^U(\phi,\overline{s}) + q(1-\hat{\mu}^U(\phi,\overline{s}))} = \frac{f(\phi)}{f(\phi + \delta(\lambda))} \frac{q\mu + (1-q)(1-\mu)}{(1-q)\mu + q(1-\mu)}, \tag{A.16}$$

where

$$\delta(\lambda) = \alpha^{\frac{1}{1-\alpha}} \lambda \Big(\mathbb{E}[z \,|\, \overline{s}]^{\frac{1}{1-\alpha}} - \mathbb{E}[z \,|\, \underline{s}]^{\frac{1}{1-\alpha}} \Big). \tag{A.17}$$

Then, one finds the equilibrium wage from

$$w = \Big(\phi + \alpha^{\frac{1}{1-\alpha}} \Big[(1-\lambda)\mathbb{E}[z \,|\, \hat{\mu}^U(\phi, s)]^{\frac{1}{1-\alpha}} + \lambda \mathbb{E}[z \,|\, s]^{\frac{1}{1-\alpha}} \Big] \Big)^{1-\alpha}. \tag{A.18}$$

Thus, for each (ϕ, μ, s) triplet there exists a unique rational expectations equilibrium wage, given by (17) and (18).

Proof of Lemma 3

The lemma follows from (A.9), as $f(\cdot) = (\overline{\phi} - \underline{\phi})^{-1}$ implies that $\hat{\mu}^U(w) = \mu$ for any wage w which does not fully reveal the signal s.

Proof of Proposition 2

We want to show that the expected gain function satisfies $G'(\lambda) < 0$ for all $\lambda < \bar{\lambda}$. Given that uninformed and informed firms make identical choices for wages that fully reveal the signal s, the gain from becoming informed prior to opening of the labor market pertains to realizations of the signal and the taste shock which support non-fully revealing wages. From (17) and (18) it follows that the lowest and highest non-fully revealing wages, denoting them $\underline{w}$ and $\overline{w}$, respectively, are given by

$$\underline{w} = \left(\underline{\phi} + \alpha^{\frac{1}{1-\alpha}} \left[(1-\lambda)\mathbb{E}[z]^{\frac{1}{1-\alpha}} + \lambda \mathbb{E}[z \mid \overline{s}]^{\frac{1}{1-\alpha}}\right]\right)^{1-\alpha} \tag{A.19}$$

$$\overline{w} = \left(\overline{\phi} + \alpha^{\frac{1}{1-\alpha}} \left[(1-\lambda)\mathbb{E}[z]^{\frac{1}{1-\alpha}} + \lambda \mathbb{E}[z \mid \underline{s}]^{\frac{1}{1-\alpha}}\right]\right)^{1-\alpha}, \tag{A.20}$$

where $\mathbb{E}[z]$ denotes the expectation with respect to the prior belief μ. Given that the belief of the uninformed firms is constant over the interval of uninformative wages, the conditional density of w becomes

$$f(w \mid s) = \frac{1}{\overline{\phi} - \underline{\phi}} \left(\frac{w^{\frac{\alpha}{1-\alpha}}}{1-\alpha}\right) \quad \text{for } w \in [\underline{w}, \overline{w}]. \tag{A.21}$$

Consequently, the prior-to-information-acquisition probability of observing an uninformative wage is

$$\left[q\mu + (1-q)(1-\mu)\right] \int_{\underline{w}}^{\overline{w}} f(w \mid \overline{s}) \mathrm{d}w + \left[(1-q)\mu + q(1-\mu)\right] \int_{\underline{w}}^{\overline{w}} f(w \mid \underline{s}) \mathrm{d}w \tag{A.22}$$

$$= 1 - \lambda \frac{\alpha^{\frac{1}{1-\alpha}} \left(\mathbb{E}[z \mid \overline{s}]^{\frac{1}{1-\alpha}} - \mathbb{E}[z \mid \underline{s}]^{\frac{1}{1-\alpha}}\right)}{\overline{\phi} - \underline{\phi}} =: P(\lambda) \tag{A.23}$$

for $\lambda < \bar{\lambda}$ and 0 otherwise.

Uninformed and informed firms' profits, for optimal choices of labor conditional on w, z and s, are

$$\Pi^I(w, z, s) = \alpha^{\frac{\alpha}{1-\alpha}} \left(\frac{1}{w}\right)^{\frac{\alpha}{1-\alpha}} \mathbb{E}[z \mid s]^{\frac{\alpha}{1-\alpha}} (z - \alpha \mathbb{E}[z \mid s]), \tag{A.24}$$

$$\Pi^U(w, z, s) = \alpha^{\frac{\alpha}{1-\alpha}} \left(\frac{1}{w}\right)^{\frac{\alpha}{1-\alpha}} \mathbb{E}[z \mid w]^{\frac{\alpha}{1-\alpha}} (z - \alpha \mathbb{E}[z \mid w]), \tag{A.25}$$

respectively. The expected gain from becoming informed is then found by integrating the difference between the profit of an informed and that of an uninformed firm over uninformative wages and accounting for the fixed cost of the signal:

$$\begin{aligned}G(\lambda) =& \mathbb{P}(s=\overline{s})\int_{\underline{w}}^{\overline{w}}\Big(\mathbb{E}[\Pi^I(w,z,\overline{s})-\Pi^U(w,z,\overline{s})\,|\,w,\overline{s}]\Big)f(w\,|\,\overline{s})\mathrm{d}w \\ &+\mathbb{P}(s=\underline{s})\int_{\underline{w}}^{\overline{w}}\Big(\mathbb{E}[\Pi^I(w,z,\underline{s})-\Pi^U(w,z,\underline{s})\,|\,w,\underline{s}]\Big)f(w\,|\,\underline{s})\mathrm{d}w-\kappa \\ =& \alpha^{\frac{\alpha}{1-\alpha}}\Big[\mathbb{P}(s=\overline{s})\mathbb{E}[z\,|\,\overline{s}]^{\frac{1}{1-\alpha}}+\mathbb{P}(s=\underline{s})\mathbb{E}[z\,|\,\underline{s}]^{\frac{1}{1-\alpha}}-\mathbb{E}[z]^{\frac{1}{1-\alpha}}\Big]\left(\frac{\overline{w}-\underline{w}}{\overline{\phi}-\underline{\phi}}\right)-\kappa,\end{aligned} \tag{A.26}$$

where the last line obtains as

$$\mathbb{E}[\Pi^I(w,z,s)\,|\,w,s]=\alpha^{\frac{\alpha}{1-\alpha}}\mathbb{E}[z\,|\,s]^{\frac{1}{1-\alpha}}(1-\alpha)\left(\frac{1}{w}\right)^{\frac{\alpha}{1-\alpha}}, \tag{A.27}$$

$$\mathbb{E}[\Pi^U(w,z,s)\,|\,w,s]=\alpha^{\frac{\alpha}{1-\alpha}}\mathbb{E}[z]^{\frac{\alpha}{1-\alpha}}(\mathbb{E}[z\,|\,s]-\alpha\mathbb{E}[z])\left(\frac{1}{w}\right)^{\frac{\alpha}{1-\alpha}}. \tag{A.28}$$

Note that the expected gain is equal to the scaled difference $\overline{w}-\underline{w}$ multiplied by the difference in expected profits for a unitary wage, which is independent of λ. Moreover, the latter is strictly positive by Jensen's inequality as $\mathbb{E}[z] = \mathbb{P}(s=\overline{s})\mathbb{E}[z\,|\,\overline{s}]+\mathbb{P}(s=\underline{s})\mathbb{E}[z\,|\,\underline{s}]$. Finally, the difference $\overline{w}-\underline{w}$ is strictly positive for all $\lambda < \bar{\lambda}$ and is decreasing in λ. Thus, $G'(\lambda) < 0$ for all $\lambda < \bar{\lambda}$ as was to be shown.

Proof of Proposition 3

The proposition is proven in two steps. First, it is shown that the expected gain for a unitary wage is higher for the low than for the high prior belief. Then, it is shown that $\overline{w}-\underline{w}$ is higher when firms hold the low than when they hold the high prior belief.

Consider the part of the expected gain which is proportional to the difference in expected profits for a unitary wage,

$$g(\mu) := \mathbb{P}(s=\overline{s}\,|\,\mu)\mathbb{E}[z\,|\,\overline{s},\mu]^{\frac{1}{1-\alpha}}+\mathbb{P}(s=\underline{s}\,|\,\mu)\mathbb{E}[z\,|\,\underline{s},\mu]^{\frac{1}{1-\alpha}}-\mathbb{E}[z\,|\,\mu]^{\frac{1}{1-\alpha}}. \tag{A.29}$$

Evaluating the beliefs of the informed firms yields

$$g(\rho) = \mathbb{P}(s=\overline{s}\,|\,\rho)\big(\mathbb{E}[z\,|\,\rho]+a\big)^{\frac{1}{1-\alpha}} + \mathbb{P}(s=\underline{s}\,|\,\rho)\big(\mathbb{E}[z\,|\,\rho]-b\big)^{\frac{1}{1-\alpha}}, \\ -\mathbb{E}[z\,|\,\rho]^{\frac{1}{1-\alpha}} \tag{A.30}$$

$$g(1-\rho) = \mathbb{P}(s=\underline{s}\,|\,\rho)\big(\mathbb{E}[z\,|\,1-\rho]+b\big)^{\frac{1}{1-\alpha}} + \mathbb{P}(s=\overline{s}\,|\,\rho)\big(\mathbb{E}[z\,|\,1-\rho]-a\big)^{\frac{1}{1-\alpha}} \\ -\mathbb{E}[z\,|\,1-\rho]^{\frac{1}{1-\alpha}}, \tag{A.31}$$

where

$$a = \frac{(2q-1)(1-\rho)\rho(\overline{z}-\underline{z})}{q\rho+(1-q)(1-\rho)}, \tag{A.32}$$

$$b = \frac{(2q-1)(1-\rho)\rho(\overline{z}-\underline{z})}{(1-q)\rho+q(1-\rho)}. \tag{A.33}$$

Note that $b > a$ for $\rho > 1/2$. Given that $p := \mathbb{P}(s=\overline{s}\,|\,\mu) = 1-\mathbb{P}(s=\underline{s}\,|\,\mu) > 1/2$ for all $\rho > 1/2$, we want to show that

$$h(x) := (1-p)(x+b)^{\frac{1}{1-\alpha}} + p(x-a)^{\frac{1}{1-\alpha}} - x^{\frac{1}{1-\alpha}} > p(y+a)^{\frac{1}{1-\alpha}} + (1-p)(y-b)^{\frac{1}{1-\alpha}} - y^{\frac{1}{1-\alpha}} \tag{A.34}$$

where $y = \mathbb{E}[z\,|\,\rho] > \mathbb{E}[z\,|\,1-\rho] = x$. First note that

$$h'(x) = \frac{1}{1-\alpha}\Big((1-p)(x+b)^{\frac{\alpha}{1-\alpha}} + p(x-a)^{\frac{\alpha}{1-\alpha}} - x^{\frac{\alpha}{1-\alpha}}\Big) < 0 \tag{A.35}$$

by the strict concavity of $x^{\frac{\alpha}{1-\alpha}}$ for $\alpha < 1/2$. Let $z = y-(b-a)$ and note that

$$u(q) := z - x = (2\rho-1)(\overline{z}-\underline{z})\left(1 - \frac{(2q-1)^2(1-\rho)\rho}{[q\rho+(1-q)(1-\rho)][(1-q)\rho+q(1-\rho)]}\right). \tag{A.36}$$

We have that $u(1/2) > 0$, $u(1) = 0$ and

$$u'(q) = -(2\rho-1)(\overline{z}-\underline{z})\frac{(2q-1)(1-\rho)\rho}{[q\rho+(1-q)(1-\rho)]^2[(1-q)\rho+q(1-\rho)]^2} \leq 0. \tag{A.37}$$

Thus, $z - x \geq 0$ for all $q \in (1/2, 1]$. This allow us to establish that

$$(1-p)(x+b)^{\frac{1}{1-\alpha}} + p(x-a)^{\frac{1}{1-\alpha}} - x^{\frac{1}{1-\alpha}} \geq (1-p)(z+b)^{\frac{1}{1-\alpha}} + p(z-a)^{\frac{1}{1-\alpha}} - z^{\frac{1}{1-\alpha}} \\ = (1-p)(y+a)^{\frac{1}{1-\alpha}} + p(y-b)^{\frac{1}{1-\alpha}} - z^{\frac{1}{1-\alpha}}. \tag{A.38}$$

It remains to be shown that

$$(1-p)(y+a)^{\frac{1}{1-\alpha}}+p(y-b)^{\frac{1}{1-\alpha}}-z^{\frac{1}{1-\alpha}} > p(y+a)^{\frac{1}{1-\alpha}}+(1-p)(y-b)^{\frac{1}{1-\alpha}}-y^{\frac{1}{1-\alpha}}, \tag{A.39}$$

which is equivalent to

$$\begin{aligned} d(p) :=& (1-p)x_1^{\frac{1}{1-\alpha}} + p x_2^{\frac{1}{1-\alpha}} - ((1-p)x_1 + p x_2)^{\frac{1}{1-\alpha}} \\ &- \left[p x_1^{\frac{1}{1-\alpha}} + (1-p)x_2^{\frac{1}{1-\alpha}} - (p x_1 + (1-p)x_2)^{\frac{1}{1-\alpha}}\right] > 0, \end{aligned} \tag{A.40}$$

where $x_1 > x_2$. Note that $d(1/2) = d(1) = 0$ and

$$d''(p) = \frac{\alpha}{(1-\alpha)^2}(x_1 - x_2)^2\left[(p x_1 + (1-p)x_2)^{\frac{2\alpha-1}{1-\alpha}} - ((1-p)x_1 + p x_2)^{\frac{2\alpha-1}{1-\alpha}}\right] < 0 \tag{A.41}$$

for all $p \in (1/2, 1)$ and $\alpha < 1/2$. Therefore, $d(p) > 0$. We have established that $g(1-\rho) > g(\rho)$ for all $\rho \in (1/2, 1)$.

Let us turn to analyzing how $v(\mu) := \overline{w} - \underline{w}$ depends on the prior belief μ. Using the same notation as in the first part of the proof, we have

$$\begin{aligned} v(1-\rho) =& \left(\overline{\phi} + \alpha^{\frac{1}{1-\alpha}}\left[(1-\lambda)x^{\frac{1}{1-\alpha}} + \lambda(x-a)^{\frac{1}{1-\alpha}}\right]\right)^{1-\alpha} \\ &- \left(\underline{\phi} + \alpha^{\frac{1}{1-\alpha}}\left[(1-\lambda)x^{\frac{1}{1-\alpha}} + \lambda(x+b)^{\frac{1}{1-\alpha}}\right]\right)^{1-\alpha} \end{aligned} \tag{A.42}$$

$$\begin{aligned} v(\rho) =& \left(\overline{\phi} + \alpha^{\frac{1}{1-\alpha}}\left[(1-\lambda)y^{\frac{1}{1-\alpha}} + \lambda(z-a)^{\frac{1}{1-\alpha}}\right]\right)^{1-\alpha} \\ &- \left(\underline{\phi} + \alpha^{\frac{1}{1-\alpha}}\left[(1-\lambda)y^{\frac{1}{1-\alpha}} + \lambda(z+b)^{\frac{1}{1-\alpha}}\right]\right)^{1-\alpha}. \end{aligned} \tag{A.43}$$

We want to show that $v(1-\rho) > v(\rho)$. Given that $z \geq x$ and $y > x$, it is sufficient to show that $v(\rho)$ is decreasing in both y and z. Differentiating with respect to y and z yields

$$\frac{\partial}{\partial y} v(\rho) = (1-\lambda)y^{\frac{\alpha}{1-\alpha}}\left[\left(\frac{1}{\overline{w}}\right)^{\frac{\alpha}{1-\alpha}} - \left(\frac{1}{\underline{w}}\right)^{\frac{\alpha}{1-\alpha}}\right] < 0, \tag{A.44}$$

$$\frac{\partial}{\partial z} v(\rho) = \lambda\left[\left(\frac{z-a}{\overline{w}}\right)^{\frac{\alpha}{1-\alpha}} - \left(\frac{z+b}{\underline{w}}\right)^{\frac{\alpha}{1-\alpha}}\right] < 0. \tag{A.45}$$

Thus, $\overline{w} - \underline{w}$ is higher for the low than for the high prior belief. It is worth noting that this result holds also for all $\alpha \in (0, 1)$.

Finally, we note that $z \geq x$ implies that $\bar{\lambda}(1-\rho) \geq \bar{\lambda}(\rho)$. Therefore, the expected gain is strictly higher for the low than for the high prior belief for all $\lambda < \bar{\lambda}(1-\rho)$.

Proof of the countercyclicality of the terms (2a) and (2b) in equation (28)

It is to be shown that the terms (2a) and (2b) in

$$\frac{\overline{w}-\underline{w}}{\overline{\phi}-\underline{\phi}} = (1-\alpha)\overbrace{\mathbb{E}\left[\left(\frac{1}{w}\right)^{\frac{\alpha}{1-\alpha}} \middle| \, w \in [\underline{w},\overline{w}]\right]}^{\text{(2a)}}\overbrace{\mathbb{P}(w \in [\underline{w},\overline{w}])}^{\text{(2b)}} \tag{A.46}$$

are higher for the low prior belief $1-\rho$ than for the high prior belief ρ. Consider first (2a). Given that $(1/w)^{\frac{\alpha}{1-\alpha}}$ is decreasing in w, it suffices to show the conditional distribution of w for a prior belief μ first-order stochastically dominates that for $\mu' < \mu$. That is,

$$F(w|w \in [\underline{w},\overline{w}],\mu) \leq F(w|w \in [\underline{w},\overline{w}],\mu'). \tag{A.47}$$

Integrating equation (A.21), one obtains

$$F(w|w \in [\underline{w},\overline{w}],\mu) = \begin{cases} 0 & \text{if } w < \underline{w}, \\ \frac{w^{\frac{1}{1-\alpha}} - \underline{w}^{\frac{1}{1-\alpha}}}{\overline{w}^{\frac{1}{1-\alpha}} - \underline{w}^{\frac{1}{1-\alpha}}} & \text{if } w \in [\underline{w},\overline{w}], \\ 1 & \text{if } w > \overline{w}. \end{cases} \tag{A.48}$$

Differentiating with respect to the prior belief μ yields

$$\begin{aligned} \frac{\partial F(w|w \in [\underline{w},\overline{w}],\mu)}{\partial \mu} =& \frac{1}{\left(\overline{w}^{\frac{1}{1-\alpha}} - \underline{w}^{\frac{1}{1-\alpha}}\right)^2}\Bigg[-\frac{1-\alpha}{2-\alpha}\underline{w}^{\frac{2-\alpha}{1-\alpha}}\frac{\partial \underline{w}}{\partial \mu}\left(\overline{w}^{\frac{1}{1-\alpha}} - \underline{w}^{\frac{1}{1-\alpha}}\right) \\ & - \left(\frac{1-\alpha}{2-\alpha}\overline{w}^{\frac{2-\alpha}{1-\alpha}}\frac{\partial \overline{w}}{\partial \mu} - \frac{1-\alpha}{2-\alpha}\underline{w}^{\frac{2-\alpha}{1-\alpha}}\frac{\partial \underline{w}}{\partial \mu}\right)\left(w^{\frac{1}{1-\alpha}} - \underline{w}^{\frac{1}{1-\alpha}}\right)\Bigg] \\ =& \frac{1-\alpha}{(2-\alpha)\left(\overline{w}^{\frac{1}{1-\alpha}} - \underline{w}^{\frac{1}{1-\alpha}}\right)^2}\Bigg[-\underline{w}^{\frac{2-\alpha}{1-\alpha}}\frac{\partial \underline{w}}{\partial \mu}\left(\overline{w}^{\frac{1}{1-\alpha}} - w^{\frac{1}{1-\alpha}}\right) \\ & - \overline{w}^{\frac{2-\alpha}{1-\alpha}}\frac{\partial \overline{w}}{\partial \mu}\left(w^{\frac{1}{1-\alpha}} - \underline{w}^{\frac{1}{1-\alpha}}\right)\Bigg] \end{aligned} \tag{A.49}$$

for $w \in [\underline{w}, \overline{w}]$. Thus, if $\partial \underline{w}/\partial \mu > 0$ and $\partial \overline{w}/\partial \mu > 0$, then $\partial F(w|w \in [\underline{w}, \overline{w}], \mu)/\partial \mu < 0$. From (A.19) and (A.20), one observes that $\partial \underline{w}/\partial \mu > 0$ and $\partial \overline{w}/\partial \mu > 0$ when $\partial \mathbb{E}[z\,|\,\mu]/\partial \mu > 0$ and $\partial \mathbb{E}[z\,|\,s,\mu]/\partial \mu \geq 0$. Given that $\mathbb{E}[z\,|\,\mu] = \mu\overline{z} + (1-\mu)\underline{z}$, one immediately obtains that $\partial \mathbb{E}[z\,|\,\mu]/\partial \mu > 0$. Similarly, as

$$\frac{\partial \hat{\mu}^I(\underline{s},\mu)}{\partial \mu} = \frac{(1-q)q}{[(1-q)\mu + q(1-\mu)]^2} \geq 0 \tag{A.50}$$

$$\frac{\partial \hat{\mu}^I(\overline{s},\mu)}{\partial \mu} = \frac{(1-q)q}{[q\mu + (1-q)(1-\mu)]^2} \geq 0, \tag{A.51}$$

it follows that $\partial \mathbb{E}[z\,|\,s,\mu]/\partial \mu \geq 0$. Hence, $\partial F(w|w \in [\underline{w}, \overline{w}], \mu)/\partial \mu < 0$ for all $w \in [\underline{w}, \overline{w}]$. Moreover, given that $\partial \underline{w}/\partial \mu > 0$ and $\partial \overline{w}/\partial \mu > 0$, it follows that $F(w|w \in [\underline{w}, \overline{w}], \mu) \leq F(w|w \in [\underline{w}, \overline{w}], \mu')$ for all w and $\mu' < \mu$. Thus, the term (2a) is decreasing in the prior belief μ.

Turning to the term (2b), from (A.23), we have

$$\mathbb{P}(w \in [\underline{w}, \overline{w}], \mu) = 1 - \lambda \frac{\alpha^{\frac{1}{1-\alpha}} \left(\mathbb{E}[z\,|\,\overline{s},\mu]^{\frac{1}{1-\alpha}} - \mathbb{E}[z\,|\,\underline{s},\mu]^{\frac{1}{1-\alpha}} \right)}{\overline{\phi} - \underline{\phi}}. \tag{A.52}$$

Thus, it suffices to prove that

$$\mathbb{E}[z\,|\,\overline{s},\rho]^{\frac{1}{1-\alpha}} - \mathbb{E}[z\,|\,\underline{s},\rho]^{\frac{1}{1-\alpha}} \geq \mathbb{E}[z\,|\,\overline{s},1-\rho]^{\frac{1}{1-\alpha}} - \mathbb{E}[z\,|\,\underline{s},1-\rho]^{\frac{1}{1-\alpha}}. \tag{A.53}$$

Using the same notation as in the proof of Proposition 3 above, this condition becomes

$$(z+b)^{\frac{1}{1-\alpha}} - (z-a)^{\frac{1}{1-\alpha}} \geq (x+b)^{\frac{1}{1-\alpha}} - (x-a)^{\frac{1}{1-\alpha}}, \tag{A.54}$$

where $z \geq x$. Given that

$$\frac{\partial}{\partial x}\left[(x+b)^{\frac{1}{1-\alpha}} - (x-a)^{\frac{1}{1-\alpha}}\right] = \frac{1}{1-\alpha}\left[(x+b)^{\frac{\alpha}{1-\alpha}} - (x-a)^{\frac{\alpha}{1-\alpha}}\right] > 0, \tag{A.55}$$

(A.54) holds. Thus, $\mathbb{P}(w \in [\underline{w}, \overline{w}], 1-\rho) \geq \mathbb{P}(w \in [\underline{w}, \overline{w}], \rho)$.

Proof of Corollary 1

From Propositions 2, 3 and Definition 2, for κ such that $\lambda^* \in (0,1)$, the equilibrium fraction of informed firms, λ^* is higher for the low than the high prior belief, i.e. $\lambda^*(1-\rho) > \lambda^*(\rho)$. Moreover, given that $G(\lambda^*) = 0$ when $\lambda^* \in (0,1)$, the proof of Proposition 3 implies that in equilibrium $\overline{w}(1-\rho) - \underline{w}(1-\rho) < \overline{w}(\rho) - \underline{w}(\rho)$.

What remains to be shown is $P(1-\rho) < P(\rho)$, where $P(\cdot)$ denotes the probability of observing an uninformative wage in equilibrium. Suppose otherwise. Then, from (A.23) it follows that

$$\begin{aligned} &\lambda^*(1-\rho)\alpha^{\frac{1}{1-\alpha}}\left(\mathbb{E}[z\,|\,\overline{s},1-\rho]^{\frac{1}{1-\alpha}} - \mathbb{E}[z\,|\,\underline{s},1-\rho]^{\frac{1}{1-\alpha}}\right) \\ <&\lambda^*(\rho)\alpha^{\frac{1}{1-\alpha}}\left(\mathbb{E}[z\,|\,\overline{s},\rho]^{\frac{1}{1-\alpha}} - \mathbb{E}[z\,|\,\underline{s},\rho]^{\frac{1}{1-\alpha}}\right). \end{aligned} \tag{A.56}$$

Next, consider $\underline{w}(\mu)$. Starting from (A.19), one obtains

$$\underline{w}(\mu) = \left(\underline{\phi} + \alpha^{\frac{1}{1-\alpha}}\overbrace{\left[(1-\lambda^*(\mu))\mathbb{E}[z\,|\,\mu]^{\frac{1}{1-\alpha}} + \lambda^*(\mu)\mathbb{E}[z\,|\,\underline{s},\mu]^{\frac{1}{1-\alpha}}\right]}^{(1)} + \underbrace{\lambda^*(\mu)\alpha^{\frac{1}{1-\alpha}}\left[\mathbb{E}[z\,|\,\overline{s},\mu]^{\frac{1}{1-\alpha}} - \mathbb{E}[z\,|\,\underline{s},\mu]^{\frac{1}{1-\alpha}}\right]}_{(2)}\right)^{1-\alpha}. \tag{A.57}$$

First note that (1) is decreasing in λ^*. Moreover, as shown in the previous proof, $\mathbb{E}[z\,|\,1-\rho] < \mathbb{E}[z\,|\,\rho]$ and $\mathbb{E}[z\,|\,\underline{s},1-\rho] \leq \mathbb{E}[z\,|\,\underline{s},\rho]$. Thus, given that $\lambda^*(1-\rho) > \lambda^*(\rho)$, the term (1) is smaller for $\mu = 1-\rho$ than for $\mu = \rho$. Similarly, the term (2) in (A.57) is smaller for $\mu = 1-\rho$ than for $\mu = \rho$ by (A.56). Therefore, it follows that $\underline{w}(1-\rho) < \underline{w}(\rho)$. Turning back to the probability of observing an uninformative wage, from (A.21)–(A.23) it follows that

$$P(\mu) = \frac{\left[\underline{w}(\mu) + \Delta w(\mu)\right]^{\frac{1}{1-\alpha}} - \underline{w}(\mu)^{\frac{1}{1-\alpha}}}{\overline{\phi} - \underline{\phi}}, \tag{A.58}$$

where $\Delta w(\mu) = \overline{w}(\rho) - \underline{w}(\rho)$. Given that $\Delta w(1-\rho) < \Delta w(\rho)$ and $\underline{w}(1-\rho) < \underline{w}(\rho)$, we have that $P(1-\rho) < P(\rho)$, constituting a contradiction. Hence, the probability of observing an informative wage is higher when the prior belief is $1-\rho$ than for prior belief of ρ.

Appendix B. Computing equilibrium

Appendix B.1. Unrestricted labor supply elasticity

For $\gamma \neq 1-\alpha$, Lemma 2 reveals that the belief of the uninformed firms depends on the derivative $\hat{\mu}^U_w(w)$. Moreover, the distance between the two taste shocks, $\phi' - \phi''$, supporting a non-fully revealing wage varies with the belief of the uninformed firms as

$$\phi' - \phi'' = w^{\frac{1-\alpha-\gamma}{(1-\alpha)\gamma}} \alpha^{\frac{1}{1-\alpha}} \lambda \left(\mathbb{E}[z \mid \overline{s}]^{\frac{1}{1-\alpha}} - \mathbb{E}[z \mid \underline{s}]^{\frac{1}{1-\alpha}} \right), \tag{B.1}$$

$$\alpha^{\frac{1}{1-\alpha}} \left[(1-\lambda) \left(\frac{\mathbb{E}[z \mid w]}{w} \right)^{\frac{1}{1-\alpha}} + \lambda \left(\frac{\mathbb{E}[z \mid \underline{s}]}{w} \right)^{\frac{1}{1-\alpha}} \right] + \phi' \left(\frac{1}{w} \right)^{\frac{1}{\gamma}} = 1. \tag{B.2}$$

Case 1: $\gamma < 1-\alpha$

Note that for $\gamma < 1-\alpha$, the difference $\phi' - \phi''$ is increasing in $\mathbb{E}[z \mid w]$ as the $\partial w / \partial \mathbb{E}[z \mid w] > 0$. This implies that the belief of the uninformed firms cannot decrease discontinuously when the wage turns from non-fully revealing to fully revealing. Due to this continuity, equilibrium can be solved using the following procedure.

1. Find the lowest non-fully revealing wage from

$$\alpha^{\frac{1}{1-\alpha}} \left[(1-\lambda) \left(\frac{\mathbb{E}[z \mid \underline{s}]}{\underline{w}} \right)^{\frac{1}{1-\alpha}} + \lambda \left(\frac{\mathbb{E}[z \mid \overline{s}]}{\underline{w}} \right)^{\frac{1}{1-\alpha}} \right] + \underline{\phi} \left(\frac{1}{\underline{w}} \right)^{\frac{1}{\gamma}} = 1. \tag{B.3}$$

   Note that the uninformed firms' belief is equal to that of the informed firms when the signal is low. This ensures the continuity of the equilibrium belief.

2. Solve for the belief of the uninformed firms for wages above $\underline{w}$ from the differential equation in Lemma 2 using the initial condition $\hat{\mu}^U(\underline{w}) = \hat{\mu}^I(\underline{s})$.

3. Find the highest non-fully revealing wage from

$$\alpha^{\frac{1}{1-\alpha}} \left[(1-\lambda) \left(\frac{\mathbb{E}[z \mid \overline{w}]}{\overline{w}} \right)^{\frac{1}{1-\alpha}} + \lambda \left(\frac{\mathbb{E}[z \mid \underline{s}]}{\overline{w}} \right)^{\frac{1}{1-\alpha}} \right] + \overline{\phi} \left(\frac{1}{\overline{w}} \right)^{\frac{1}{\gamma}} = 1. \tag{B.4}$$

4. For wages above $\overline{w}$, set $\hat{\mu}^U(w) = \hat{\mu}^I(\overline{s})$.

Case 2: $\gamma > 1-\alpha$

For $\gamma > 1-\alpha$, the difference $\phi' - \phi''$ is decreasing in $\mathbb{E}[z\,|\,w]$. Thus, the belief of the uninformed firms cannot increase discontinuously when the wage turns from non-fully revealing to fully revealing. In this case, equilibrium can be found as follows.

1. Find the highest non-fully revealing wage from

$$\alpha^{\frac{1}{1-\alpha}}\left[(1-\lambda)\left(\frac{\mathbb{E}[z\,|\,\overline{s}]}{\overline{w}}\right)^{\frac{1}{1-\alpha}} + \lambda\left(\frac{\mathbb{E}[z\,|\,\underline{s}]}{\overline{w}}\right)^{\frac{1}{1-\alpha}}\right] + \overline{\phi}\left(\frac{1}{\overline{w}}\right)^{\frac{1}{\gamma}} = 1. \tag{B.5}$$

2. Solve for the belief of the uninformed firms for wages below $\overline{w}$ from the differential equation in Lemma 2 using the initial condition $\hat{\mu}^U(\overline{w}) = \hat{\mu}^I(\overline{s})$.
3. Find the lowest non-fully revealing wage from

$$\alpha^{\frac{1}{1-\alpha}}\left[(1-\lambda)\left(\frac{\mathbb{E}[z\,|\,\underline{w}]}{\underline{w}}\right)^{\frac{1}{1-\alpha}} + \lambda\left(\frac{\mathbb{E}[z\,|\,\overline{s}]}{\underline{w}}\right)^{\frac{1}{1-\alpha}}\right] + \underline{\phi}\left(\frac{1}{\underline{w}}\right)^{\frac{1}{\gamma}} = 1. \tag{B.6}$$

4. For wages below $\underline{w}$, set $\hat{\mu}^U(w) = \hat{\mu}^I(\underline{s})$.

Appendix B.2. Continuously distributed state

Supposing that the uninformed firms' demand schedule is downward sloping,[52] the equilibrium wage is informationally equivalent to

$$\begin{aligned} r :=& w^{\frac{1}{1-\alpha}} - \alpha^{\frac{1}{1-\alpha}}(1-\lambda)\mathbb{E}[z\,|\,w]^{\frac{1}{1-\alpha}} \\ =& \alpha^{\frac{1}{1-\alpha}}\lambda\mathbb{E}[z\,|\,s]^{\frac{1}{1-\alpha}} + \phi. \end{aligned} \tag{B.7}$$

When the signal is perfectly revealing, the uninformed firms' posterior distribution of z upon observing the equilibrium wage w is given by

$$f(z\,|\,w) = \frac{f(r - \alpha^{\frac{1}{1-\alpha}}\lambda z^{\frac{1}{1-\alpha}})g(z)}{\int_0^{\hat{z}} f(r - \alpha^{\frac{1}{1-\alpha}}\lambda z^{\frac{1}{1-\alpha}})g(z)\mathrm{d}z}, \tag{B.8}$$

where $\hat{z} = (r/(\alpha^{\frac{1}{1-\alpha}}\lambda))^{1-\alpha}$ and $g(\cdot)$ denotes the prior distribution of z. Using (B.8), one can calculate $\mathbb{E}[z\,|\,w]$ for any realization of (ϕ, z).

[52] This ensures that r in (B.7) is strictly increasing in w.

Appendix B.3. Utility concave in consumption

Under the log-specification of utility, the representative household's labor supply is given by

$$h^S(w,\phi) = 1 - \frac{\phi}{w\mathbb{E}[c^{-1} \mid w]}. \tag{B.9}$$

For $\lambda > 0$, the equilibrium wage perfectly reveals the signal of the informed firms to the household. Thus, in the case of $\kappa = 0$, we have

$$\mathbb{E}[c^{-1} \mid w] = w^{\frac{\alpha}{1-\alpha}} \alpha^{\frac{-\alpha}{1-\alpha}} \mathbb{E}[(\lambda z^{\frac{1}{1-\alpha}} + (1-\lambda) z \mathbb{E}[z \mid w]^{\frac{\alpha}{1-\alpha}})^{-1} \mid s]. \tag{B.10}$$

Therefore, labor market clearing requires

$$\alpha^{\frac{1}{1-\alpha}} \Big[(1-\lambda)\mathbb{E}[z \mid w]^{\frac{1}{1-\alpha}} + \lambda \mathbb{E}[z \mid w, s]^{\frac{1}{1-\alpha}} \Big] = w^{\frac{1}{1-\alpha}} - \phi g(s)^{-1}, \tag{B.11}$$

where $g(s) = \mathbb{E}[(\lambda z^{\frac{1}{1-\alpha}} + (1-\lambda) z \mathbb{E}[z \mid w]^{\frac{\alpha}{1-\alpha}})^{-1} \mid s]$. For non-fully revealing wages, a belief consistent with the observed wage can be found from

$$\frac{q\hat{\mu}^U(w) + (1-q)(1-\hat{\mu}^U(w))}{(1-q)\hat{\mu}^U(w) + q(1-\hat{\mu}^U(w))} = \frac{g(\overline{s})}{g(\underline{s})} \frac{q\mu + (1-q)(1-\mu)}{(1-q)\mu + q(1-\mu)}. \tag{B.12}$$

Appendix B.4. Independently drawn signals

When all firms acquire signals of identical precision q, labor market clearing for $z = \overline{z}$ requires

$$\alpha^{\frac{1}{1-\alpha}} \Big[q\mathbb{E}[z \mid w, \overline{s}]^{\frac{1}{1-\alpha}} + (1-q)\mathbb{E}[z \mid w, \underline{s}]^{\frac{1}{1-\alpha}} \Big] = w^{\frac{1}{1-\alpha}} - \phi, \tag{B.13}$$

and similarly for $z = \underline{z}$. Proceeding as in proof of Proposition 1, one finds an equilibrium characterized by two sets of wages. Namely, a set of wages which fully reveal the state z and a set of wages for which $\mathbb{E}[z \mid w, s] = \mathbb{E}[z \mid s]$. A fully revealing wage obtains when either $z = \underline{z}$ and $\phi < \underline{\phi} + \delta(q)$ or $z = \overline{z}$ and $\phi > \overline{\phi} - \delta(q)$, where $\delta(q) = \alpha^{\frac{1}{1-\alpha}}(2q-1)\Big(\mathbb{E}[z \mid \overline{s}]^{\frac{1}{1-\alpha}} - \mathbb{E}[z \mid \underline{s}]^{\frac{1}{1-\alpha}}\Big)$.

Appendix C. Robustness with asymmetric transition probabilities

We illustrate firms' demand for information in the model variants presented in Sections 5.2–5.6 when transition probabilities are asymmetric. More specifically, we set $\underline{\rho} = 0.7719$ and $\overline{\rho} = 0.9525$, obtained by estimating the persistence of U.S. expansions and contractions, as defined by the NBER business cycle dating committee, in the period 1946:01–2013:12. As we are establishing the baseline model with asymmetric transition probabilities as the new benchmark, the other parameter values are chosen as for the baseline model with symmetric transition probabilities in Section 5. That is, we normalize $\underline{z} = 1$, set $q = 1$ and the remaining parameters such that average labor input is one third of the unitary time endowment and the variances of productivity and employment match those in the U.S. data.[53] Figure C.1 illustrates the expected gain from acquiring information in this new benchmark model.

Figures C.2–C.7 show that information demand is countercyclical in all the model variants presented in Sections 5.2–5.6 in the empirically plausible case of booms being more persistent than recessions.[54]

[53]We use data on total hours worked from the BLS (HOANBS) and the TFP data described in Section 6.3. The moments are matched when $\alpha = 2/3$ and all firms are uninformed.

[54]The model variants are parameterized as in Section 5.

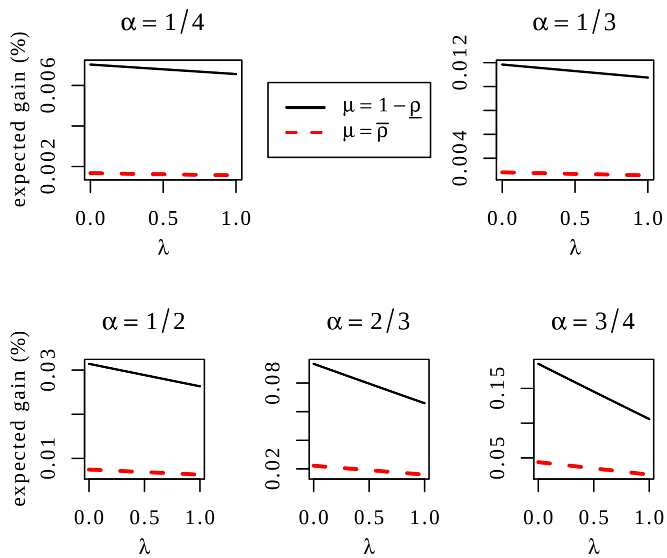

Figure C.1: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for asymmetric transition probabilities.

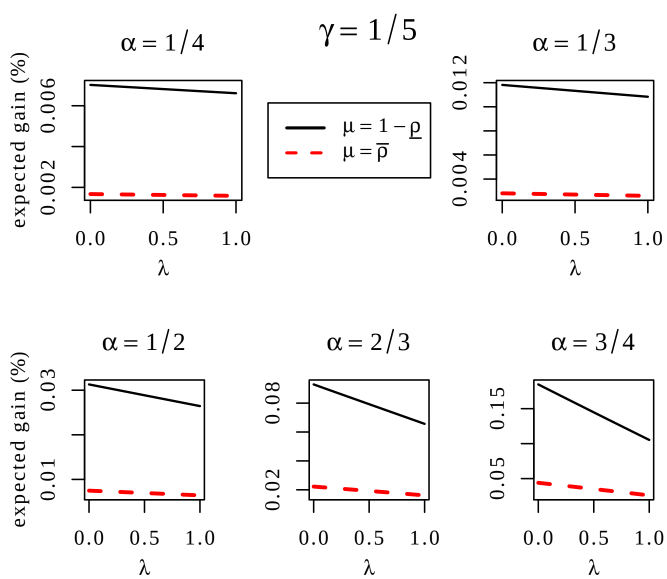

Figure C.2: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for high labor supply elasticity.

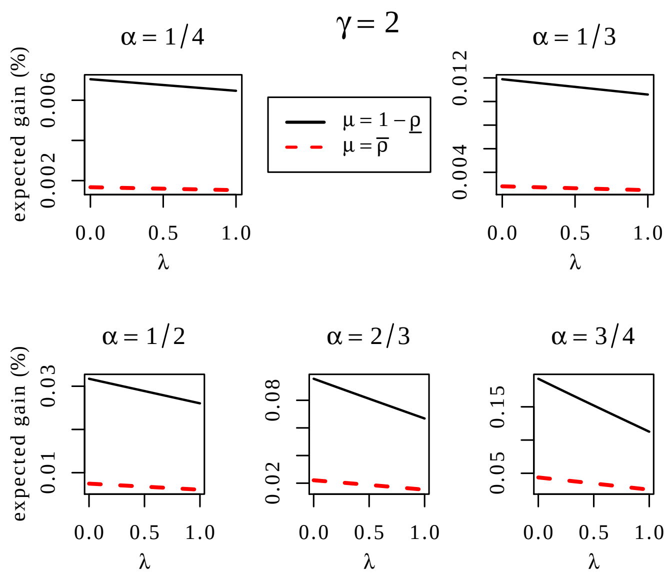

Figure C.3: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for low labor supply elasticity.

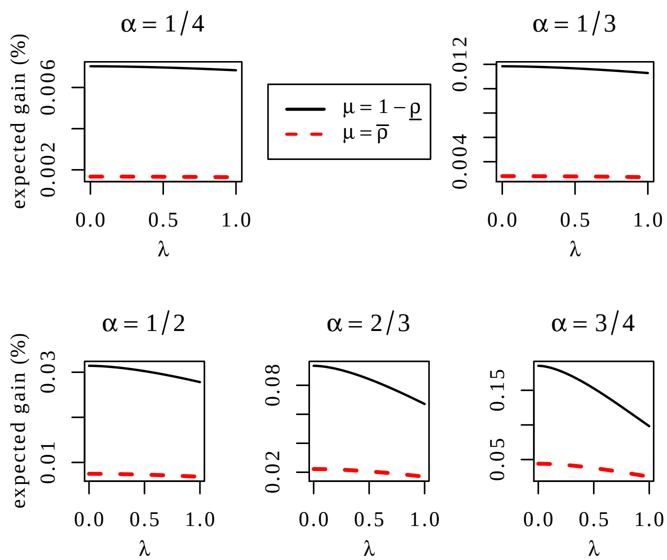

Figure C.4: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for non-uniform taste shock.

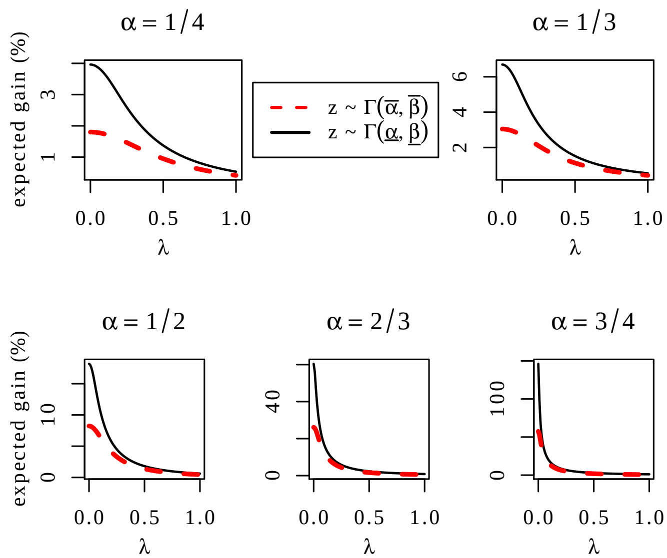

Figure C.5: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for continuous technology level.

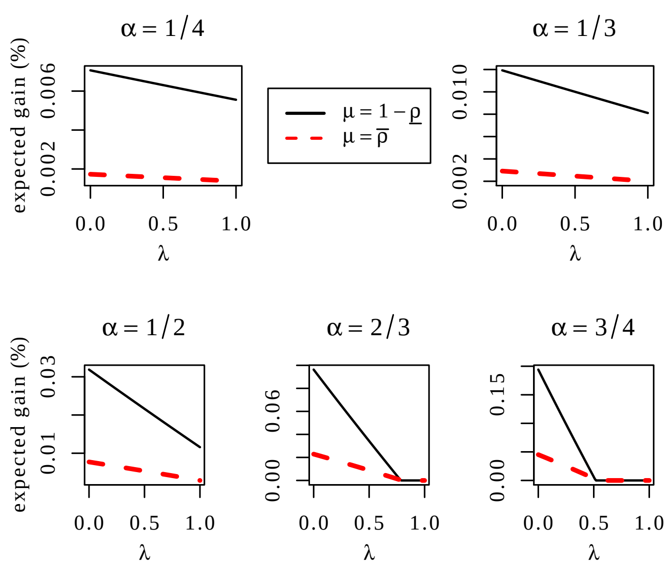

Figure C.6: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for utility concave in consumption.

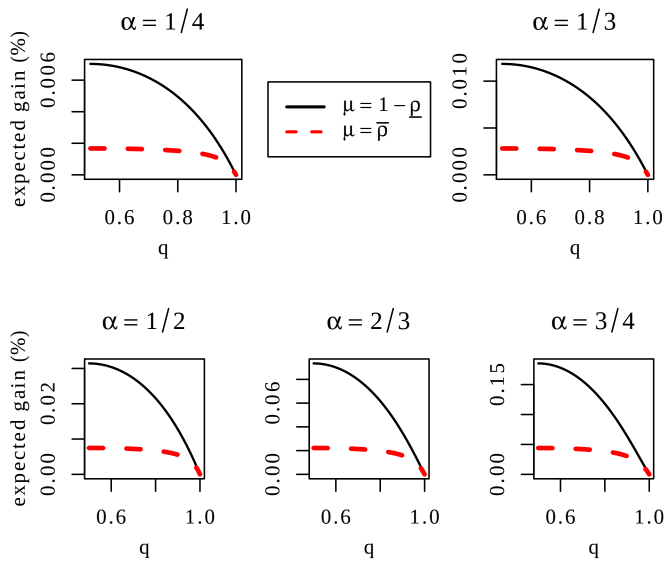

Figure C.7: Expected gross gain from becoming informed relative to the average per-period profit of an uninformed firm for independently drawn signals.