

HETEROGENEOUS INFORMATION AND THE LABOR MARKET^{*}

VENKY VENKATESWARAN[†]

UCLA

FEBRUARY 15, 2011

Job Market Paper[‡]

Abstract

I introduce dispersed information in a search and matching model of the labor market, where firms are hit by aggregate and idiosyncratic productivity shocks. The latter induce larger responses in recruiting activity than the former - because aggregate shocks have general equilibrium effects which partially offset the change in fundamentals. Informational frictions prevent firms from disentangling aggregate and idiosyncratic shocks. With Bayesian updating, firms attribute aggregate shocks largely to idiosyncratic factors, because the latter have significantly larger variances. This misattribution translates into an increased responsiveness of employment to aggregate shocks, relative to an economy with full information. I show that in a calibrated model, this channel has quantitatively significant effects and offers a potential solution to a well-known puzzle - the inability of standard search and matching models to generate sufficient volatility in labor market variables. In particular, the model with dispersed information brings the relative volatilities of employment and market tightness very close to those observed in the data.

JEL Classification: D82, E24, E32, J64

Keywords: Real business cycles, unemployment volatility puzzle, search and matching, incomplete information

^{*}I thank Andrew Atkeson, Christian Hellwig, Pierre-Olivier Weill, Ariel Burstein, Lee Ohanian, Paco Buera, Roberto Fattal-Jaef and Jose Lopez for helpful discussions and comments. I have also benefitted from the insightful remarks of seminar participants at Northwestern, Wharton, Chicago Booth, Carnegie-Mellon, Penn State, Columbia GSB, Princeton and Stanford GSB. Obviously, I am solely responsible for all remaining errors. Financial support from UCLA is gratefully acknowledged.

[†]Email: vvenkate@ucla.edu

[‡]For the most recent version, please visit <https://sites.google.com/site/vvenkate/Home>

1 Introduction

The ability of models with search and matching frictions to match the observed cyclical properties of labor market activity has received a lot of attention in recent years. Shimer (2005) showed that, in a calibrated version of the standard Mortensen and Pissarides (1994) model, productivity shocks cannot generate the large movements in unemployment or labor market tightness observed in the data. Several authors have proposed modifications to the standard model with a view to resolving this puzzle¹. In this paper, I propose a new explanation - informational frictions - and show that they can significantly resolve the discrepancy between the data and model-predicted movements.

At the heart of this result is a key feature of the firm-level data - evidence on firm-level decisions point to idiosyncratic shocks that induce large adjustments in firm-level employment. I interpret these shocks as innovations to firm-level productivity and embed them in a stochastic general equilibrium model with aggregate productivity shocks and search frictions in the labor market. These idiosyncratic factors lead to bigger changes in hiring activity at the firm level than aggregate shocks of comparable magnitude. This occurs for two reasons. Firstly, with search frictions, hiring decisions are based on expectations of future conditions and since idiosyncratic shocks are more persistent than aggregate shocks, they call for bigger changes in recruiting effort. Secondly, and more importantly, aggregate shocks have general equilibrium effects - on tightness of the labor market and on wages. These effects work to dampen the firm's incentives to change hiring in response to the change in the fundamental. For example, a positive aggregate shock increases labor market tightness and thereby makes it harder for firms to find workers. It also increases wages by affecting the households' marginal rate of substitution between consumption and leisure. A positive shock to firm-specific productivity, on the other hand, does not affect overall labor market conditions or wages (at least, not to the same degree as an aggregate shock). As a result, firms respond more aggressively to a idiosyncratic shock than to a aggregate shock of the same size.

In Figure 1, I plot monthly data on the total number of job separations and new hires in the US economy. As the graph shows, every month, about four to five million matches are destroyed every month and about the same number of new ones created. It seems natural to assume that firms, faced with this massive turbulence, find it difficult to disentangle shocks hitting the whole

¹The literature on the empirical performance of labor search models is too large to cite every worthy paper. Mortensen and Nagypal (2007) is a recent survey. Any reading list will certainly include Andolfatto (1996), Cole and Rogerson (1999), den Haan, Ramey and Watson (2000), Hall (2005), Farmer and Hollenhorst (2006), Gertler and Trigari (2006), Guerrieri (2007), Krause and Lubik (2007), Hall and Milgrom (2008), Costain and Reiter (2008), Hagedorn and Manovskii (2008) and Bruggemann and Moscarini (2010).

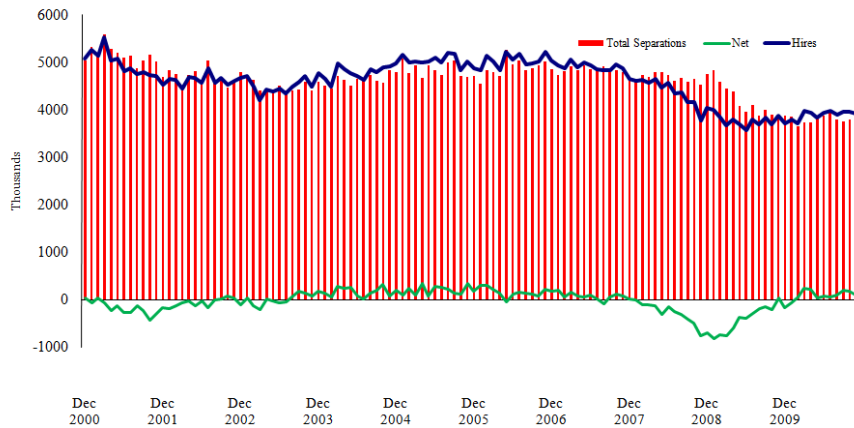


Figure 1: Job Destruction and Creation in the US

economy from the shocks affecting their own situation. This difficulty is compounded by the fact that fluctuations caused by economy-wide shocks are much more modest in comparison. This is illustrated by the green line in the figure, which plots the net hires, a proxy for overall economic conditions.

Now, suppose firms observe a combination of aggregate and idiosyncratic productivity shocks and use Bayesian updating to form forecasts of the individual components. In such a scenario, optimal filtering will lead firms to attribute aggregate shocks largely to idiosyncratic factors (because the latter tend to be an order of magnitude larger) and therefore, respond more aggressively (for the reasons discussed earlier) than they would under full information. This increased responsiveness at the firm level in turn translates into an amplified response of overall labor market activity to the aggregate shock. To evaluate the quantitative importance of this mechanism, I calibrate the model to both aggregate and micro data and show that informational frictions generates significant amplification in the volatilities of employment and hiring activity (relative to output volatility). In particular, in my benchmark calibration, informational frictions make market tightness slightly more volatile than in the data and close most of the gap between model-implied and observed relative volatilities of employment.

Quantitative evaluation of the implications of heterogeneous information has been hampered by two challenges. First, these models are not easy to solve, particularly in the kind of rich settings essential to answering quantitative questions. Second, since agents' information is seldom directly observable, it is not obvious how to calibrate these models. This paper makes a broader contribution

to the literature by developing a flexible and tractable method, that has applicability beyond the specific context studied here. To address the first issue, this paper combines standard techniques for solving dynamic optimization problems using linear approximations with the approach for handling dynamic learning developed in Hellwig (2002). The result is a solution algorithm which can handle a large number of state variables - both fundamental and informational - without losing tractability. A key assumption that makes this possible is that aggregate shocks are revealed with a finite lag. In addition to being an intuitive way of capturing the diffusion of information about aggregates, this assumption also converts the learning problem into a finite-dimensional filtering problem. This allows a recursive characterization of the state space and considerably simplifies solving for equilibrium.

The second element of the paper’s methodological contribution is a calibration strategy, which uses firm-level data to impose discipline on the information structure. This strategy is based on the intuitive idea that, before reliable information about aggregates arrives, firms use information generated in the normal course of their market activities to form forecasts about market conditions². Examples of such signals include own productivity realizations, wages and labor market outcomes. Idiosyncratic variation in these signals is an important (and in this paper, the only) source of informational heterogeneity. Micro-level data (e.g. on firm-level employment or wages) provide direct evidence on the properties of these shocks and thus, provide a useful way to calibrate the degree of informational heterogeneity.

The basic idea that agents mistake aggregate shocks for idiosyncratic ones and therefore, react differently is not a new one in macroeconomics. A well-known application is Lucas (1972) where agents try to distinguish aggregate nominal shocks from ‘island-specific’ demand shocks before making a static labor input decision. Lucas (1972) shows that this confusion can generate real effects from purely nominal shocks, since agents respond partly to perceived movements in idiosyncratic demand shocks. More recently, Hellwig and Venkateswaran (2009) investigate the implications of this mechanism in an environment where firms attempt to disentangle aggregate nominal shocks and idiosyncratic demand/cost shocks from market-generated signals before setting prices³ Apart

²Another justification for limiting the amount of information to just these signals comes from theories of costly information. For example, in Mackowiak and Wiederholt (2009), firms face a constraint on the amount of attention (defined as in Sims, 2003) and choose to allocate almost all of it to signals containing information about idiosyncratic factors. While that finding was in a price-setting context, the underlying economic rationale is a general one - firms will pay most attention to factors that have the greatest effect on their payoffs. Since idiosyncratic shocks are large and relatively persistent, they matter a great deal to firm profits.

³For other recent applications where heterogeneity in information is induced by payoff-relevant shocks (as opposed

from obvious differences in the context and the nature of the shocks, there are 2 major differences between this paper and the analysis in Hellwig and Venkateswaran (2009). The first difference relates to the dynamic nature of the choice variables in this paper compared to the static choices in Hellwig and Venkateswaran (2009). This introduces a new source of persistence and presents additional methodological challenges. The second difference lies in the nature of the conclusions reached in the two papers. In Hellwig and Venkateswaran (2009), informational frictions turn out to be largely irrelevant for the aggregate economy. Even though agents remain confused about the true nature of the shock, the economy behaves very much like a full information economy. The intuition behind this surprising result is that, despite being very uninformative about idiosyncratic vs. aggregate shocks, the firms' demand and wage signals provide a parsimonious, yet reasonably accurate indicator of their optimal full information pricing decisions. Consequently, even though firms are confused about the true source of the shocks, they manage to set prices quite close to their optimal levels. This implies that aggregate nominal shocks are reflected in prices very quickly, significantly dampening any effects on quantities (e.g. output, labor). Here, the economy behaves very differently under heterogeneous information. Confusion about the true nature of the shocks affects firms' incentive to recruit more workers and leads to 'excess' volatility in the aggregate.

Finally, for the calibration, I draw on a large literature studying idiosyncratic variation in employment, wages and hiring activity. The literature on firm dynamics has documented two robust features of firm-level growth rates in the US - one, they show a large cross-sectional dispersion and two, they are independent of firm size. The first fact is suggestive of large idiosyncratic productivity shocks, an order of magnitude larger than shocks to aggregate productivity. The latter feature, also referred to as Gibrat's Law, implies that these shocks induce almost permanent changes in the level of employment, indicating that the effect on productivity must also be highly persistent, if not permanent. Together, these observations help calibrate the stochastic process for idiosyncratic productivity shocks. In addition, the environment of this paper also assumes idiosyncratic shocks to the disutility of working in a given sector as well as to the efficiency of recruiters. These shocks serve to slow down the speed of learning about aggregate conditions from wages and labor market outcomes. To calibrate the former, I interpret these shocks as person-specific effects in the cross-sectional distribution of wages. A number of papers - Abowd, Kramarz and Margolis (1999), Postel-Vinay and Robin (2002), Davis et al. (1991), to cite a few - have found that this kind of heterogeneity contributes to a significant proportion of the cross-sectional variance in wages, even after controlling for observables. I use their estimates to pin down the magnitude of the (to observational noise), see Amador and Weill (2010) or Graham and Wright (2010).

disutility shocks. Finally, a recent paper by Davis, Faberman and Haltiwanger (2010) studies the cross-sectional distribution of vacancies and hiring patterns and reports significant variation in the rate at which vacancies are converted into hires. Their estimates for the relationship between firm growth rates and vacancy yields provide a useful way to impose discipline on the size of recruiting efficiency shocks.

This paper is related to several branches of literature. Obviously, there is a direct relationship with the large body of work using search and matching frictions in models of business cycles. One of the key findings of this literature is that standard calibrations (like the one in Shimer (2005)) induce relatively small fluctuations in the value of hiring activity for a firm in response to aggregate productivity shocks. As a result, resources devoted to recruiting activity - and consequently, employment - also do not fluctuate much with the cycle, leading to much more subdued movements in labor market activity than observed in the data. In this paper, informational frictions cause the *perceived* value of recruiting to be more volatile and thus induce bigger responses in firm decisions. This is in contrast to a number of papers which have introduced modifications to make the *actual* value more responsive to aggregate shocks. For example, Hall (2005) assumes that wages do not adjust to productivity changes, leading to bigger fluctuations in the value appropriated by the firm out of a match. However, Pissarides (2009) argues that the relevant wage for determining the value of hiring is the wage of the *marginal* worker, which moves one-for-one with productivity in the data. As an alternative, he introduces, as does Cheremukhin (2010), fixed costs associated with hiring and shows that they can generate the required volatilities in the value of posting a vacancy. Hagedorn and Manovskii (2008) pursue an alternative calibration strategy which reduces the level of the match surplus, but leads to larger *percentage* fluctuations. Costain and Reiter (2008) argue that such a calibration solves the volatility puzzle but creates another one - it implies counterfactually high elasticities of unemployment to labor market policies. In the context of this debate, the main contribution of this paper is to introduce a novel channel of amplification, distinct from the mechanisms discussed above. To highlight the contribution of informational frictions, I abstract from the other modifications and stick as close as possible to the standard model⁴.

This paper also relates to a growing literature on the role of heterogeneous information in business fluctuations⁵. In their seminal work, Phelps (1970) and Lucas (1972) showed that an economy

⁴Moreover, since my focus here is the job creation margin, I also abstract from other margins of labor adjustment explored by the literature, e.g. endogenous job destruction (as in Cheremukhin, 2010, den Haan and Ramey, 2000, Mortensen and Nagypal, 2007 or Eyigungor, 2010) or on-the-job search (as in Menzio and Shi, 2009).

⁵In addition to the papers mentioned in the text, an inexhaustive list from this literature includes Moscarini (2004), Bacchetta and Wincoop (2006), Reis (2006), Adam (2007), Veldkamp and Wolfers (2007), Angeletos and

with agents that are imperfectly informed about aggregate fundamentals can exhibit fluctuations in real variables from purely nominal shocks. Several papers have extended this basic hypothesis, by adding strategic interactions, as in Woodford (2003) and Mankiw and Reis (2002), or limited capacity for processing information, as in Mackowiak and Wiederholt (2009), or market-generated information, as in Hellwig and Venkateswaran (2009) or Graham and Wright (2010). While many of these papers focus largely on the effects of monetary shocks on real variables, more recent work, notably Mackowiak and Wiederholt (2010), Lorenzoni (2009) and Angeletos and La'o (2010a), consider implications of heterogeneous information for 'real' shocks, which is the focus of this paper as well. In these papers, informational frictions dampen (and delay) the response of the economy to aggregate productivity shocks. In contrast to these findings, I show how informational frictions can amplify the responsiveness to productivity shocks. This difference in findings stems from differences in the signal structure. In the benchmark environments of Mackowiak and Wiederholt (2010) and Angeletos and La'o (2010a), informational frictions takes the form of pure observational noise⁶. Therefore, when an aggregate shock hits the economy, it enters the signals of all agents but is partly attributed to noise and therefore, does not affect agents' responses at all. In this paper, on the other hand, signals are combinations of aggregate and idiosyncratic factors, causing the former to be mistaken for the latter and thereby inducing a stronger response.

The rest of this paper proceeds as follows. Section 2 presents a simple 2-period example which highlights the basic economic force at work and highlights the potential for amplification in this mechanism. Section 3 lays out the full model and defines the relevant equilibrium concepts. Sections 4 and 5 describe the solution algorithm and the calibration strategy respectively. Section 6 discusses the numerical results, along with some robustness exercises. Section 7 presents an extension with an alternative wage determination rule and section 8 concludes.

2 A simple example

In this section, I lay out a simple example, which will highlight the economic forces at work in the more general model and illustrate the potential for amplification. A 2-period economy is populated by a unit measure of both firms and workers. Let N_{it} , $t = 1, 2$ denote the mass of employed workers

Pavan (2007), Gorodnichenko (2008), Angeletos and La'O (2008, 2010b), Hellwig (2008b, 2008a) and Lorenzoni (2009, 2010).

⁶Lorenzoni (2009) has agent-specific productivity shocks as in this paper, but assumes that these shocks are iid. As a result, they have no effect on forward looking pricing decisions and therefore, act very much like observational noise.

at firm i in period t . At the beginning of period 1, workers and firms are uniformly matched i.e. $N_{i1} = 1 \forall i$. Period 1 output is produced according to:

$$Y_{i1} = e^{a_1 + a_{i1}} (N_{i1})^\alpha = e^{a_1 + a_{i1}} ,$$

where $e^{a_1 + a_{i1}}$ represents the firm's productivity in period 1. Productivity has an aggregate and an idiosyncratic component, denoted a_1 and a_{i1} respectively. Both are mean-zero, normally distributed random variables

$$\begin{aligned} a_1 &\sim N(0, \sigma^2) \\ a_{i1} &\sim N(0, \hat{\sigma}^2). \end{aligned}$$

I assume that a law of large numbers applies⁷ to the cross-sectional distribution of a_{i1} i.e.

$$\int a_{i1} di = 0.$$

After period 1 production, the firm's matches with its current labor force are exogenously destroyed. In other words, to be able to produce in period 2, the firm is required to go through a hiring process. This involves posting vacancies in period 1 at a constant marginal cost of 1 unit of output. Employment in period 2 is related to vacancies through an aggregate matching function⁸, which depends on the mass of unemployed in the economy (denoted U) and the the total number of vacancies posted V :

$$M = \zeta f(U, V) = \zeta U^\eta V^{1-\eta} = \zeta V^{1-\eta} , \quad \eta \in (0, 1) ,$$

where η is the elasticity of the matching function with respect to the measure of unemployed. The last equality follows from the assumption that all matches are destroyed in first period, leading to $U = 1$.

The parameter η is also the elasticity of the job-filling rate, $\frac{M}{V} = \zeta V^{-\eta}$, with respect to the total mass of vacancies. Firm i 's employment in period 2 is given by

$$N_{i2} = V_i \zeta V^{-\eta}.$$

⁷I maintain this assumption about idiosyncratic shocks throughout the paper. See Sun (2006) for the precise construction of a probability space where the exact law of large numbers holds for a continuum of pairwise independent random variables.

⁸I assume that ζ is sufficiently small so that the condition $M \leq \min(U, V)$ holds with a very high probability.

Output in period 2 is produced according to the same decreasing returns-to-scale technology

$$Y_{i2} = e^{a_2+a_{i2}}(N_{i2})^\alpha ,$$

where a_2 and a_{i2} are the aggregate and idiosyncratic components of period 2 productivity. They are linked to their period 1 counterparts as follows:

$$\begin{aligned} a_2 &= \rho a_1 & \rho &\in [0, 1] \\ a_{i2} &= \hat{\rho} a_{i1} , & \hat{\rho} &\in [0, 1]. \end{aligned}$$

The parameters ρ and $\hat{\rho}$ index the persistence of the aggregate and idiosyncratic components respectively⁹.

In both periods, wages are assumed to be proportional to output - in particular, firms pay one-half of their output to workers as wages. Dividend in the 2 periods are therefore,

$$\begin{aligned} D_{i1} &= Y_{i1} - W_{i1} - V_i = \frac{e^{a_1+a_{i1}}}{2} - V_i \\ D_{i2} &= Y_{i2} - W_{i2} - V_i = \frac{e^{a_2+a_{i2}}(N_{i2})^\alpha}{2} \end{aligned}$$

Firms maximize the expected value of dividends. Formally, firm i solves

$$\max_{V_i} D_{i1} + \mathbb{E}_i D_{i2}$$

where

$$\begin{aligned} D_{i1} &= \frac{e^{a_1+a_{i1}}}{2} - V_i \\ N_{i2} &= \zeta V^{-\eta} V_i \\ D_{i1} &= \frac{e^{a_2+a_{i2}} (N_{i2})^\alpha}{2} , \end{aligned}$$

and the expectation operator, $\mathbb{E}_i$, is with respect to firm i 's information.

⁹Introducing additional shocks to period 2 productivities - whether aggregate or idiosyncratic - will not change any of the results in this section. Therefore, I abstract from any additional uncertainty.

2.1 Optimality

The first-order condition of the above problem is

$$1 = \underbrace{\zeta V^{-\eta}}_{\text{Probability}} \underbrace{\frac{1}{2}}_{\text{Firm's share}} \underbrace{\alpha \mathbb{E} \left(e^{a_2 + a_2^i} \right) (N_{i2})^{\alpha-1}}_{\text{Match surplus}}. \quad (1)$$

The left-hand side of (1) is the cost of a vacancy and the right side is the expected value from posting a vacancy. Assuming conditional log-normality (which will be shown to hold), substituting for second period employment and taking logs on both sides, this can be written as

$$(1 - \alpha)v_i = \mathbb{E}_i(a_2 + a_{i2}) - \alpha\eta\mathbb{E}_i(v) + \text{Const}. \quad (2)$$

where $v \equiv \int v_i di$ and the constant term is a function of parameters and the (commonly known) second moments of random variables on the right hand side. Equation (2) is intuitive - the firm's hiring decision depends positively on its expected productivity and negatively on the aggregate number of vacancies posted in the economy. The latter effect arises because the vacancy yield of the firm (i.e. the number of new hires each vacancy generates) decreases with economy-wide hiring activity. As a result, for a given level of its expectation of fundamentals (i.e. future productivity), the number of vacancies posted by a firm is decreasing in its beliefs about aggregate hiring activity. The greater the aggregate number of vacancies posted in the economy, the lower is the incentive of an individual firm to post vacancies. In the language of the heterogeneous information literature, this feature makes hiring decisions strategic substitutes. The effect of this interaction is greater (i.e. more negative), the larger the elasticity of the vacancy yield with respect to aggregate vacancies (i.e. η).

The firm's belief about v takes the form of a conjecture about its relationship with a_1 , the only source of aggregate uncertainty in the economy. In a rational expectations equilibrium, this conjecture must be the same as the true relationship. I start with a guess that this relationship is linear:

$$v = \phi a_1, \quad (3)$$

where ϕ is an endogenous coefficient to be determined. Substituting this conjecture and the laws of motion for productivity in (2),

$$(1 - \alpha)v_i = \rho \mathbb{E}_i(a_1) + \hat{\rho} \mathbb{E}_i(a_{i1}) - \alpha\eta\phi \mathbb{E}_i(a_1) + \text{Const.} \quad (4)$$

$$= (\rho - \alpha\eta\phi) \mathbb{E}_i(a_1) + \hat{\rho} \mathbb{E}_i(a_{i1}) + \text{Const.} \quad (5)$$

As (5) shows, the firm's optimal response to a perceived aggregate shock, a_1 , is dampened by the effects of labor market congestion (captured by the $-\alpha\eta\phi$ in the first term). Obviously, the firm-specific component of productivity does not affect this congestion and therefore, the response to perceived idiosyncratic shocks, a_{i1} depends only on its persistence.

2.2 Full Information

First, suppose that firms have full information about the nature of shocks i.e. they observe both components of their productivity shock separately. Therefore,

$$\mathbb{E}_i(a_1) = a_1 \quad \mathbb{E}_i(a_{i1}) = a_{i1}.$$

Substituting in (5) and integrating over all i , ignoring the constant terms

$$\begin{aligned} (1 - \alpha) \int v_i di &= (\rho - \alpha\eta\phi) \int \mathbb{E}_i(a_1) di + \hat{\rho} \int \mathbb{E}_i(a_{i1}) di \\ \Rightarrow (1 - \alpha) v &= (\rho - \alpha\eta\phi)a_1 + \hat{\rho} \int a_{i1} di = (\rho - \alpha\eta\phi) a_1. \end{aligned}$$

Thus, under full information, the firm's conjecture (3) is verified when

$$(1 - \alpha) \phi^{\text{Full}} = (\rho - \alpha\eta \phi^{\text{Full}}) \Rightarrow \phi^{\text{Full}} = \frac{\rho}{1 - \alpha + \alpha\eta}. \quad (6)$$

2.3 Dispersed Information

Now, assume that, at the time of making its hiring decision, each firm only observes its composite productivity $a_1 + a_{i1}$ and nothing else. The firm uses Bayes rule to form expectations of the aggregate and idiosyncratic components. This leads to

$$\mathbb{E}_i(a_1) = \pi(a_1 + a_{i1}) \quad \mathbb{E}_i(a_{i1}) = (1 - \pi)(a_1 + a_{i1}), \text{ where } \pi = \frac{\sigma^2}{\sigma^2 + \hat{\sigma}^2}.$$

In other words, Bayes rule implies that the signal is allocated to the 2 components according to the ratio of their variances. Again, substituting in (5) and integrating over all i ,

$$\begin{aligned}
(1 - \alpha) \int v_i di &= (\rho - \alpha\eta\phi) \int \mathbb{E}_i(a_1) di + \hat{\rho} \int \mathbb{E}_i(a_{i1}) di \\
(1 - \alpha) v &= (\rho - \alpha\eta\phi)\pi \int (a_1 + a_{i1}) di + \hat{\rho}(1 - \pi) \int (a_1 + a_{i1}) di \\
\Rightarrow (1 - \alpha) v &= (\rho - \alpha\eta\phi)\pi a_1 + \hat{\rho}(1 - \pi) a_1,
\end{aligned}$$

where the last equality makes use of the fact that $\int a_{i1} di = 0$. Under heterogeneous information, the firms' conjecture (3) is verified when

$$(1 - \alpha) \phi^{\text{Het}} = (\rho - \alpha\eta \phi^{\text{Het}})\pi + \hat{\rho}(1 - \pi) \quad (7)$$

$$\Rightarrow \phi^{\text{Het}} = \frac{\pi \rho + (1 - \pi) \hat{\rho}}{1 - \alpha + \alpha\eta\pi}. \quad (8)$$

A comparison of (6) and (8) reveals that heterogeneous information changes the equilibrium response of hiring activity to aggregate shocks in 2 ways. The first comes from changes in the forecast of future productivity in response to an aggregate shock. Under full information, firms observe a_1 perfectly and correctly forecast its implications for their productivity next period. Under heterogeneous information, firms attribute a fraction $1 - \pi$ of all changes in their signals (including those coming from aggregate shocks) to an idiosyncratic shock. Therefore, the firm's forecast for period 2 productivity is computed using a weighted average of the persistence of the 2 components, with weights determined by π . This is reflected in the numerator in (8).

The second change comes from the fact that informational frictions also affect the firm's expectation of aggregate labor market conditions (through the $\mathbb{E}_i(v)$ term). For example, a positive aggregate shock increases overall hiring activity and therefore, leads to lower vacancy yields. However, to the extent aggregate shocks are mistakenly attributed to idiosyncratic factors, firms underestimate this effect. Since their hiring decisions depend negatively on expectations of overall market tightness, this underestimation works to increase the number of vacancies posted. This effect shows up through the π multiplying the $\alpha\eta$ term in the denominator of (8).

The following proposition shows that if the idiosyncratic shock is sufficiently persistent, the confusion caused by informational frictions leads to an amplified response in hiring activity.

Proposition 1 *Suppose $\hat{\rho} \geq \rho \left(\frac{1-\alpha}{1-\alpha+\alpha\eta} \right)$. Then, the economy under heterogeneous information is more responsive to aggregate shocks i.e. $\phi^{\text{Het}} \geq \phi^{\text{Full}}$.*

Note that $\left(\frac{1-\alpha}{1-\alpha+\alpha\eta} \right) < 1$, so informational frictions can lead to amplification even when idiosyncratic shocks are less persistent than aggregate shocks. This occurs due to the second effect discussed above (i.e. through firms' expectations about aggregate labor market conditions). To see this, consider the case as the strategic interactions disappear i.e. $\eta \rightarrow 0$. Then,

$$\phi^{\text{Full}} \rightarrow \frac{\rho}{1-\alpha} \quad \phi^{\text{Het}} \rightarrow \frac{\pi \rho + (1-\pi) \hat{\rho}}{1-\alpha}.$$

In other words, without the strategic links introduced by the aggregate matching function, the differences in responses under full and heterogeneous information stem purely from the relative persistence of the two shocks. In this limiting case, heterogeneous information leads to amplification in aggregate responsiveness if and only if idiosyncratic shocks are more persistent than aggregate ones. More generally, the greater the link between vacancy yield and aggregate hiring, i.e. the higher the value of η , the lower is the threshold level of idiosyncratic persistence necessary to generate amplification.

While this example is too stylized for a full-fledged calibration and quantitative evaluation, I use a simple numerical calculation to illustrate that this mechanism can generate economically significant amplification. I set¹⁰ the returns to scale parameter $\alpha = 0.9$, the persistence of the aggregate shock, $\rho = 0.98$ and make the idiosyncratic shocks perfectly persistent i.e. $\hat{\rho} = 1$. Figure 2 plots the equilibrium response of vacancies in the economy under heterogeneous information relative to the full information case i.e. $\phi^{\text{Het}}/\phi^{\text{Full}}$, for various values of η , the elasticity parameters as well as for the relative variance of the idiosyncratic shocks $\hat{\sigma}/\sigma$. Recall that higher the relative volatility of firm-specific shocks, the greater the fraction of the signal attributed to them.

As the graph shows, the degree of amplification generated by informational frictions can be quite large. For the empirically relevant range of the relative variance, (i.e. towards the high end of the X-axis in Figure 2), vacancies are anywhere from 3 to 9 times as volatile under heterogeneous information compared to the full information economy. This is approximately the factor by which standard search and models underpredict labor market volatility, indicating that informational frictions can go a long way in closing the gap between these models and the data. The primary

¹⁰These parameter values are similar to the ones used in the calibration of the general model in Section 5.

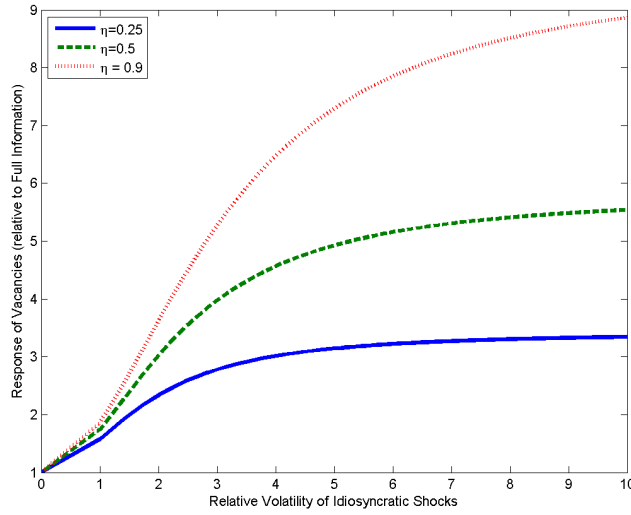


Figure 2: Effect of Confusion and Congestion

purpose of the general model in the sections that follow is to verify the robustness of this finding.

2.4 Relation to the Literature

This simple example also offers a convenient way to relate the mechanism to others used by the literature to amplify cyclical fluctuations in the labor market. Recall, from the FOC (1), that firms equate costs of a vacancy to its expected benefits.

$$\text{Cost of a vacancy} = \mathbb{E}_i [\text{Probability of a match} \times (\text{Firm's share} \times \text{Match surplus})] \quad (9)$$

The volatility puzzle in Shimer (2005) can be represented in terms of this expression. Assume that the left hand side does not vary with the cycle. Given a matching function and data on employment/vacancies, cyclical movements in the probability of a match can be directly observed in the data. Under standard functional form assumptions for a matching function, that probability turns out to be quite volatile i.e. declines (rises) sharply during booms(recessions). Therefore, if the model is to match the data, it must generate significant volatility in the term within parentheses i.e. the benefit to the firm from a successful match must rise (decline) sharply during booms (recessions). This is the source of the puzzle - the standard search model does not generate sufficient movement in this object in response to productivity shocks. Various modifications to the standard model have been proposed to make the firm's value from a match more responsive to shocks. For example,

when wages are sticky, as in Hall (2005), the firm's share becomes more cyclical. Training costs, as in Pissarides (2009), or higher outside options of workers, as in Hagedorn and Mannovskii (2008), serve to generate bigger fluctuations in the net surplus from a match. In contrast, I argue that, in the presence of information frictions, firms equate the cost of a vacancy to the *perceived* benefit from posting one. In such a scenario, when firms mistake an aggregate shock for an idiosyncratic one, they underestimate the movements in the probability of a match and overestimate the change in the other terms. This mechanism acts through the $\mathbb{E}_i$ operator and is present even when the *actual* benefit from a vacancy behaves as in the standard model. In other words, informational frictions can generate amplification, without the need to rely on the other modifications used by the literature.

3 The Full Model

In this section, I lay out a micro-founded dynamic stochastic general equilibrium model with search frictions. The model setup is very similar to those used in the search and matching literature and closely follows the approach in Shimer (2010), augmented to allow for heterogeneity and dispersed information. The full model will have a number of features - infinite horizon, a more standard specification of preferences and technology, a richer set of signals - that were not present in the simple example discussed above. These features will preclude an analytical characterization of the solution but will allow a more robust quantitative evaluation of the role of informational frictions. They will also present a few challenges in solving the model - a dynamic learning problem, both physical and informational state variables, to cite a couple. Addressing these challenges is part of the methodological contribution of this paper and I discuss them in greater detail in Section 4.

3.1 Model description

I denote the history of the economy upto time t by s^t , with an associated probability $\Pi(s^t)$. The state space for s^t includes all aggregate and idiosyncratic shocks (to be specified later).

Households: There is a representative household with a measure 1 of members, who work in one of a continuum of markets i . The household maximizes the expected discounted sum of utilities of all its members

$$\sum_t \int_{s^t} \beta^t \Pi(s^t) \left(\ln C_t(s^t) - \gamma \int N_{it}(s^t) Z_{it}(s^t) di \right),$$

where $C_t(s^t)$ is aggregate household consumption, $N_{it}(s^t)$ is employment in i and $Z_{it}(s^t)$ is an idiosyncratic preference shock affecting the disutility of working in i . The measure of employed members of the household, $N_t(s^t)$, is :

$$N_t(s^t) \equiv \int N_{it}(s^t) di .$$

The household is assumed to have access to complete contingent claims markets and faces a lifetime budget constraint:

$$\sum_t \int_{s^t} Q_t(s^t) C_t(s^t) = \sum_t \int_{s^t} Q_t(s^t) \int (W_{it}(s^t) N_{it}(s^t) + D_{it}(s^t)) di .$$

where $Q(s^t)$ is price of an Arrow-Debreu security which pays off 1 unit in state s^t , W_{it} and D_{it} denote the wage rate and dividends paid out by the representative firm in i . Standard optimization arguments imply

$$\lambda Q_t(s^t) = \frac{1}{C_t(s^t)} ,$$

where λ is the multiplier on the lifetime budget constraint.

Firms: The representative firm in market i maximizes the expected discounted sum of dividends:

$$\mathbb{E}_i \sum_{t=0}^{\infty} \beta^t Q_t D_{it} ,$$

subject to

$$D_{it} + K_{i,t+1} = Y_{it} - W_{it} N_{it} + K_{i,t}(1 - \delta) + \frac{\psi}{2} \left(\frac{I_{it}}{K_{it}} - \delta \right)^2 ,$$

where I have suppressed the explicit dependence on s^t for brevity. The expectation $\mathbb{E}_i$ is taken with respect to firm i 's information set (to be defined later). As in the simple example, informational frictions will act through this operator.

The firm operates a Cobb-Douglas technology:

$$Y_{it} = A_t A_{it} K_{it}^{\alpha_1} (N_{it}(1 - V_{it}))^{\alpha_2}$$

where V_{it} is the fraction of the firm's labor force allocated to recruiting efforts. Note that this is slightly different from the recruiting technology used in the simple example. Here, I assume that recruiting is a labor-intensive activity and so, instead of posting vacancies, the firm devotes a fraction of its labor force to recruiting activity. Aggregate and idiosyncratic productivity shock processes are denoted by A_t and A_{it} respectively. I assume decreasing returns at the firm level i.e. $\alpha_1 + \alpha_2 < 1$.

Labor Markets: The law of motion for employment in i is given by:

$$N_{i,t} = (1 - \delta_n)N_{it-1} + V_{i,t-1}N_{it-1}F_{i,t-1} . \quad (10)$$

where δ_n is the (exogenous) separation rate and $F_{i,t-1}$ is the (endogenous) number of hires each recruiter deployed in i in period $t - 1$ is able to attract. $L_{i,t}$ is an (exogenous) idiosyncratic shock to recruiter efficiency¹¹. The firm takes as given $F_{i,t-1}$ while choosing $V_{i,t-1}$. The household, on the other hand, takes this law of motion as completely exogenous.

Finally, I specify the relationship between matches created in sector i and labor market conditions. I adopt a flexible parameterization, which allows the effectiveness of each recruiter in a sector to depend on both i -specific variables as well as overall conditions in the labor market.

$$F_{it} = \bar{\mu} (\Theta_{it})^{-\eta} L_{it}, \quad \eta \in (0, 1) \quad (11)$$

$$\text{where} \quad \Theta_{it} = \left(\frac{V_{it}N_{it}}{1 - N_{it}} \right)^{1-\kappa} \left(\frac{V_tN_t}{1 - N_t} \right)^{\kappa}, \quad \kappa \in (0, 1). \quad (12)$$

Aggregate labor market tightness is defined as the ratio of aggregate recruiting effort to the measure of unemployed:

$$\Theta_t \equiv \frac{V_tN_t}{1 - N_t}$$

The parameter κ controls how Θ_{it} , the relevant measure of tightness for i , depends on aggregate tightness Θ_t . Higher the value of κ , the greater the degree to which recruiter effectiveness of a particular firm is affected by hiring efforts of other firms. This specification is a slightly generalized version of functional forms commonly used in the literature. In particular, setting $\kappa = 1$ reduces the above expression to the standard assumption of an economy-wide matching function, with all

¹¹Cheremukhin and Restrepo-Echavarria (2010) find a significant role for *aggregate* shocks to matching efficiency in explaining the US post-war data. Here, I employ only idiosyncratic ones.

firms facing the same average vacancy filling rates. At the other extreme, $\kappa = 0$ implies segmented labor markets i.e. where each i has its own labor market. However, matching elasticities estimated using aggregate data generated by the above formulation are invariant to κ , at least in a log-linear approximation around a steady state.

Lemma 1 *Upto a first order log-approximation, the elasticities of the total measure of matches in the economy with respect to total recruiting effort and the measure of unemployed are given by $(1 - \eta)$ and η respectively.*

Wages: For now, I assume a general wage determination rule:

$$W_{it} = G(\{Y_{it-s}, N_{it-s}, V_{it-s}, C_{t-s}, N_{t-s}, V_{t-s}, Z_{it-s}\}_{s=0}^{\infty}) . \quad (13)$$

This specification is flexible enough to nest a large class of wage determination processes. In Section 3.7, I discuss the particular functional form of $G(\cdot)$ and relate it to some of the standard wage determination protocols used in the literature.

3.2 Optimality

The first-order condition for capital takes the standard form:

$$\left[1 + \frac{\psi}{K_{it}} \left(\frac{K_{it+1}}{K_{it}} - 1 \right) \right] \mathbb{E}_{it} Q_t = \beta \mathbb{E}_{it} Q_{t+1} \left[\alpha_1 \frac{Y_{it+1}}{K_{it+1}} + 1 - \delta + (1 - \delta) \frac{\psi}{K_{it+1}} \left(\frac{K_{it+2}}{K_{it+1}} - 1 \right) \frac{K_{it+2}}{K_{it+1}} \right] .$$

Under the assumption that the firm chooses an interior solution for the fraction of recruiters¹², the optimality condition is,

$$\alpha_2 \frac{Y_{it}}{N_{it}(1 - V_{it})} \mathbb{E}_{it} Q_t = \beta \mathbb{E}_{it} \xi_{it+1} F_{it} L_{it+1} .$$

where ξ_{it} is the shadow price of employment (i.e. the multiplier on (10), the law of motion for employment) and follows:

$$\xi_{it} = \left(\frac{\alpha_2 Y_{it}}{N_{it}(1 - V_{it})} - W_{it} \right) \mathbb{E}_{it} Q_t + \beta(1 - \delta_n) \mathbb{E}_{it} \xi_{it+1} .$$

¹²With unbounded shocks, this will in general not be true for all i . Unfortunately, explicitly modeling this situation makes the problem almost intractable numerically. However, if shocks are sufficiently small, the probability that a firm will want to choose a corner value will be small as well.

3.3 Aggregate and Idiosyncratic Shock Processes

In this subsection, I specify the nature of the stochastic process followed by the aggregate and idiosyncratic shocks. All the shocks are assumed to follow AR(1) processes in logs

$$\ln A_t = \rho \ln A_{t-1} + u_t \quad (14)$$

$$\ln A_{it} = \rho_a \ln A_{it-1} + u_{it}^a \quad (15)$$

$$\ln Z_{it} = \rho_z \ln Z_{it-1} + u_{it}^z \quad (16)$$

$$\ln L_{it} = \rho_m \ln L_{it-1} + u_{it}^l. \quad (17)$$

where u_t, u_{it}^a, u_{it}^z and u_{it}^l are normally distributed with mean zero and variances $\sigma^2, \sigma_a^2, \sigma_z^2$ and σ_m^2 respectively.

I also make the standard assumption that a law of large numbers applies to the cross-sectional distribution of idiosyncratic shocks i.e. $\forall t$,

$$\int u_{it}^j di = 0, \quad j = a, z, l.$$

3.4 Information Structure

All shocks become common knowledge after a lag of T^* periods. This is a natural, though somewhat stark, way of modeling the delay in the collection of direct information about aggregates from asset prices, published aggregate data. This will also allow me to examine the robustness of my results to the arrival of additional information in a direct way.

Apart from these, firms do not observe any aggregates directly. They only have access to variables which arise in the natural course of their business - wages, productivities, outcomes of their labor market activities. Formally, I assume that firm i 's information set at time t , denoted s_i^t

- Productivities: $\{a_{t-\tau} + a_{i,t-\tau}\}_{\tau=0}^{\infty}$
- Wages: $\{W_{i,t-\tau}\}_{\tau=0}^{\infty}$
- All firm-specific variables: $\{V_{i,t-\tau-1}, K_{i,t-\tau}, N_{i,t-\tau}\}_{\tau=0}^{\infty}$
- $\{U_{t-T^*-\tau}, U_{it-T^*-\tau}, Z_{it-T^*-\tau}, L_{it-T^*-\tau}\}_{\tau=1}^{\infty}$

3.5 An Approximate Equilibrium

A rational expectations equilibrium for this economy is defined in the usual manner (see, for example, Townsend, 1983). Appendix A presents the formal equilibrium definition. However, solving for the exact equilibrium allocations in this economy is quite challenging - with both fundamental and informational heterogeneity, the distribution of types is a high dimensional state variable. Therefore, I construct and solve for an equilibrium in the neighborhood of a deterministic steady state (i.e. one without aggregate or idiosyncratic shocks). I assume that the equations characterizing individual decisions are well-approximated by a first order log-approximation. Further, log-deviations of aggregate variables are assumed to be well approximated by the cross-sectional averages of the log-deviations of individual state variables. Formally, an approximate equilibrium is a set of log-deviations of

- i. Aggregate variables q_t, c_t, n_t, v_t as linear functions of $(u_t, u_{t-1}, \dots)$
- ii. Wages w_{it} as a linear function of $(u_t, u_{it}^a, u_{it}^z, u_{it}^l, u_{t-1}, u_{it-1}^a \dots)$
- iii. Firm-level employment n_{it}
- iv. Firm decisions k_{it+1}, v_{it}, d_{it} as linear functions of the variables that make up the individual histories

such that, to a log-linear approximation,

- (i)-(iv) are consistent with the wage determination equation (13) and the law of motion for employment (10)
- The choices in (iv) solve the firm's problem, taking as given (ii), the law of motion (10) and forecasts of the aggregate variables in (i) made using the firm's information set
- The aggregate allocations are consistent with choices of individual firms and market clearing for state-contingent claims i.e.

$$n_t = \int n_{it} di$$

$$\bar{C}c_t = \bar{W}\bar{N} \int (w_{it} + n_{it}) di + \bar{D} \int d_{it} di ,$$

where $\bar{X}$ denotes the steady state value of X .

3.6 Solution under Full Information

Now, consider the approximate equilibrium under full information i.e. assuming all shocks are common knowledge. The log-linear approximations of the equations characterizing the solution to firm's problem depend only on parameters and the relationship between aggregate variables and aggregate shocks. Importantly, they do not depend on variances of the idiosyncratic (or the aggregate) shock processes. Therefore, given a conjecture about aggregates, the response of agents to either aggregate or idiosyncratic shocks are unaffected by variances. Next, note that due to certainty equivalence, only the expected values of future variables are relevant to the firm's problem. Under full information, the actual realizations of shocks are assumed to be commonly known and so, expectations are common knowledge and unaffected by the variances as well. Finally, variances play no role in a linear aggregation. These features point to an equilibrium in which the relative magnitude of idiosyncratic shocks plays no role in aggregate dynamics. The next proposition formalizes this idea and delivers a key insight: fundamental heterogeneity by itself does have any implications for aggregate behavior in this economy, at least to a first-order approximation.

Proposition 2 *The laws of motion for aggregate variables in the approximate equilibrium is independent of σ_a^2 . In particular, the aggregate behavior of the economy is the same as that of a representative agent economy i.e. one with $\sigma_a^2 = 0$.*

This benchmark result stems from the fact that a log-linear approximation splits the state and optimal policies of each firm into two separate components - one arising from the history of aggregate shocks and the other from the realizations of idiosyncratic shocks. These coefficients are independent of second (or higher) moments. Upon aggregation, the component due to idiosyncratic conditions averages out to zero (because of the law of large numbers assumption). Therefore, aggregate laws of motion depend only on aggregate states and expectations of future aggregate conditions. Without informational frictions, these expectations depend only on (the commonly known) realizations of current and past aggregate productivity shocks. A representative agent version of the model using the same preferences and technology is subject to the same optimality and market clearing conditions and so generates the same relationship between aggregates and the history of aggregate shocks. With informational frictions, this logic no longer holds. Relative variances now matter for the firm's forecasting problem, which changes the response of aggregate variables to aggregate shocks, which in turn affects an individual firm's optimal response to aggregate conditions - in other words, a different equilibrium emerges.

3.7 Wages

Next, I specify the functional form of $G(\cdot)$, the wage determination equation. The standard assumption for wages in the search and matching literature is through a Nash bargaining rule. Applying that protocol to the environment of this paper raises some issues. The first is the need to specify - and impose discipline on - what firms and workers know about fundamentals as well as each others' information. Unlike the natural assumption that firms use the information generated by their market activities to form forecasts, there is no obvious way to model the interconnections between information sets of firms and the workers they hire. The second issue is one of tractability. Existing work on bargaining under informational frictions (Brugemann and Moscarini 2010, Kennan 2010) work in environments that are much simpler and more stylized than the one studied in this paper¹³. The final issue is a pedagogical one. Menzio (2005) and Kennan (2010) show informational asymmetry can lead to a form of wage stickiness. This is good news from the perspective of the volatility puzzle - we know, from Hall (2005), that dampening the response of wages to productivity shocks increases the response of employment. However, the main contribution of this paper is to highlight the implications of informational frictions acting through the confusion about the true nature of shocks. Using a wage determination process that induces wage stickiness confounds this mechanism with the well-known effects of wage rigidity.

For these reasons, in this paper, I take a different approach. I present results under two alternative assumptions for wages. In the first, I directly make assumptions about the relationship of wages to aggregate and idiosyncratic variables. In the second, I assume workers and firms are symmetrically informed and wages are determined by Nash bargaining.

I start by presenting results under the first approach¹⁴. I adopt a specification of the wage equation which allows me to relate my results to earlier work using models with full information and Nash bargaining and help isolate the role of the misattribution mechanism. My starting point is a version of my model without heterogeneity. Appendix D shows that, for sufficiently small shocks, Nash bargaining leads to the following expression for wages:

$$(1 - \tau)W_t = \phi(1 - \tau) \frac{\alpha_2 Y_t}{N_t(1 - V_t)} (1 + \Theta_t) + (1 - \phi)C_t \gamma. \quad (18)$$

where ϕ is a parameter indexing the bargaining power of the worker and τ is the constant labor tax rate. This expression has an intuitive interpretation - the wage is then a weighted average of the

¹³Menzio (2005) and Guerrieri (2007, 2008) also study search models with informational asymmetries but under the assumption that firms post wages.

¹⁴In Section 7, I discuss the numerical results under the alternative approach.

marginal product of labor (adjusted for the dynamic nature of the hiring decision) and the marginal rate of substitution between consumption and leisure, with the relative weights determined by ϕ .

With heterogeneity, I assume that the wage determination equation takes the same form as (18), with some modifications:

$$(1 - \tau)W_{it} = \phi(1 - \tau)\frac{\alpha_2 Y_{it}}{N_{it}(1 - V_{it})}(1 + \Theta_{it}) + (1 - \phi)Z_{it}C_t\gamma. \quad (19)$$

Note that the interpretation of this expression as the outcome of a Nash bargaining protocol is no longer true when we have heterogeneity. Even so, under full information, the log-linear approximation of the average wage rate will be the same as in the representative agent case. Along with Proposition 2, this assumption about wages will ensure that the approximate equilibrium under full information will be identical to that of an economy with a representative agent with wages determined through Nash bargaining, the canonical case studied by most of the literature. In this sense, this specification of wages provides a natural benchmark to evaluate the quantitative contribution of informational frictions.

4 Solution Strategy

This section describes the algorithm for computing the approximate equilibrium described above. For the full information case, Proposition 2 directly points to a solution strategy - simply solve the representative agent model i.e an economy without idiosyncratic shocks. Solving the heterogeneous information case presents two challenges. The first stems from the fact that firms care not only about the realizations of the shocks but also about the reactions of other firms. This strategic linkage arises because (a) the stochastic discount factor Q_t used by the firm depends on aggregate household consumption (and therefore, on the recruiting and investment decisions of all the firms in the economy) (b) the effectiveness of recruiters in sector i depends partly on overall labor market conditions as well, through (11) and (c) future wages depend on aggregate conditions in the economy. Therefore, firms have to form forecasts not just of fundamentals but also of actions of other firms. Since they in turn depend on the others actions, the entire structure of higher order beliefs (what firms believe about other firms' beliefs about others actions, what firms believe about others beliefs about others beliefs and so on) about becomes relevant for determining equilibrium actions. In a one-shot game (like the example in Section 2), all these higher-order beliefs are functions of a single random variable. This allowed the use of a simple method of undetermined

coefficients to solve the problem. With more periods, higher-order beliefs depend in an arbitrary way on the history of signals. As a result, the set of relevant state variables can become quite large as the number of periods increases. Consider the case where past realizations are never revealed i.e. $T^* = \infty$. In this case, strategic linkages lead to the well-known "infinite regress" problem (Townsend, 1983). The evolution of the economy depends on the realizations of an infinite history of signals, making the problem generally intractable. The heterogeneous information literature has dealt with this problem either by restricting attention to special cases where the relevant history can be summarized in a finite dimensional state variable (e.g. Woodford, 2003) or by truncating the dependence of equilibrium actions on higher order beliefs (e.g. Graham and Wright, 2010 or Nimark, 2008) or by modeling the history dependence using finite-order ARMA processes (e.g. Sargent, 1991 or Mackowiak and Wiederholt, 2010).

In this paper, this issue is resolved by the assumption that information is fully revealed after a finite number of periods. Now, only the history over the last T^* periods is relevant for determining the structure of higher-order beliefs. This allows me to summarize the effects of informational frictions on current equilibrium objects in the form of a solution to a finite-dimensional filtering problem. This approach for dealing with the infinite-regress follows Hellwig (2002) and Hellwig (2008a).

The second challenge arises because of the presence of two 'physical' state variables, capital and employment. Now, the history of signals received by a firm affects current decisions in two ways. One, since the learning problem is a dynamic one, they directly affect current forecasts of fundamentals. Two, they also determine the level of its employment and capital at the beginning of the period ¹⁵. Both these effects could be significant in determining the response of equilibrium objects and therefore, it becomes important to keep track of them separately. One of the contributions of this paper is to develop a method to do this in a tractable manner. The methodology combines standard techniques for solving dynamic optimization problems using linear approximations with the approach for dealing with heterogeneous information from Hellwig (2002). The result is a flexible (and tractable) methodology that can handle a rich set of individual state variables as well as complicated signal structures (with both endogenous and exogenous as well as public or private components).

Note that all the shocks - aggregate and idiosyncratic - are assumed to be ultimately transitory, though they may be persistent to an arbitrarily high degree. Also, both capital and employment are

¹⁵This channel is missing, for example, in Hellwig and Venkateswaran (2009) and Mackowiak and Wiederholt (2010).

subject to exogenous depreciation rates. Therefore, the effects of past shocks on current allocations will become arbitrarily small over time. I exploit this feature in my numerical analysis and assume that there exists some large lag T , such that shocks more than T periods old do not have any effect on current variables. In the discussion that follows, any reference to the ‘entire’ history of shocks in period t means the history of shocks upto $t - T$.

A summary of the iterative procedure that is used to solve for allocations in an approximate equilibrium is as follows:

- **Step 1:** Conjecture a (linear) relationship of aggregates to aggregate shocks
- **Step 2:** Derive full information equilibrium policy functions using a log-linear approximation
- **Step 3:** Invoke certainty equivalence to replace unknowns by their conditional expectations
- **Step 4:** Aggregate individual policy rules to express aggregate variables as (linear) functions of aggregate state variables and ‘average’ conditional expectations
- **Step 5:** Exploit normality to write ‘average’ conditional expectations as (linear) functions of aggregate shock realizations
- **Step 6:** Combine to express aggregates in terms of the aggregate shocks
- **Step 7:** Verify conjecture and iterate until convergence

Appendix C provides a more detailed exposition of the solution algorithm.

5 Calibration

Calibration of most of the aggregate parameters is fairly standard and closely follows the strategy in Shimer (2010). Table 1 presents the calibrated values. Appendix E discusses the moments used to pin down most of these parameters. The two new parameters are ψ , the capital adjustment cost parameter and κ , the elasticity of the recruiting efficiency to aggregate conditions. I set the former to match the volatility of investment in the data. The latter is an important choice, because it affects the problem in a number of ways. First, a higher κ makes the outcome of a firm’s recruiting efforts more dependent on aggregate conditions. This implies that when firms mistakenly attribute a positive aggregate shock to idiosyncratic ones, they also overestimate the effectiveness of their recruiters. This reinforces the amplifying effect of informational frictions. Second, κ also enters the wage equation (19) through Θ_{it} and therefore, affects the elasticity of wages with respect to

Description		Value
<i>Preferences and Production</i>		
	Time period	1 month
β	Discount factor	0.996
α_1	Share of capital	0.23
α_2	Share of labor	0.67
δ	Dep. of capital	0.0028
γ	Disutility of leisure	0.43
ρ	Persistence of agg. TFP	0.98
<i>Labor Markets</i>		
δ_n	Rate of exogenous destruction	0.034
τ	Labor tax	0.4
ϕ	Workers' share of surplus	0.5
κ	Elasticity to aggr. conditions	0.75
η	Elasticity of job filling rate	0.5
$\bar{\mu}$	Scale parameter of job filling rate	2.32

Table 1: Calibrated values of aggregate parameters

aggregate and idiosyncratic shocks. A higher κ increases the elasticity to aggregates and dampens the sensitivity to idiosyncratic conditions. Finally, again through wage equation (19), κ affects the amount of information contained in the wage signal. All else equal, higher κ means wages contain more information about aggregate activity. Given these different effects and that fact that there are no direct estimates for κ , I adopt a strategy of presenting results for a range of values for this parameter.

For my baseline calibration of κ , I look to the recent findings in Davis, Faberman and Haltiwanger (2010). They find little evidence of decreasing returns to vacancies at the firm level. Recall that for low κ , the effectiveness of a firm's recruiters is decreases more sharply with its own hiring effort V_{it} . This is precisely the implication that Davis et al. (2010) reject in their data. Note that a common assumption in search models with heterogeneous firms is a common labor market for all i i.e. $\kappa = 1$. I use a baseline value of 0.75 and show the sensitivity of results to this choice in Section 6.3.

Next, I discuss my choice of parameters for the 3 idiosyncratic shock processes - productivity, disutility of working and recruiter efficiency. For each of the shocks, I need to pin down the autocorrelation parameter and the relative variance of the innovation (relative to the variance of the innovation to aggregate productivity). I interpret i , the informational unit in my model, as

a firm. This is a natural starting point for my analysis. It seems reasonable to assume that the sources of information in my model - productivity, wages, labor market outcomes - are most likely to be aggregated at the firm level.

The first set of moments I make use of is from a large body of work documenting the empirical features of firm growth rates in the US. Two robust findings emerge from this literature. One, there is a large cross sectional dispersion in firm level growth rates. Davis et al. (2006) report that from 1970 to 1980, the cross-sectional variance in annual growth rates ranged from 20% to 25%. As a conservative starting point, I use an estimate of 10 % in my calibration. Second, firm growth rates are independent of firm size. This observation, commonly referred to as Gibrat's law, implies that firm-level shocks induce permanent changes in the level of the firm's employment. In the context of my model, this implies that innovations to idiosyncratic productivity have to be permanent¹⁶. For my baseline calibration, I use a value of 0.995 for the persistence of the idiosyncratic process ρ_a . In Section 6.3, I discuss the sensitivity of the results with respect to this choice.

Next, I calibrate the idiosyncratic shocks to recruiter efficiency and disutility of working. The primary purpose of both these shocks is to slow down learning about aggregates from wages and labor market outcomes. Recall that firms' information set includes the history of wages and the results of its past recruiting efforts. Without additional sources of variation, either of these variables would perfectly reveal the aggregate state (albeit, in the case of labor market, with a 1-period lag). With shocks to recruiter efficiency and disutility, learning occurs more gradually. Given that these shocks are introduced primarily for informational reasons, I abstract from any direct effects on intertemporal incentives from them. In other words, I assume that these shocks are completely transitory i.e.

$$\begin{aligned} z_{it} &= u_{it}^z \\ l_{it} &= u_{it}^l . \end{aligned}$$

To calibrate the variance of u_{it}^l , the shocks to recruiter efficiency, I use recent work on vacancies and hiring by Davis, Faberman and Haltiwanger (2010). They find evidence of a strong positive relationship between a firm's employment growth rate and its vacancy yield i.e. the fraction of vacancies that are converted into new hires. Their estimate for the elasticity of vacancy yield to

¹⁶This also finds support from the work of Franco and Philippon (2007), who document the presence of large and permanent firm-specific shocks along with significantly smaller, transitory aggregate shocks using data on large US firms.

hiring of 0.72. To see how this is related to the efficiency shock in my model, consider the case without these idiosyncratic shocks. In that case, the analogue of the vacancy yield in my model, the number of new hires brought in by each recruiter, F_{it} depends negatively on the tightness in market i , Θ_{it} and overall tightness Θ_t . Overall tightness is the same for all firms in the economy while market specific tightness will be higher for firms that are growing (i.e. assigning more workers V_{it} to recruiting activity). Therefore, all else equal, F_{it} will typically be lower for growing firms. In other words, absent shocks to efficiency, growth and vacancy yield will be negatively related. Efficiency shocks affect both growth and vacancy yield in the same direction (by construction) and therefore, are a source of positive comovement. The greater the variance of the efficiency shocks, the greater the degree of positive correlation. Now, there could be other, potentially non-random, mechanisms responsible for this positive comovement¹⁷. Therefore, I conservatively choose a calibration which targets a lower elasticity than the observed value of 0.72. In particular, I set the relative variance of shocks to recruiting efficiency to deliver an elasticity of 0.5.

Next, to discipline the volatility of the idiosyncratic shock to the disutility of working in sector i , u_{it}^z , I interpret the shock as a cause of person-specific effects in wage distribution¹⁸. This interpretation follows from my specification of wages, where z_i is an disturbance orthogonal to both the firm-specific and aggregate components of the wage. A number of papers find a significant role for person-specific effects in the cross-sectional distribution of wages. Abowd, Kramarz and Margolis (1999) find that they account for 50-60% of wage dispersion in the French data. Postel-Vinay and Robin (2002) estimate a structural model using French labor market data and find that person-effects can account for as much as 40% of wage dispersion at high skill levels though this share declines quite sharply for low skilled jobs. Davis et al. (1991) report that within-plant heterogeneity explains as much as 35-40% of the variance in wages.

Obviously, assuming that this individual heterogeneity in its entirety serves to confound the signalling value of wages might be too extreme an assumption. One could argue that firms might be able to observe certain characteristics of the individuals they hire and so may have some information about the realization of z_{it} . In the limit, if they could observe z_{it} perfectly, wages will fully reveal the aggregate state, undoing the informational frictions entirely. Therefore, as with the other shocks, I take a conservative approach and calibrate the relative variance of z_{it} so that it accounts for only 25% of the cross-sectional variance in wages.

¹⁷For example, Davis, Faberman and Haltiwanger (2010) posit that growing firms might be varying an unobserved recruiting intensity per vacancy or that there are increasing returns to vacancies at the micro-level.

¹⁸Nimark (2008) also makes use of a similar interpretation to find empirical counterparts for idiosyncratic marginal cost shocks.

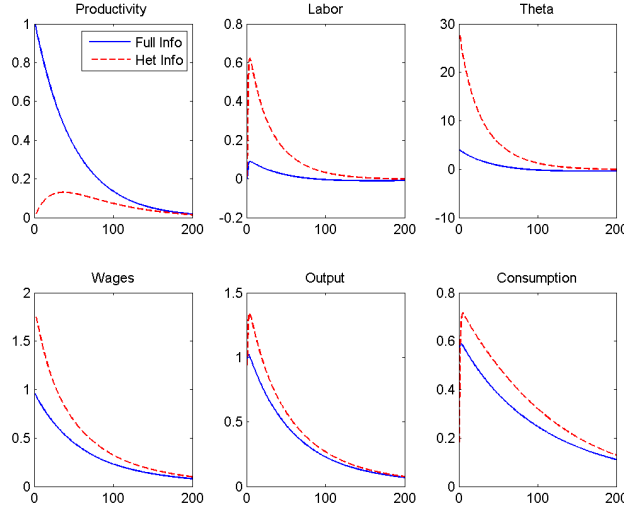


Figure 3: Response of aggregate variables to a positive productivity shock

The other crucial parameter is the full information revelation lag T^* . One option is to use actual delays in the release of data. But that would also require taking a stand on measurement errors or other sources of aggregate uncertainty. I pursue a different approach in this paper. In my baseline calibration, I set T^* to a very large number (in effect, shocks become common knowledge only after they have ceased to have any meaningful effect on equilibrium actions). In Section 6.3, I present some robustness exercises which will show that the quantitative results are still significant even for reasonably low values of T^* .

6 Results

Figure 3 presents impulse responses of the aggregate variables in response to a positive aggregate productivity shock in the economy under full information as well as under heterogeneous information. The first panel plots the evolution of the aggregate productivity along with the average expectations about aggregate productivity. As the graph shows, under the baseline calibration, learning occurs relatively slowly. The remaining panels reveal that this slow learning amplifies the response of other variables to the aggregate shock. In particular, the response of employment and market tightness is an order of magnitude larger under heterogeneous information.

So why does confusion about the nature of the shock amplify the firms' responses? Or to put it differently, why do firms respond more aggressively to perceived changes in idiosyncratic

productivity shocks, relative to aggregate ones ? The basic intuition is the same as in the simple example, though there are more channels for the general equilibrium and learning effects in the full model. Amplification happens for four reasons, only two of which were present in the simple example in Section 2. First, in the baseline calibration, firm-specific shocks are slightly more persistent than aggregate shocks. Second, a firm-specific productivity shock, unlike an aggregate shock, has no effect on aggregate labor market conditions. Therefore, when hit by a positive idiosyncratic shock, the firm can expect to be more successful in its hiring efforts (as measured by the expected efficiency of its recruiters) and so, it responds more aggressively when it mistakes an an aggregate shock for an idiosyncratic one. Thirdly, wages respond differently to the two types of shocks¹⁹. Recall from (19) that wages are a weighted average of (firm-specific) marginal product of labor as well as the marginal rate of substitution (which depends on aggregate consumption). Both aggregate and idiosyncratic productivity shocks affect the MPL (albeit to slightly different degrees), but only aggregate shocks affect the MRS of the representative household. As a result, wages are more responsive to aggregate shocks than idiosyncratic ones. A firm which perceives a positive shock specific to itself expects a greater surplus from new hires and is therefore more inclined to expand its hiring activity. Last, to the extent that firms attribute aggregate shocks to idiosyncratic factors, they also do not make any adjustments to their expectations of the stochastic discount factor.

Another striking feature of the graph is that heterogeneous information amplifies the response of the average wage rate. Many authors (notably Hall, 2005) have argued that the standard model generates too little cyclical movement in the incentives to create new jobs because it assumes that wages respond ‘too much’ to productivity shocks. In other words, wage movements - both current and expected - largely offset the changes in the value of a vacancy from the firm’s perspective. If, on the other hand, wages were rigid (or sufficiently sticky), then the response of vacancies is considerably magnified. Figure 3 shows that informational frictions act through a different mechanism. In fact, relative to the full information case, the economy with heterogeneous information actually has average wages responding more to aggregate shocks. Having said that, expectations about future wage movements do play a role. As discussed in the previous paragraph, informational frictions cause firms to underestimate the response of future wages to the aggregate productivity shock. However, this is not the result of a direct assumption about the wage-setting process, but because of the distinction between aggregate and idiosyncratic productivity shocks.

¹⁹This channel was absent in the example because wages were assumed to be proportional to firm output.

	y	n	θ	c	c-y
Data	1.00	0.64	14.70	0.61	0.66
Full Info	1.00	0.09	3.66	0.58	0.42
Het. Info	1.00	0.46	19.15	0.53	0.37
Sticky Wages	1.00	0.51	21.88	0.26	0.81

Table 2: Relative Standard Deviation (Annual growth rates)

6.1 Moments

Table 2 presents the key second moments of aggregate variables in the model and compares them to their counterparts in the post-war US data. The first panel reports the standard deviation of the annual growth rates of aggregates. For the relevant moments in data, I use the numbers reported by Shimer (2010). Recall that, by Proposition 2, the response of aggregates under full information case is the same as in an economy with a representative agent. Not surprisingly, the row labeled ‘Full Info’ is almost identical to the results reported by Shimer (2010) using a very similar model as the one in this paper, but without heterogeneity. It highlights the inability of the standard model to generate sufficient volatility in labor market activity - the standard deviations of employment and market tightness are off by an order of magnitude.

Adding informational frictions improves the picture significantly. The relative volatility of both employment and market tightness are increased significantly, with the latter now in excess of observed levels. Table 3 repeats the exercise with the logs of the variables (as opposed to growth rates) and tells a very similar story - informational frictions significantly close the gap between volatilities predicted by the model and those observed in the data. Given that the model abstracts from a number of other modifications to the standard model emphasized by other papers, this improvement in performance is quite remarkable.

For purposes of comparison, Table 2 also shows the results from a model with wage stickiness. These are the results reported by Shimer (2010) for a model similar to the one used here but with a representative firm and a sticky wage assumption of the form:

$$W_t = 0.95 W_{t-1} + 0.05 W_t^{\text{Nash}},$$

where W_t^{Nash} is the wage under Nash bargaining. As the table shows, heterogeneous information leads to roughly the same degree of amplification in labor market volatility as the sticky wage

	y	n	θ	c	c-y
Data	1.00	0.65	15.30	0.59	0.64
Full Info	1.00	0.07	2.80	0.76	0.33
Het. Info	1.00	0.35	14.19	0.76	0.37
Sticky Wages	1.00	0.26	11.21	0.68	0.55

Table 3: Relative Standard Deviation (Logs)

	y	n	θ	c	c-y
Data	0.14	-0.46	-0.11	-0.04	-0.49
Full Info	0.98	0.85	0.99	0.96	-0.99
Het. Info	0.19	-0.07	0.41	-0.04	-0.43
Sticky Wages	0.92	0.67	0.75	0.79	-0.88

Table 4: Correlation with Labor Wedge

model. However, informational frictions in this paper operate through a very different channel and therefore lead to different implications for other moments in the data. Two such moments are worth emphasizing. The first is the elasticity of wages to aggregate shocks. As discussed earlier, heterogeneous information magnifies the response of wages to aggregate shocks whereas wage stickiness, by construction, dampens it. This is an important difference, particularly in light of the critique of the sticky wage assumption by Pissarides (2009). Using micro data, he finds that wages of marginal workers are much more responsive to aggregate shocks than those of average workers. He shows that firms' incentives to create new jobs are affected only by wages of marginal workers and therefore, argues that wage stickiness is unlikely to be a big driver of the cyclical behavior of hiring activity. The second difference between the two models relates to the behavior of the aggregate labor wedge, which I define and analyze in the next subsection.

6.2 The Labor Wedge

The *aggregate labor wedge*, denoted $\hat{\tau}_t$, is defined as the deviation between the marginal product of labor and marginal rate of substitution, both computed using aggregate data:

$$\alpha_2 \frac{Y_t}{N_t} (1 - \hat{\tau}_t) = \frac{u'(N_t)}{u'(C_t)} .$$

The wedge is thus the implicit tax on labor income that emerges when an econometrician looks at the data through the eyes of a frictionless representative agent model²⁰ Many authors have documented two key properties of this object in the post-war US data - one, it shows significant amounts of volatility and two, it comoves negatively with the cycle, in particular with aggregate employment. In other words, relative to the frictionless model, the data behave as if the implied labor tax rises significantly during recessions, exacerbating the decline in employment. The opposite happens in a boom.

A good theory of the business cycle, therefore, must be able to match these cyclical patterns. The frictionless real business cycle framework with only productivity shocks implies a constant or *acyclical* wedge. Shimer (2009) surveys alternative explanations for the movements in the wedge and argues that search and matching frictions are the natural framework for analyzing why the marginal product of labor is not equated to the marginal rate of substitution. However, as he shows in Shimer (2010), they tend to induce *procyclical* movements in the wedge. This occurs because search frictions, at some level, act like labor adjustment costs and therefore, serve to dampen the response of labor.

Table 4 shows the correlation of various aggregate variables with the labor wedge $\hat{\tau}_t$. As with relative volatilities, the full information case replicates the earlier findings of the literature i.e. search frictions lead to a strongly procyclical labor wedge. Heterogeneous information acts in the opposite direction. In a boom, for example, firms attribute a positive aggregate shock to a favorable idiosyncratic disturbance and therefore, increase hiring aggressively. From the perspective of the frictionless model, they behave as if they are being subsidized (relative to the full information case). In other words, the misattribution shows up as a reduction in the implicit tax on labor. The net effect of these two opposing forces is an aggregate labor wedge that comoves negatively with employment, although the negative correlation is not as strong as in the data²¹.

Table 4 also highlights an important dimension in which heterogeneous information outperforms

²⁰Note that, with search frictions, the wedge $\hat{\tau}_t$ is not the same as the actual labor tax rate τ , though the two objects are closely related.

²¹Angeletos and La'o (2010a) also generate a source of countercyclical movement in the labor wedge in an economy with heterogeneous information. But, in their setup, this comes from the economy's response to 'noise' in the public signal about productivity. False good news about the economy causes an increase in output and employment, without a corresponding increase in technology. This lowers the MPL and raises the MRS, leading to a drop in the observed wedge. However, in their model, informational frictions lead to *procyclical* movements in the labor wedge in response to aggregate productivity shocks - because output and employment respond less than they would under full information. Here, on the other hand, informational frictions induce a negative comovement between the labor wedge and employment.

	Full Revelation Lag T^*					
	Data	Full Info	T	24	12	6
Rel. Volatility						
Employment	0.65	0.07	0.35	0.35	0.31	0.24
Tightness	15.30	2.80	14.18	14.11	12.57	10.26
Corr. w/ Wedge						
Output	0.05	0.80	-0.29	0.17	0.43	0.61
Employment	-0.46	0.96	-0.30	0.01	0.10	0.24
Tightness	-0.20	0.99	0.01	0.21	0.31	0.45

Table 5: Effect of the Full Revelation Lag, T^*

Relative Volatility of Growth Rates						
	Elas. to aggr. conditions, κ					
	Data	Full Info	1	0.75	0.5	0
Employment	0.64	0.09	0.36	0.46	0.34	0.22
Tightness	14.70	3.66	18.24	19.15	14.20	9.02
No learning from wages						
Employment	0.64	0.09	0.76	0.47	0.34	0.22
Tightness	14.70	3.66	35.52	19.57	14.23	9.02

Table 6: Sensitivity to κ , the elasticity of tightness to aggregate conditions

the model with wage stickiness. The latter achieves only a modest reduction in the procyclicality of the labor wedge. For example, the correlation with employment drops to 0.67 under sticky wages²², whereas in the data, it is -0.46. Informational frictions, on the other hand, generate the right sign for this comovement.

6.3 Robustness

In this section, I present some robustness exercises, which will explore the sensitivity of the results to key parameter assumptions. I start with T^* , the full revelation lag. As mentioned earlier, the baseline calibration sets this parameter to a very large number, implying that the only sources of learning are productivity, wages and labor market outcomes. In Table 5, I report the change

²²Of course, increasing the degree of rigidity will help matters. If wages are completely rigid, as in Hall (2005), then the wedge is indeed countercyclical. See Table 4.3 in Shimer (2010).

	Pers. of idio. prod., ρ_a				
	Data	Full Info	0.995	0.95	0.5
Rel. Volatility					
Employment	0.64	0.09	0.46	0.37	0.17
Tightness	14.70	3.66	19.15	15.60	7.11

Table 7: Sensitivity to Persistence of Idiosyncratic Shocks

in results²³ when all shocks are revealed with much shorter lags. Obviously, the shorter this lag, the less the amplification generated by the confusion between aggregate and idiosyncratic shocks. But, as the table shows, even when the confusion lasts only for a year, there is a quantitatively significant amount of amplification. The improvement on the wedge-employment comovement, however, is slightly more sensitive to this assumption.

Next, I examine the role of κ . Recall that κ controls the dependence of the recruiter efficiency of firm i on overall market tightness. Higher κ increases the degree of this strategic interaction. Also, given the form of the wage equation (13), higher κ reduces the elasticity of wages to idiosyncratic conditions. Both these effects imply that higher κ reinforces the amplification due to misattribution of aggregate productivity shocks to idiosyncratic factors. However, this is partly offset by the fact that a higher κ also increases the flow of information about aggregates in wages. The results in Table 6.2 reflect the net effects of these forces²⁴. The $\kappa = 1$ case actually has lower amplification than the benchmark $\kappa = 0.75$ case - because the increased informativeness of wages more than offsets the other effects. The second panel confirms this intuition - without learning from wages, relative volatilities of employment and θ increase with κ .

Finally, in Table 7, I show the sensitivity of my results to the persistence of idiosyncratic productivity shocks. As in the simple example, strategic interactions lead to amplification even when the persistence of the idiosyncratic shocks is less than that of aggregate shocks (recall that aggregate shocks have a persistence of 0.98). Table 7 shows that these effects are quite strong - even for relatively transitory processes, heterogeneous information increases the volatility of employment and tightness by a factor of 2 or 3.

²³I report the volatilities of the log-deviations, as in Table 3, instead of growth rates. This is because the discrete nature of information causes additional variability in growth rates. Adding measurement errors would help smoothen the arrival of new information and therefore, the response of growth rates, but I do not pursue this approach here.

²⁴For each value of κ , I recalibrate the stochastic processes following the strategy in Section 5.

7 Symmetric Nash Bargaining

In this section, I present results under an alternative assumption for wage determination. Instead of making assumptions about the wage equation directly, now I assume that wages are determined by Nash bargaining between firms and workers. To get around the tractability problems caused by informational asymmetries, I make the additional assumption that each firm and its workers are symmetrically informed²⁵. In Appendix F, I show that the outcome of the bargain is given by the following expression for the after-tax wage:

$$(1 - \tau)W_{it} = (1 - \phi) \frac{\mathbb{E}_{it}(\gamma Z_{it} + \Omega_t)}{\mathbb{E}_{it}Q_t} + \phi \frac{\alpha_2 Y_{it}(1 - \tau)}{N_{it}(1 - V_{it})} ,$$

where Ω_t is the future value to the household of an unemployed worker.

7.1 Results

Table 8 compares key moments under the symmetric bargaining protocol with the results laid out in the previous sections. In both cases, I set the matching function parameter κ to 1. The key feature that emerges from the table is that the symmetric bargaining assumption delivers even greater amplification than the reduced form wage equation. The intuition behind this result is that when bargaining happens with symmetric information, wages contain no additional information about aggregates. Firms learn only from productivity and past labor market outcomes. With the wage equation, firms also learn from their wage bill every period. As a result, the amplification effect from misattribution of shocks also persists for much longer in the symmetric bargaining case²⁶. The last row of the table provides support for this intuition - it shows results when firms do not learn from wages. The reduced form wage equation and symmetric bargaining yield similar results when the additional learning effects in the former specification are turned off.

²⁵One way to interpret this is that the firm bargains with an in-house agent of the representative household. The agent does not communicate with the household and has access to only the information that the firm has. In this interpretation, workers who move across firms (or between the the unemployment pool and firms) from period to period are assumed to carry no information with them.

²⁶Under this assumption, wages also become less responsive to aggregate shocks, providing a further source of amplification. but as the last row of Table 8 indicates, that is relatively less important.

	y	n	θ	c	c-y
Data	1.00	0.64	14.70	0.61	0.66
Full Info	1.00	0.09	3.66	0.58	0.42
Sym. Bargaining	1.00	0.79	37.27	0.58	0.92
Wage Equation	1.00	0.36	18.24	0.46	0.84
Wage Equation *	1.00	0.76	35.52	0.54	0.95

Table 8: Relative Standard Deviation of Growth Rates

* : Without learning from wages

8 Conclusion

A well-known puzzle in modern macroeconomics is the finding that search models, a widely used framework to think about labor markets, fail to generate quantitatively significant aggregate variability, compared to what is observed in the data. The main point of this paper is to argue that this anomaly can be significantly resolved by relaxing the assumption that aggregate conditions are perfectly observed by firms while making hiring decisions. In particular, in an environment where firms are hit by both aggregate and idiosyncratic shocks, the firms' inference problem causes them to be attribute aggregate shocks largely to idiosyncratic factors. Since idiosyncratic shocks do not have offsetting general equilibrium effects, perceived movements in them induce larger adjustments in hiring. As a result, misattribution of aggregate shocks to idiosyncratic factors amplifies the response of the economy to aggregate shocks. In a calibrated model, this mechanism closes most of the gap between a full information benchmark model and the data.

Much work remains ahead. Due to considerations of tractability, the analysis has abstracted from several interesting amplification mechanisms highlighted by the large literature on search and matching models. Endogenous job destruction and on-the-job search are two examples. An investigation of the interactions between these frictions and the information friction that is the focus of this paper holds a lot of promise, both for explaining aggregate behavior but also in understanding features of the cross-sectional distribution. Similarly, the analysis in this paper uses simple wage determination protocols which serve the pedagogical motive of isolating the direct effects of the confusion on firms' incentives to create jobs. Exploring the implications of informational heterogeneity for environments with alternative mechanisms for wage determination is another important and challenging direction for future research. On the informational front, endogenizing the information

structure - either with explicit costs or under the rational inattention paradigm - is a natural next step.

Appendix A Equilibrium Definition

An equilibrium is a set of

- i. State-contingent prices Q_t
- ii. Aggregate allocations C_t, N_t, V_t
- iii. Wages W_{it}
- iv. Firm-level employment N_{it}
- v. Firm decisions K_{it+1}, V_{it}, D_{it}

such that

- (ii)-(v) satisfy the wage determination equation (13) and the law of motion for employment (10)
- The choices in (v) above solve the firm's problem, taking as given the wages in (iii), the law of motion for employment (10) and beliefs about the aggregate variables in (i)-(ii) based on the firm's information set
- The aggregate allocations are consistent with individual choices and market-clearing conditions for the state-contingent securities i.e.

$$N_t = \int N_{it} di$$

$$C_t = \int (W_{it}N_{it} + D_{it}) di$$

Appendix B Steady State

Here, I characterize the deterministic steady state of this economy i.e. assuming no aggregate or idiosyncratic shocks. Note that since firms are identical, informational frictions are irrelevant.

$$\begin{aligned}
\bar{Y} &= \bar{K}^{\alpha_1} \bar{N}^{\alpha_2} (1 - \bar{V})^{\alpha_2} \\
\bar{C} &= \bar{Y} - \delta \bar{K} \\
\frac{1}{\beta} &= \alpha_1 \frac{\bar{Y}}{\bar{K}} + (1 - \delta) \\
\bar{\Theta} &= \frac{\bar{V} \bar{N}}{1 - \bar{N}} \\
\delta_n &= \bar{V} \bar{F} \\
\bar{W} &= \frac{\alpha_2 \bar{Y}}{\bar{N} (1 - \bar{V}) \bar{F}} \left(\frac{1 - \beta (\bar{F} + 1 - \delta_n)}{\beta} \right) \\
\bar{W} &= G(\bar{Y}, \bar{N}, \bar{V}, \bar{C}, \bar{N})
\end{aligned}$$

Appendix C Numerical Solution Methodology

First, I introduce some notation. Define

$$\Omega_{it} \equiv \begin{pmatrix} U_t \\ U_{it}^a \\ U_{it}^z \\ U_{it}^l \end{pmatrix} \text{ where } U_t \equiv (u_t, u_{t-1}, \dots, u_{t-T})' .$$

and U_{it}^j , $j = a, z, l$ are defined analogously.

Step 1: The effect of aggregates on an individual firms problem can be summarized in 2 variables - the (log of the) stochastic discount factor q_t and overall market tightness θ_t . The starting point of the algorithm is a conjecture for the (linear) relationship between these two variables and the entire history of aggregate shocks:

$$\begin{bmatrix} q_t \\ \theta_t \end{bmatrix} = P U_t , \tag{20}$$

where P is a $2 \times T$ matrix. Note that this specification allows aggregate variables, upto a log-linear approximation, to depend on the history of aggregate shocks in an arbitrary way.

Step 2: Next, I solve the problem of firm i , assuming it is perfectly informed i.e. assuming it knows the entire history of aggregate and idiosyncratic shocks affecting it. The firm enters period t with its current capital stock k_{it} as well as the level of employment and choice of recruiting effort in $t - 1$, n_{it-1} and v_{it-1} respectively. The last two are state variables because they affect the level of employment in the current period. In addition, the entire history of innovations to all the shock processes affecting the firm's payoffs (Ω_{it}) will affect the firm's decisions. These shocks are relevant not only because they directly affect the firm's current productivity, wages etc., but also because they form the basis for the firm's forecasts of future values of aggregate and firm-specific factors. The solution to this problem can be expressed in the form of a law of motion for the firm's state and policy variables:

$$X_{it} = BX_{i,t-1} + D\Omega_{it} \quad \text{where } X_{it} \equiv \begin{pmatrix} k_{it+1} \\ n_{it} \\ v_{it} \\ w_{it} \\ d_{it} \end{pmatrix}. \quad (21)$$

Step 3: The next step makes use of certainty equivalence implicit in the linear approximation of the policy rules and replaces the actual realizations in (21) with conditional expectations.

$$X_{it} = BX_{i,t-1} + D\mathbb{E}_{it}\Omega_{it}. \quad (22)$$

Step 4: To derive the laws of motion for the aggregate state variables, I add (22) over all i . The result is a law of motion which depends only on aggregate state variables and 'average' expectations about aggregate and firm-specific shocks in the economy.

$$X_t = BX_{t-1} + D\bar{\mathbb{E}}_t\Omega_{it} \quad \text{where} \quad \bar{\mathbb{E}}_t(\cdot) = \int \mathbb{E}_{it}(\cdot) \, di. \quad (23)$$

Step 5: Next, I characterize the average expectations in this economy. To achieve this, note that the signals received firm i are linear combinations of Ω_{it} i.e., for a suitably defined Γ ,

$$s_i^t = \Gamma \Omega_{it}.$$

Then, standard filtering results using normally distributed variables imply that

$$\mathbb{E}_{it}\Omega_{it} \equiv \mathbb{E}(\Omega_{it}|s_{it}) = \Sigma \Gamma' (\Gamma \Sigma \Gamma')^{-1} s_{it} \quad (24)$$

$$= \Sigma \Gamma' (\Gamma \Sigma \Gamma')^{-1} \Gamma \Omega_{it}, \quad (25)$$

where Σ is the variance-covariance matrix of Ω_{it} . Average expectations are given by

$$\begin{aligned}\bar{\mathbb{E}}_t(\Omega_{it}) &= \int \mathbb{E}_{it}\Omega_{it} \, di = \int \mathbb{E}(\Omega_{it}|s_{it}) \, di = \Sigma \Gamma' (\Gamma \Sigma \Gamma')^{-1} \Gamma \int \Omega_{it} \, di \\ &= \Sigma \Gamma' (\Gamma \Sigma \Gamma')^{-1} \Gamma \bar{\Omega}_t ,\end{aligned}$$

where $\bar{\Omega}_{it}$ is the cross-sectional average of the shocks. Since we assume a law of large numbers to be in effect for the idiosyncratic shock realizations,

$$\bar{\Omega}_t = \begin{pmatrix} U_t \\ \mathbf{0} \\ \mathbf{0} \\ \mathbf{0} \end{pmatrix} .$$

Average expectations thus can be written as a function only of the aggregate shock vector U_t i.e.

$$\bar{\mathbb{E}}_t(\Omega_{it}) = H \, U_t .$$

Step 6: Substituting the expression for average expectations back into (23),

$$X_t = B X_{t-1} + D H \, U_t . \tag{26}$$

Step 7: Equation (26) implies a relationship between the stochastic discount factor q_t and market tightness θ_t and the realizations of the aggregate shock U_t :

$$\begin{bmatrix} q_t \\ \theta_t \end{bmatrix} = \tilde{P} \, U_t . \tag{27}$$

If $\tilde{P} = P$, my initial guess, then the algorithm has converged and the allocations implied by (22), (25) and (26) constitute an approximate equilibrium as defined in Section 3.5. If not, i.e. $\tilde{P} \neq P$, then we repeat the above steps using a new conjecture:

$$P_1 = g \, P + (1 - g) \, \tilde{P} , \quad g \in (0, 1) .$$

Appendix D Nash Bargaining without heterogeneity

For this analysis in this section, I assume that there is no heterogeneity. The value to the representative firm of hiring an additional worker at an arbitrary wage W at time t (as before, I suppress the s^t notation for brevity) is given by

$$J_t(W) = Q_t(W_t - W) + \xi_t ,$$

where ξ_t is the shadow value of an additional worker (at the equilibrium wage W_t). The law of motion for this value is given by

$$\xi_t = \left(\frac{\alpha_2 Y_t}{N_t(1 - V_t)} - W_{it} \right) Q_t + \beta(1 - \delta_n) \mathbb{E}_t \xi_{t+1} . \quad (28)$$

To derive an analogous expression for the household, I first specify the household's perceived law of motion for aggregate employment.

$$N_t = N_{t-1}(1 - \delta_n) + (1 - N_{t-1})\Theta_{t-1}F_{t-1} .$$

Let χ_t be the multiplier associated with this constraint. As with the firm's multiplier, we can show that χ_t satisfies

$$\chi_t = \frac{1}{C_t}(1 - \tau)W_t - \gamma + (1 - \delta_n - \Theta_t F_t)\beta \mathbb{E}_t \chi_{t+1} . \quad (29)$$

The household's value from having an additional worker employed at an arbitrary wage W is

$$H_t(W) = \frac{1}{C_t}(1 - \tau)(W - W_t) + \chi_t .$$

Nash bargaining implies that the equilibrium wage W_t solves

$$\max_W H_t(W)^\phi J_t(W)^{1-\phi}$$

The FOC of this problem

$$\begin{aligned} \phi \frac{1}{C_t}(1 - \tau) \left(\frac{1}{H_t} \right)_{W=W_t} &= (1 - \phi) Q_t \left(\frac{1}{J_t} \right)_{W=W_t} \\ \phi \frac{1}{C_t}(1 - \tau) \frac{1}{\chi_t} &= (1 - \phi) Q_t \frac{1}{\xi_t} \\ \phi (1 - \tau) \frac{1}{\chi_t} &= (1 - \phi) \frac{1}{\xi_t} \\ \chi_t &= \frac{\phi(1 - \tau)}{1 - \phi} \xi_t , \end{aligned}$$

where the second step makes use of the fact that $H_t = \chi_t$ and $J_t = \xi_t$ at the equilibrium wage and the third equality simply notes that $Q_t = \frac{1}{C_t}$. Substituting the last relationship into (29) and rearranging,

$$\xi_t = \frac{(1-\phi)}{\phi(1-\tau)} \left(\frac{1}{C_t}(1-\tau)W_t - \gamma \right) + (1-\delta_n - \Theta_t F_t) \beta \mathbb{E}_t \xi_{t+1} . \quad (30)$$

Next, note that the FOC for the firm's choice of V_t implies²⁷

$$\beta \mathbb{E}_t \xi_{t+1} = \frac{\alpha_2 Y_t}{N_t(1-V_t)F_t} Q_t .$$

Using this to eliminate $\mathbb{E}_t \xi_{t+1}$ from the right sides of (28) and (30), we get

$$\begin{aligned} \xi_t &= \left(\frac{\alpha_2 Y_t}{N_t(1-V_t)} - W_t \right) Q_t + (1-\delta_n) \frac{\alpha_2 Y_t}{N_t(1-V_t)F_t} Q_t \\ \xi_t &= \frac{(1-\phi)}{\phi(1-\tau)} \left(\frac{1}{C_t}(1-\tau)W_t - \gamma \right) + (1-\delta_n - \Theta_t F_t) \frac{\alpha_2 Y_t}{N_t(1-V_t)F_t} Q_t . \end{aligned}$$

Equating the right-hand sides and noting that $Q_t = \frac{1}{C_t}$, I solve for the after tax wage:

$$(1-\tau)W_t = \phi(1-\tau) \frac{\alpha_2 Y_t}{N_t(1-V_t)} (1 + \Theta_t) + (1-\phi)C_t \gamma .$$

Appendix E Calibration

The strategy for picking preference and technology parameters is based largely on Shimer (2010). The values for the discount rate β , the share of labor α_2 and the capital depreciation rate δ are borrowed directly from the real business cycle literature. The share of capital, α_1 is set to target a total share paid to factors of 90%. The persistence of the aggregate shock ρ also corresponds to the values used in the RBC literature, adjusted for the fact that a time period in this paper is a month.

The rate of exogenous separation δ_n is taken from Shimer (2005). Hagedorn and Manovskii (2008) estimate that hiring a worker costs about 4% of a worker's quarterly wage, which implies that each recruiter attracts 25 workers on average per quarter (i.e. the monthly counterpart $\bar{F} = 8.33$). The following steady-state relationship then pins down the fraction of workers engaged in recruiting in the steady state:

$$\delta_n \bar{N} = \bar{V} \bar{N} \bar{F} \quad \Rightarrow \quad \bar{V} = \frac{\delta_n}{\bar{F}} .$$

Given a target for steady state employment ($\bar{N} = 0.95$), the estimate for $\bar{V}$ determines the steady state tightness, $\bar{\Theta}$. The matching function in this paper takes as input recruiting effort,

²⁷Note that this assumes an interior solution for V_t . This is true at the steady state and will hold in a neighborhood around the steady state for sufficiently small shocks.

instead of the usual measure of vacancies posted, so there are no direct estimates of the elasticity available. I follow Shimer (2010) and consider the symmetric case i.e. $\eta = 0.5$. Given this choice, equation (11) pins down the scale parameter $\bar{\mu}$. The worker’s ‘share’ of the surplus ϕ is set to 0.5. The disutility of leisure, γ , is chosen so that steady state unemployment is 5%. Finally, the labor tax τ is set to match the average marginal tax rate.

Appendix F Symmetric Nash Bargaining

References

- Abowd, John, Francis Kramarz, and David N. Margolis. 1999. “High Wage Workers and High Wage Firms.” *Econometrica* 67 (2): 251–333.
- Adam, Klaus. 2007. “Optimal monetary policy with imperfect common knowledge.” *Journal of Monetary Economics* 54 (2): 267 – 301.
- Amador, Manuel, and Pierre-Olivier Weill. 2010. “Learning from Prices: Public Communication and Welfare.” *Journal of Political Economy*. forthcoming.
- Andolfatto, David. 1996. “Business Cycles and Labor-Market Search.” *American Economic Review* 86 (1): 112–32 (March).
- Angeletos, George-Marios, and Jennifer La’O. 2008. “Dispersed Information over the Business Cycle: Optimal Fiscal and Monetary Policy.” Mimeo, MIT.
- . 2010a. “Noisy Business Cycles.” In *NBER Macroeconomics Annual 2009, Volume 24*, NBER Chapters, 319–378. National Bureau of Economic Research, Inc.
- . 2010b. “Sentiments.” Mimeo, MIT.
- Angeletos, George-Marios, and Alessandro Pavan. 2007. “Efficient Use of Information and Social Value of Information.” *Econometrica* 75 (4): 1103–1142.
- Bacchetta, Philippe, and Eric van Wincoop. 2006. “Can Information Heterogeneity Explain the Exchange Rate Determination Puzzle?” *The American Economic Review* 96 (3): pp. 552–576.
- Brugemann, Bjorn, and Giuseppe Moscarini. 2010. “Rent Rigidity, asymmetric information, and volatility bounds in labor markets.” *Review of Economic Dynamics* 13 (3): 575 – 596.
- Cheremukhin, Anton A. 2010. “Labor Matching Models: Putting The Pieces Together.” Mimeo, UCLA.

- Cheremukhin, Anton A., and Paulina Restrepo-Echavarria. 2010. "The Labor Wedge as a Matching Friction." Mimeo, UCLA.
- Cole, Harold L., and Richard Rogerson. 1999. "Can the Mortensen-Pissarides Matching Model Match the Business-Cycle Facts?" *International Economic Review* 40 (4): 933–959.
- Costain, James S., and Michael Reiter. 2008. "Business cycles, unemployment insurance, and the calibration of matching models." *Journal of Economic Dynamics and Control* 32 (4): 1120 – 1155.
- Davis, Steve J., John Haltiwanger, Lawrence F. Katz, and Robert Topel. 1991. "Wage Dispersion between and within U.S. Manufacturing Plants, 1963-86." *Brookings Papers on Economic Activity. Microeconomics* 1991:pp. 115–200.
- Davis, Steven J., R. Jason Faberman, and John C. Haltiwanger. 2010, August. "The Establishment-Level Behavior of Vacancies and Hiring." Working paper 16265, National Bureau of Economic Research.
- Davis, Steven J., John Haltiwanger, Ron Jarmin, and Javier Miranda. 2006, July. "Volatility and Dispersion in Business Growth Rates: Publicly Traded versus Privately Held Firms." Working paper 12354, National Bureau of Economic Research.
- Eyigungor, Burcu. June 2010. "Specific Capital and Vintage Effects on the Dynamics of Unemployment and Vacancies." *The American Economic Review* 100:1214–1237(24).
- Farmer, Roger E., and Andrew Hollenhorst. 2006. "Shooting the Auctioneer." *SSRN eLibrary*.
- Franco, Francesco, and Thomas Philippon. 2007. "Firms and Aggregate Dynamics." *Review of Economics and Statistics* 89 (4): 587–600.
- Gertler, Mark, and Antonella Trigari. 2006. "Unemployment Fluctuations with Staggered Nash Wage Bargaining." *SSRN eLibrary*.
- Gorodnichenko, Yuriy. 2008. "Endogenous Information, Menu Costs and Inflation Persistence." NBER Working Paper No. 14184.
- Graham, Liam, and Stephen Wright. 2010. "Information, heterogeneity and market incompleteness." *Journal of Monetary Economics* 57 (2): 164 – 174.
- Guerrieri, Veronica. 2007. "Heterogeneity, Job Creation and Unemployment Volatility." *Scandinavian Journal of Economics* 109 (4): 667–693.
- . 2008. "Inefficient Unemployment Dynamics under Asymmetric Information." *Journal of Political Economy* 116 (4): 667–708.

- Haan, Wouter J. den, Garey Ramey, and Joel Watson. 2000. "Job Destruction and Propagation of Shocks." *The American Economic Review* 90 (3): pp. 482–498.
- Hagedorn, Marcus, and Iourii Manovskii. 2008. "The Cyclical Behavior of Equilibrium Unemployment and Vacancies Revisited." *The American Economic Review* 98:1692–1706(15).
- Hall, Robert E. 2005. "Employment Fluctuations with Equilibrium Wage Stickiness." *The American Economic Review* 95:50–65(16).
- Hall, Robert E., and Paul R. Milgrom. 2008. "The Limited Influence of Unemployment on the Wage Bargain." *The American Economic Review* 98:1653–1674(22).
- Hellwig, Christian. 2002. "Public Announcements, Adjustment Delays and the Business Cycle." Mimeo, UCLA.
- . 2008a. "Heterogeneous Information and Business Cycle Fluctuations." Mimeo, UCLA.
- . 2008b. "Monetary Business Cycles (Imperfect Information)." In *The New Palgrave Dictionary of Economics*, edited by Steven N. Durlauf and Lawrence E. Blume. London: Palgrave-Macmillan.
- Hellwig, Christian, and Venky Venkateswaran. 2009. "Setting the right prices for the wrong reasons." *Journal of Monetary Economics* 56 (Supplement 1): S57 – S77.
- Kennan, John. 2010. "Private Information, Wage Bargaining and Employment Fluctuations." *Review of Economic Studies* 77:633–664.
- Krause, Michael U., and Thomas A. Lubik. 2007. "The (ir)relevance of real wage rigidity in the New Keynesian model with search frictions." *Journal of Monetary Economics* 54 (3): 706 – 727.
- Lorenzoni, Guido. December 2009. "A Theory of Demand Shocks." *The American Economic Review* 99:2050–2084(35).
- . 2010. "Optimal Monetary Policy with Uncertain Fundamentals and Dispersed Information." *Review of Economic Studies* 77 (1): 305–338.
- Lucas, Robert Jr. 1972. "Expectations and the neutrality of money." *Journal of Economic Theory* 4 (2): 103–124 (April).
- Mackowiak, Bartosz Adam, and Mirko Wiederholt. 2009. "Optimal Sticky Prices Under Rational Inattention." *American Economic Review* 99 (2): 769–803.

- . 2010. “Business Cycle Dynamics Under Rational Inattention.” Mimeo, European Central Bank/Nothwestern University.
- Mankiw, N. Gregory, and Ricardo Reis. 2002. “Sticky Information Versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve.” *Quarterly Journal of Economics* 117 (4): 1295–1328.
- Menzio, Guido. 2005. “High Frequency Wage Rigidity.” Mimeo, University of Pennsylvania.
- Menzio, Guido, and Shouyong Shi. 2009. “Efficient Search on the Job and the Business Cycle.” *SSRN eLibrary*.
- Mortensen, Dale T., and Eva Nagypal. 2007. “More on unemployment and vacancy fluctuations.” *Review of Economic Dynamics* 10 (3): 327 – 347.
- Mortensen, Dale T., and Christopher A. Pissarides. 1994. “Job Creation and Job Destruction in the Theory of Unemployment.” *The Review of Economic Studies* 61 (3): pp. 397–415.
- Mortensen, Dale T., and va Nagypal. 2007. “Labor-market Volatility in Matching Models with Endogenous Separations.” *Scandinavian Journal of Economics* 109 (4): 645 – 665.
- Moscarini, Giuseppe. 2004. “Limited information capacity as a source of inertia.” *Journal of Economic Dynamics and Control* 28 (10): 2003 – 2035.
- Nimark, Kristoffer. 2008. “Dynamic pricing and imperfect common knowledge.” *Journal of Monetary Economics* 55 (2): 365 – 382.
- Phelps, Edmund S. 1970. “Introduction: The New Microeconomics in Employment and Inflation Theory.” In *Microeconomic Foundations of Employment and Inflation Theory*, edited by Edmund et al. Phelps. New York: Norton.
- Pissarides, C. A. 2009. “The Unemployment Volatility Puzzle: Is Wage Stickiness the Answer?” *Econometrica* 77 (5): 13391369.
- Postel-Vinay, Fabien, and JeanMarc Robin. 2002. “Equilibrium Wage Dispersion with Worker and Employer Heterogeneity.” *Econometrica* 70 (6): 2295–2350.
- Reis, Ricardo. 2006. “Inattentive Producers.” *Review of Economic Studies* 73 (3): 793–821 (07).
- Sargent, Thomas J. 1991. “Equilibrium with signal extraction from endogenous variables.” *Journal of Economic Dynamics and Control* 15 (2): 245 – 273.
- Shimer, Robert. 2005. “The Cyclical Behavior of Equilibrium Unemployment and Vacancies.” *The American Economic Review* 95 (1): pp. 25–49.

- . 2009. “Convergence in Macroeconomics: The Labor Wedge.” *American Economic Journal: Macroeconomics* 1 (1): 280–97 (January).
- . 2010. *Labor Markets and Business Cycles*. Princeton University Press.
- Sims, Christopher A. 2003. “Implications of Rational Inattention.” *Journal of Monetary Economics* 50 (5): 665–690.
- Sun, Yeneng. 2006. “The exact law of large numbers via Fubini extension and characterization of insurable risks.” *Journal of Economic Theory* 126 (1): 31 – 69.
- Townsend, Robert M. 1983. “Forecasting the Forecasts of Others.” *Journal of Political Economy* 91 (4): 546–588.
- Veldkamp, Laura, and Justin Wolfers. 2007. “Aggregate shocks or aggregate information? Costly information and business cycle comovement.” *Journal of Monetary Economics* 54 (Supplement 1): 37 – 55. Supplement issue: October 20-21 2006 Research Conference on ‘Microeconomic Adjustment and Macroeconomic Dynamics’ Sponsored by the Swiss National Bank (<http://www.snb.ch>) and Study Center Gerzensee (www.szgerzensee.ch).
- Woodford, Michael D. 2003. “Imperfect Common Knowledge and the Effects of Monetary Policy.” In *Knowledge, Information and Expectations in Modern Macroeconomics: In Honor of Edmund S. Phelps*, edited by Phillippe Aghion et al.