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# Endogenous Real Wage Rigidity in a Search Frictions Model\*

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## Abstract

The existing literature often incorporates ad-hoc models of exogenous real wage rigidity into search frictions models of the labour market in order to match the large volatility of unemployment observed in the data. In this paper, we develop an alternative version of the search frictions model that incorporates insights from behavioural economics. We derive a model in which endogenous real wage rigidity emerges from optimal wage-setting and show that this model can match the observed volatility of unemployment. Thus our proposed model can match the data as closely as the existing literature but without the disadvantage of assuming exogenous and ad hoc forms of real wage rigidity.

Keywords: real wage rigidity, search frictions, behavioural economics, unemployment volatility puzzle

JEL Classification: *E23, E32, J23, J30, J64*

## 1 Introduction

Explaining movements of labour market variables across the business cycle has proved to be difficult. Models based around search frictions in the labour market that use standard parameterisations of the structural parameters imply a low volatility of unemployment and vacancies, in contrast to empirical evidence of substantial volatility. An influential strand of argument suggests that generating high volatility of unemployment and vacancies requires the volatility of the real wage to be low (eg Shimer, 2005). Real wage rigidity has proved to be a successful way of achieving this; many authors have found that adding some type of real wage rigidity to the standard search frictions model enables them to

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generate sufficient volatility in unemployment to match the data. But although these types of real wage rigidity enable the search frictions model to match the data, they are not microfounded in the behaviour of households or firms. We refer to these as models of exogenous wage rigidity. In the literature, there are four widely used representations of exogenous wage rigidity. These comprise (i) the case of a fixed real wage (eg Hall, 2005); (ii) partial adjustment of the wage towards the bargained wage (eg Krause and Lubik, 2007, Christoffel and Linzert, 2010, and Shimer, 2010); (iii) relating the real wage to both the bargained wage and the steady-state value of the bargained wage (eg, Krause and Lubik, 2007, and Faia, 2008) and (iv) assuming that the wage fluctuates around the steady-state value of the bargained wage in response to the shocks that drive the business cycle (eg, Blanchard and Gali, 2007 and Michaillait, 2012).

In this paper, we develop an alternative version of the search frictions model that incorporates insights from behavioural economics; we refer to this as a "behavioural search" model for simplicity. We use this model to derive four models of optimal wage-setting by firms that closely resemble the four widely-used representations of exogenous wage rigidity in the literature. We also show that these models are able to match the observed volatility of unemployment and other moments of the data. Thus our proposed model can match the data as closely as the existing literature but without the disadvantage of assuming exogenous and ad hoc forms of real wage rigidity.

We are not the first to develop behavioural search models; other examples include Danthine and Donaldson (1990), Danthine and Kurmann (2007, 2010), Eliaz and Speigler (2013) and Kuang and Wang (2017). Our contribution is to argue that this framework enables the derivation of models of optimal wage-setting that resemble existing models of exogenous real wage rigidity. We do not use our model to address the wider issue of how unemployment volatility can best be modelled, as this is beyond the scope of this paper. Therefore we do not compare our model against alternatives such as the alternating offer bargaining approach to wage determination proposed by Hall and Milgrom (2008), the staggered wage-setting approach of Gertler and Trigari (2009), or other models that have been proposed to address unemployment volatility.

In our model, output depends on effort exerted by workers where effort is determined by workers. We assume that effort affects worker utility through two offsetting channels, a dislike of exerting effort and a reciprocity effect. With the reciprocity effect, the worker derives utility from responding to a generous wage offer from the firm by increasing effort, or from "punishing" a low wage offer from the firm by reducing effort; evidence for this includes Kahneman et al (1986), Bewley (1999) and Fehr et al (2009). We model the reciprocity effect, following Rabin (1993) and Danthine and Kurmann (2007), by assuming that workers evaluate the firm's wage offer relative to a reference wage; this is supported by evidence in Fehr and Falk (1999), Brown et al (2004) and Della Vigna and Pope (2016). Using this framework, we derive an optimal supply of effort function in which effort depends on the wage offered by the firm relative to the worker's reference wage. In this model, effort is unobservable and so cannot be the subject of a worker-firm negotiation; this distinguishes our approach from the related

literature (eg Gali and van Rens, 2016) in which effort is determined through a bargain. We also assume wage-posting: the firm makes a wage offer to the worker; if accepted, the worker determines their level of effort and production occurs. Wages are determined through two trade-offs. Workers determine their optimal supply of effort by trading off the costs of exerting effort against the reciprocity benefit, at the margin. Firms in turn trade off the cost of higher wages against the benefit of higher output. We show that the optimal wage offered by firms minimises the average cost of output through a version of the Solow Condition (Solow, 1979), modified to reflect labour market frictions. The resultant wage is closely linked to the reference wage used by workers to evaluate the generosity of wage offers from the firm. Our optimal wage equations show that incorporating insights from behavioural economics can give an interesting new perspective on wage determination in which the focus is on the forces driving the worker's optimal choice of effort and how the firm incorporates these into the choice of the wage they offer to the worker.

Existing models of exogenous real wage rigidity incorporate the Nash bargained wage. In order to obtain a similar variable in our model of behavioural search with wage posting, we use the concept of the "fair wage". Although the fair wage has been widely used in the literature (eg Danthine and Kurmann, 2010, Kuang and Wang, 2017), this has to date been modelled using reduced form functions of employment and the wage; wage rigidity is obtained by including the lagged wage in the reduced form representation of the fair wage. We instead derive an endogenous representation of the fair wage by assuming that workers feel entitled to at least a minimum share of the surplus from their job match. This fair wage resembles the Nash bargained wage but has a sharply different interpretation, consistent with a model of wage posting. We obtain our four models of optimal wage-setting by assuming that the reference wage is either (i) fixed (giving a wage equation similar to Hall (2005)); (ii) a function of the fair wage and the lagged wage (giving a wage equation similar to Krause and Lubik, 2007, Christoffel and Linzert, 2010, and Shimer, 2010); (iii) a function of the fair wage and the average value of the fair wage (in which case the wage equation is similar to Faia, 2008); or (iv) a function of the steady-state value of the fair and productivity shocks, giving a wage equation that is similar to Blanchard and Gali (2007) and Michaillait (2012).

In models of exogenous wage rigidity, the intuition for fluctuations in unemployment across the business cycle is simple and follows Hall (2005). In response to a positive productivity shock, firms post an increased number of vacancies, resulting in increased labour market tightness and a reduction in unemployment. In response to a negative shock, firms post fewer vacancies, resulting in an increase in unemployment and a reduced marginal cost of hiring. Through this mechanism, sharp movements in unemployment across the business cycle are generated and thus the model can generate a large unemployment volatility. This process is stronger when wages are less responsive to the business cycle, as highlighted by Shimer (2005) in his interpretation of the unemployment volatility puzzle. A similar intuition applies with the behavioural search model. Since the wage equations we obtain exhibit substantial real wage rigidity, firms again

respond to a positive productivity shock by posting an increased number of vacancies, leading to a reduction in unemployment. Thus, these wage equations also imply a large volatility of unemployment. A key feature of our optimal wage equations is the presence of extensive wage rigidity. This arises because the reference wage has a low volatility across the business cycle. We argue that there is no mechanism in behavioural search models that implies a stable reference wage and hence there is nothing intrinsic in behavioural models that generates wage rigidity. Rather, our argument for a stable reference wage is empirical. We argue that there is substantial evidence of a stable reference wage, including Koenig et al (2017), Gneezy and List (2006), Crawford and Meng (2011) and Wadhvani and Wall (1991).

The paper is structured as follows. In section 2), we document models of exogenous real wage rigidity that have been used in the literature. Section 3) then outlines the standard search frictions model and highlights the mechanism through which unemployment volatility is generated. In section 4), we develop our alternative behavioural search model and discuss how alternative relationships between the reference wage and the fair wage imply wage equations that resemble existing models of exogenous real wage rigidity. Section 5) discusses calibration of our model and presents our simulation results. Section 6) concludes by suggesting avenues for future research.

## 2 Exogenous Real Wage Rigidity in the Literature

We can classify approaches to real wage rigidity in the existing literature into four main types. The first type, introduced by Hall (2005), simply assumes a fixed real wage, so

$$w_t = w \tag{1}$$

where  $w_t$  is the real wage. Hall (2005) motivates this approach by noting that any outcome within the bargaining set is a potential equilibrium and arguing that a fixed wage that lies within this set can be sustained through a “social norm”. However, as noted by Kennan (2009), there is no theory of social norms and so the wage equation in (1) is not fully microfounded<sup>1</sup>. The second type, used by Krause and Lubik (2007), Christoffel and Linzert (2010) and Shimer (2010), assumes that wages reflect Nash bargaining and uses the lagged wage to capture rigidity, so

$$w_t = \phi w_{t-1} + (1 - \phi) w_t^{Nash} \tag{2}$$

where  $w_t^{Nash}$  is the real wage obtained through Nash bargaining and  $\phi$  is a measure of real wage rigidity. The literature has generally assumed substantial

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<sup>1</sup>Kennan (2009) derives a fixed real wage using a model where productivity, which can be either high or low, is observed by the firm but not the worker. This mechanism requires a richer theoretical framework than the standard search frictions model.

rigidity: Krause and Lubik (2007) use  $\phi = 1$ , while Christoffel and Linzert (2010) and Shimer (2010) assume  $\phi = 0.9^2$ . This wage equation is not microfounded<sup>3</sup>. The third type of real wage rigidity, introduced by Krause and Lubik (2007) and Faia (2008), takes a similar approach by assuming

$$w_t = \phi w^{Nash} + (1 - \phi) w_t^{Nash} \quad (3)$$

where  $w^{Nash}$  is the steady-state value of the bargained wage. Krause and Lubik (2007) assume  $\phi = 1$ . Faia (2008) assumes  $\phi = 0.6$ , as do more recent contributions such as Albertini and Fairise (2013) and Torrachi (2017). The fourth main type, introduced by Blanchard and Gali (2007), models the cyclicalty of the real wage using

$$w_t = w^{Nash} s_t^{1-\phi_1} \quad (4)$$

where  $s_t$  is a productivity shock (which drives movements in output in this model) and  $\phi_1$  is an alternative measure of real wage rigidity. Blanchard and Gali (2007) and Michaillat (2014) assume  $\phi_1 = 0.5$ , while Michaillat (2012) assumes  $\phi_1 = 0.3$  and Kohlbrecher (2016) assume  $\phi_1 = 0.2$ .

### 3 A Simple Search Model

In this section, we briefly discuss the standard search frictions model without behavioural effects and discuss why wage rigidity implies an increased volatility of unemployment. We use a discrete time model. Within a time period, first shocks are realised and then hiring occurs. After this, wages are determined, then production occurs followed by exogenous separation. If there is no agreement about the wage, the worker is unemployed for the remainder of period and the firm has an unfilled vacancy. A job match dissolves at the end of the period with exogenous probability  $\tau$ .

#### 3.1 The Labour Market

The labour market is characterised by search frictions. Aggregate hiring is determined by the matching function

$$h_t = m u_t^\alpha v_t^{1-\alpha} \quad (5)$$

where  $h$  is the number of workers hired,  $u$  is the unemployment rate and  $v$  is the vacancy rate.  $m$  and  $\alpha$  are parameters characterising the matching function.

<sup>2</sup>Abbritti and Weber (2008) assume  $\phi = 0.5$ , while Merkl (2009) assumes  $\phi = 0.6$ . In a recent contribution, Leduc and Liu (2017) assume  $\phi = 0.95$ .

<sup>3</sup>Gali and van Rens (2014) motivate a generalisation of (2) given by  $w_t = \phi_t w_{t-1} + (1 - \phi_t) w_t^{Nash}$ , where  $\phi_t$  is a function of the distance between the wage and the boundaries of the bargaining set, by assuming that the wage is fixed with the bargaining set but adjusted to the Nash wage if the fixed wage hits the boundaries of the bargaining set.

Defining labour market tightness as

$$\theta_t = \frac{v_t}{u_t} \quad (6)$$

the matching function can also be written as

$$h_t = mu_t\theta_t^{1-\alpha} \quad (7)$$

The vacancy filling rate, the probability of a firm filling a vacancy, is

$$q_t = \frac{h_t}{v_t} = m\theta_t^{-\alpha} \quad (8)$$

while the job finding rate, the probability that an unemployed worker finds a job is

$$f_t = \frac{h_t}{u_t} = \theta_t q_t \quad (9)$$

### 3.2 Workers

There is a continuum of identical workers on the unit interval. In period  $t$  a worker is either employed or unemployed. If employed, the worker earns (and consumes) real wage  $w_t$ ; if unemployed, they receive the opportunity cost of employment  $z$ , reflecting unemployment benefits and the flow value of non-work activities. An employed worker becomes unemployed in the next period with exogenous probability  $\tau$ . An unemployed worker finds a job and is employed in the next period with probability  $f_{t+1}$ , where  $f$  is exogenous to the worker but endogenous to the model. The value functions for employed and unemployed workers are

$$L_t = w_t + \frac{1}{1+r} E_t[(1-\tau)L_{t+1} + \tau U_{t+1}] \quad (10)$$

and

$$U_t = z + \frac{1}{1+r} E_t[f_{t+1}L_{t+1} + (1-f_{t+1})U_{t+1}] \quad (11)$$

### 3.3 Firms

There is a continuum of identical firms on the unit interval. Each firm can hire up to one worker. The production function is

$$y_t = s_t \quad (12)$$

where  $s_t = e^{\varepsilon_t^s}$  is a technology shock; we assume  $\varepsilon_t^s = \rho^s \varepsilon_{t-1}^s + \eta_t^s$  where  $\eta_t^s$  is distributed as  $N(0, \sigma_s^2)$ . The value function of a filled job is

$$J_t = y_t - w_t + \frac{1}{1+r} E_t[(1-\tau)J_{t+1} + \tau V_{t+1}] \quad (13)$$

where  $V$  is the value function of a vacant job, given by

$$V_t = -\gamma + \frac{1}{1+r} E_t[q_{t+1}J_{t+1} + (1 - q_{t+1})V_{t+1}] \quad (14)$$

Firms must pay a real cost of  $\gamma$  to post a vacancy. Vacancies are then filled at the start of the next period with probability  $q^4$ .

We assume free entry of firms, so  $V_t = 0$ . This implies that the value function for vacancies simplifies to

$$J_t = (1+r) \frac{\gamma}{q_t} \quad (15)$$

and so the value function for a filled job becomes

$$(1+r) \frac{\gamma}{q_t} = y_t - w_t + (1-\tau) \frac{\gamma}{E_t q_{t+1}} \quad (16)$$

or

$$y_t = w_t + \lambda_t \quad (17)$$

where  $\lambda_t = \frac{\gamma}{m} \{(1+r)\theta_t^\alpha - (1-\tau)E_t\theta_{t+1}^\alpha\}$  is the real cost of hiring a worker.

### 3.4 The Sources of Unemployment Volatility

The firm's optimality condition in (17) implies

$$\frac{\partial w_t}{\partial y_t} + \frac{\partial \lambda_t}{\partial y_t} = 1 \quad (18)$$

The impact of productivity shocks on unemployment volatility can be understood through this relationship. Consider the extreme case in which the wage is fixed, as in Hall (2008). In response to a positive productivity shock, firms post an increased number of vacancies, resulting in increased labour market tightness and a reduction in unemployment; this results in an increased marginal cost of hiring, satisfying (18). In response to a negative shock, firms post fewer vacancies, resulting in an increase in unemployment and a reduced marginal cost of hiring, again satisfying (18). Through this mechanism, a fixed real wage leads to sharp movements in unemployment across the business cycle and thus the model can generate a large unemployment volatility.

The amount of unemployment volatility generated by the model is smaller the more responsive the wage is to productivity shocks, as the model then requires weaker fluctuations in unemployment in order to satisfy (18). This is why the models reviewed in section 2) require substantial amounts of wage rigidity in order to generate empirically plausible levels of unemployment volatility. The role of wage adjustment in reducing unemployment volatility is also highlighted

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<sup>4</sup>As we discuss below, we numerically solve and then simulate our model. The assumption that vacancy that is matched to a worker becomes immediately productive ensures the model satisfies the Blanchard-Khan condition.



in the case where the wage is determined through Nash bargaining. Here, the wage can be expressed as (e.g. Mortensen and Nagypal, 2007)

$$w_t^{Nash} = \eta(y_t + \gamma E_t \theta_{t+1}) + (1 - \eta)z \quad (19)$$

where  $\eta$  is the relative bargaining power of workers. In this case it is well known that wages are highly responsive to productivity shocks. The strong responsiveness of wages to productivity shocks, implies, through (18), a small adjustment of the marginal cost of hiring; which implies only a mild volatility of unemployment. This is the underlying cause of the "unemployment volatility puzzle" highlighted by Shimer (2005).

## 4 A Behavioural Search Model

In this section we construct our behavioural search model and use this to derive a series of optimal wage equations that are similar to the existing models of exogenous wage rigidity outlined in section 2). Our model incorporates two non-standard elements into an otherwise standard search frictions model. First, output depends on effort exerted by workers, where the optimal supply of effort is determined by the worker. Second, wages are set by firms, rather than being determined through worker-firm bargaining. These modelling choices are motivated by insights from the behavioral economics literature, supported by empirical evidence. We now briefly summarise these.

First, considering effort, Williamson (1985) and Hart and Moore (2008) argue that employment contracts are inherently incomplete since only a minimum level of job performance can be legally enforced. As a result, workers have discretion over the amount of effort they devote to the job. The effort supplied by workers is often modelled as depending on a worker's perception of the fairness of the wage offered by the firm, where the fairness of a wage offer is evaluated relative to a worker's reference wage. The relationship between effort and fairness is motivated by reciprocity; this idea was the basis of the "gift exchange" variant of efficiency wage theory proposed by Akerlof (1982) and Akerlof and Yellen (1990); these effects were introduced into the business cycle literature by Danthine and Donaldson (1990). The role of the reference wage was stressed by Kahnemann and Tversky (1979), who relate this to the concept of reference dependent preferences (see also Della Vigna, 2009). Using this concept, reciprocity and reference wages were introduced to game theory by Rabin (1993), whose approach was used by Danthine and Kurmann (2007) to derive a macroeconomic relationship between effort and wages.

There is a large empirical literature documenting the importance of these effects (summarised in Della Vigna, 2009, and Fehr, 2009). Laboratory studies supporting fairness effects include Fehr and Falk (1999), who find wages above the competitive level, sustained by reciprocal high levels of worker effort, in the context of an experimental labour market in which firms cannot monitor effort. Camerer (2003) finds frequent rejection of outcomes perceived as being unfair within the ultimatum game; similar evidence is obtained by Brown et al (2004),

although in this study a sizeable minority of participants do not exhibit such pro-social behaviour. Beyond the laboratory, Kreuger and Mas (2004) document how attempts by major US tyre producers to reduce the wage were perceived as unfair and led to a sharp reduction on the quality of output. Other examples include Gneezy and List (2006), who find that higher paid workers input data into a library information system more rapidly and Cohn et al (2014) who found that workers were productive in distributing free newspapers when they perceived their wages as fair.

Further support for the importance of these effects comes from outside the behavioural literature. A number of studies have analysed the responses of firms to questions about the determinants of wages using data derived from a series of surveys conducted at different dates in a number of different countries. These include Blinder and Choi (1990), Bewley (1999), Campbell and Kamlani (1997) and Levine (1993) for the US, Galuščák et al (2012) for 15 EU countries, Millard and Tatomir (2015) for the UK and Agell and Lundborg (2003) for Sweden. These studies find that firms consistently cite the adverse impact on the effort of workers as a primary reason for not reducing wages when their economic environment deteriorates.

Second, considering wage posting, Hall and Kreuger (2012) note that there are two main approaches to wage determination in search frictions models, wage posting, in which firms make take-it-or-leave-it offers to workers, and wage bargaining. Hall and Kreuger (2012) also note that although wage posting is associated with models of directed search, "the assumption of a posted wage in a model with random search would not be unreasonable".

There are two studies of the incidence of different types of wage setting. Hall and Kreuger (2012) study responses of 1400 workers to survey questions on the circumstances in which they took their most recent job. In total, only 31% of workers reported some type of wage bargaining. This proportion is larger for professional and knowledge-based occupations. It is also much larger for workers engaged in on-the-job-search. Brenzel et al (2014) examine the responses of over 9,000 firms to the recurrent German Job Vacancy Survey and find similar results. They find that only 38% of firms report wage bargaining; this proportion falls to 27% in industries covered by a collective wage agreement and to 32% when an unemployed worker is hired. Wage bargaining is much more likely when the job opening requires an experienced and more highly skilled worker. These studies reveal a good deal of diversity in wage-setting. But it is clear that wage bargaining is not common, especially in the type of hiring consistent with the standard search frictions model: hiring to occupations where there is no difference in productivity between workers and where newly-hired workers come from unemployment rather than an alternative employer.

However, as Hall and Kreuger (2012) stress, this is not inconsistent with the alternating offer bargaining protocol of Hall and Milgrom (2008) where the first offer made in a negotiation, assumed to come from the firm, is always accepted. But evidence in Galuščák et al (2012) argues against alternating offer wage bargaining. Galuščák et al (2012) examine responses of Chief Executive Officers or Human Resource Managers of around 15,000 firms to a firm-level

survey on wage- and price-setting practices in 15 EU countries, conducted under the auspices of the European Central Bank. They find that wages offered to newly-hired workers are more strongly affected by wages offered within the firm than by wages on the wider labour market (the relative weights on internal and external factors are roughly 4:1); similar evidence is found in Levine (1993) and other papers that examine the role of internal and external factors in wage setting. This goes against alternating offer bargaining, where the wage is driven by external factors.

Given this evidence, we assume wage posting in our model with undirected search, in contrast to almost all of the existing literature that uses a wage bargaining framework. Two issues arise. First, why do firms choose not to bargain with workers? Empirical evidence in Galuščák et al (2012) suggests a possible reason. They find that only 16% of firms would consider offering newly hired workers a higher wage in a tight labour market (and only 13% would consider offering a lower wage in a loose labour market); the reasons cited for not doing so include the adverse impact on the effort of incumbent workers, the impact on the reputation of the firm and the presence of collective agreements with the workforce. Thus, many firms do not bargain over wages with newly-hired workers as they are unwilling to offer a wage different from the going wage within the firm because this would reduce the productivity of existing workers. Second, why does the Diamond Paradox, whereby wages are driven down to the worker's reservation wage, not apply? In our model, as we show below, it is optimal for firms to offer a wage that exceeds the reference wage, so the Diamond Paradox is not applicable in this case.

## 4.1 Optimal Effort

We amend the value function of an employed worker to be

$$L_t = w_t - c(e_t) + R(e_t, w_t) + \frac{1}{1+r} E_t[(1-\tau)L_{t+1} + \tau U_{t+1}] \quad (20)$$

where  $c(e_t)$  is the disutility of exerting effort and  $R(e_t, w_t)$  is utility gained from reciprocity. We follow Rabin (1993) and Danthine and Kurmann (2007) by assuming that

$$R(e_t, w_t) = g(w_t)d(e_t) \quad (21)$$

where  $g(w_t)$  is the worker's perception of the wage offer of the firm and  $d(e_t)$  is the worker's reciprocal response. In this specification, the specification of  $g(w_t)$  captures how workers view the offer of a wage  $w_t$  by the firm and  $d(e_t)$  captures how they respond to this through a willingness to exert effort. Thus, if workers perceive a wage offer as generous, they reciprocate through a greater willingness to exert effort.

Workers determine their optimal supply of effort to maximise the value function in (20); the optimal level of effort satisfies

$$c_e(e_t) = d_e(e_t)g(w_t) \quad (22)$$

We assume  $c(e_t) = \frac{\omega e_t^{1+\varphi}}{1+\varphi}$  and  $d(e_t) = \frac{\kappa e_t^{1+\chi}}{1+\chi}$ ; the optimal supply of effort is then

$$e_t = \mu_1 g(w_t)^\sigma \quad (23)$$

where  $\sigma = \frac{1}{\varphi-\chi}$  and  $\mu_1 = (\frac{\kappa}{\omega})^\sigma$ .

We follow the literature in assuming that workers evaluate the firm's wage offer relative to a reference wage  $w_t^{ref}$ , so  $g(w_t) = (\frac{w_t - w_t^{ref}}{w - w^{ref}})$ , where  $(w - w^{ref})$  is the differential of the wage over the reference wage in steady-state. The optimal effort function is

$$e_t = \mu_1 \left( \frac{w_t - w_t^{ref}}{w - w^{ref}} \right)^\sigma \quad (24)$$

This simple effort function has two interesting properties. First, a similar effort function was estimated in Della Vigna and Pope (2016), providing an estimate of  $\sigma$  that can be used in calibrating the model; this estimate is small. Second,  $w_t^{ref}$  acts as a form of reservation wage as workers will not exert positive effort for a lower wage.

## 4.2 The Optimal Wage

To accomodate endogenous effort and wage posting, we amend the sequence of events within a time period. After shocks are realised, hiring occurs. Then the firm posts a wage; if the worker accepts this offer, they become employed and determine the amount of effort to expend. Production then occurs followed by exogenous separation. If the worker does not accept the wage offer, they are unemployed for the remainder of period and the firm has an unfilled vacancy. We amend the production function to be

$$y_t = \mu s_t e_t \quad (25)$$

where  $e_t$  is the amount of effort exerted by the worker and  $\mu = (\frac{\kappa}{\omega})^{-\sigma}$  is a constant, set to ensure output equals unity in steady-state.

The firm will choose the wage to maximise the value of a filled job, given by

$$J_t = E_t \sum_{k=0}^{\infty} \left( \frac{1-\tau}{1+r} \right)^k (\mu s_{t+k} e_{t+k} - w_{t+k}) \quad (26)$$

The optimality condition is

$$\mu s_t e_{w,t} = 1 \quad (27)$$

where  $e_{w,t}$  is the derivative of effort with respect to the wage. In setting the wage, the firms trades off the impact of a higher wage on the wage bill against the benefit of higher effort, at the margin. Writing the optimality condition for the wage as

$$\varepsilon_{e,w} = \frac{w_t}{y_t} \quad (28)$$

where  $\varepsilon_{e,w}$  is the elasticity of effort with respect to the wage. This is a version of the classic Solow (1979) condition, adapted to a search frictions context. From

(19), the wage is less than output because of search costs and so  $\varepsilon_{e,w} < 1$  (in the absence of search frictions, we obtain the original Solow Condition,  $\varepsilon_{e,w} = 1$ ). Thus effort and the wage are higher than in the original Solow model, as a result of search frictions. Noting that  $\varepsilon_{e,w} = \sigma \frac{w_t}{w_t - w_t^{ref}}$ , the optimal wage is

$$w_t = w_t^{ref} + \sigma y_t \quad (29)$$

Using (17) to substitute output then gives

$$w_t = \frac{1}{1 - \sigma} w_t^{ref} + \frac{\sigma}{1 - \sigma} \lambda_t \quad (30)$$

This wage equation shows that incorporating insights from behavioural economics gives an interesting new perspective on wage determination in which the focus is on the forces driving the worker's optimal choice of effort and how the firm incorporates these into the choice of the wage they offer to the worker. The firm offers workers a wage that is a mark-up over the reference wage and also depends on labour market search frictions, embedded in the marginal cost of hiring. We note that with this wage equation, the wage exceeds the reference wage, in contrast to some influential studies such as Kahneman et al (1986).

### 4.3 The Fair Wage

The models of exogenous real wage rigidity in section 2) feature the Nash bargained wage. In this section we outline how we obtain similar relationships in our behavioural search model where wages are determined through wage posting by firms rather than through worker-firm bargaining. The behavioural literature has stressed the importance of the "fair wage", although this has tended to be modelled as being exogenous. We develop a simple endogenous model of the fair wage, where we interpret this as the minimum wage to which workers feel entitled. To be specific, we assume that workers feel entitled to at least a minimum share of the surplus generated by a job match. Denoting the surplus generated by an employed worker's job match as  $S$ , we assume that the worker feels entitled to at least a minimum share  $v$  of this surplus. This implies <sup>5</sup>

$$(L_t - U_t) = v S_t \quad (31)$$

Denoting the minimum wage to which the worker feels entitled to as  $w_t^{fair}$ , then

$$w_t^{fair} = v(y_t + \gamma E_t \theta_{t+1}) + (1 - v)z \quad (32)$$

This appears similar to the Nash bargained wage in (19) but has a markedly different interpretation.  $w^{fair}$  is not the wage; it is a worker's perception of the

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<sup>5</sup>For simplicity, this uses the value function for employed workers in (10) rather than in (20), so workers calculate the fair wage without reference to effort. In practice, this makes little difference since simulations of our model, reported below, show that  $c(\cdot) - R(\cdot)$  is close to zero and our small calibrated value for  $\sigma$  implies that  $c(\cdot)$  and  $d(\cdot)$  are highly unresponsive to the wage.

lowest wage to which they feel entitled. If the reference wage is the minimum wage to which the worker feels entitled, so

$$w_t^{ref} = w_t^{fair} \tag{33}$$

then the optimal wage offered by firms is

$$w_t = \frac{1}{1-\sigma} w_t^{fair} + \frac{\sigma}{1-\sigma} \lambda_t \tag{34}$$

Since  $\sigma$  is small, the main driver of the wage in (34) is the "fair wage". Since the fair wage will be strongly cyclical unless the worker's entitled share of the surplus,  $v$ , is calibrated to be small, this simple model is unable to generate a large volatility of unemployment. This highlights the fact that there is no mechanism in behavioural search models that leads to wage rigidity and hence there is nothing intrinsic in behavioural models that generates a large volatility of unemployment.

#### 4.4 Optimal Wage Equations With Endogenous Rigidity

We next explore alternative specifications of the reference wage that lead to wage equations with endogenous real wage rigidity that resemble the exogenous wage rigidity models in Section 2). These alternative specifications are based on a similar idea; that the reference wage has a low volatility across the business cycle.

This assumption is supported by empirical evidence that the reference wage has low volatility across the business cycle. Koenig et al (2017) analyse longitudinal micro data on the lowest wage at which workers would take a job, taken from the British Household Panel Survey, covering 1991-2009, and the German Socio Economic Panel, covering 1984-2010. They argue that this variable cannot be interpreted as the reservation wage, the wage at which workers are indifferent between employment and unemployment, as it's volatility is much lower than the highly volatile reservation wage. They instead provide a more behavioural interpretation that corresponds closely to the concept of the reference wage. In the light of this, we can use this evidence on the cyclical nature of this reservation wage as being informative about how the reference wage varies across the business cycle. Koenig et al (2017) find that this variable is slightly less volatile than the actual wage in the UK and almost three times less volatile than the wage in Germany. They also estimate that the elasticity of this wage with respect to unemployment is small. We can therefore interpret this evidence as showing that the reference wage has low volatility across the business cycle. Other evidence suggestive of a low volatility of the reference wage includes Wadhvani and Wall (1991), who find evidence of partial adjustment of reference wages in estimated wage equations using UK firm-level data, Gneezy and List (2006), who find adaptation of reference wages in response to changes in the actual wage in their study of library workers, and the study of the behaviour of New York cab drivers in Crawford and Meng (2011).

From this empirical evidence, we infer that the reference wage has low volatility across the business cycle and frame our modelling of this variable accordingly. In doing so, we follow authors such as Eliaz and Speigler (2013), who develop a model in which effort takes one of two values, and Kuang and Wang (2017), who follow Danthine and Kurmann (2007) in expressing effort as a reduced form function of wages and employment. Although we take a similar approach, we differ from Eliaz and Speigler (2013) by assuming that effort is continuous rather than binary and differ from Kuang and Wang (2017) in developing a model of the fair wage in order to derive wage equations that resemble those in section 2).

#### 4.4.1 A Fixed Fair Wage

We first consider the case where

$$w_t^{ref} = w^{fair} \quad (35)$$

so the reference wage is the steady-state value of the fair wage; here, workers view a wage offer that exceeds the normal value of the fair wage as generous. The optimal wage offered by firms is

$$w_t = \frac{1}{1-\sigma} w^{fair} + \frac{\sigma}{1-\sigma} \lambda_t \quad (36)$$

Recalling that econometric estimates of  $\sigma$  are small, this wage equation is similar to the real wage equation proposed by Hall (2005), in (1). This wage equation exhibits substantial real wage rigidity, consistent with empirical evidence of a low volatility of the reference wage. Therefore firms respond to a positive productivity shock by posting an increased number of vacancies. This implies a reduction in unemployment and an increased marginal cost of hiring. Thus, this wage equation implies a large volatility of unemployment, generated through the mechanism highlighted by Hall (2005).

#### 4.4.2 An Adaptative Fair Wage

The experimental literature on fair wages and effort has found that workers' reference wages adjust to changes in the wage (Kahneman et al, 1986, Fehr et al, 2009, Cohn et al, 2014). In addition, Koenig et al (2017) argue that their reservation wage measure is influenced by a worker's labour market history. To capture these adaptation effects, we next assume that the reference wage is

$$w_t^{ref} = (1-\varpi)w_t^{fair} + \varpi w_{t-1} \quad (37)$$

With this specification, workers respond to a higher wage than normal by increasing the wage to which they feel entitled. The implied wage is

$$w_t = \frac{(1-\varpi)}{1-\sigma} w_t^{fair} + \frac{\varpi}{1-\sigma} w_{t-1} + \frac{\sigma}{1-\sigma} \lambda_t \quad (38)$$

This is similar to the wage equation in (2), used by Krause and Lubik (2007), Christoffel and Linzert (2010) and Shimer (2010). Evidence of a low cyclical volatility of the reference wage suggests a relatively large value for  $\varpi$ , enabling the model to generate a large unemployment volatility through a similar mechanism to the case of the fixed fair wage.

#### 4.4.3 An Adjustable Fair Wage

Alternatively, a wage equation similar to those used by Faia (2008), Albertini and Fairise (2013) and Torrachi (2017) can be obtained if

$$w_t^{ref} = \varpi w_t^{fair} + (1 - \varpi) w_t^{fair} \quad (39)$$

The optimal wage is

$$w_t = \frac{(1 - \varpi)}{1 - \sigma} w_t^{fair} + \frac{\varpi}{1 - \sigma} w_t^{fair} + \frac{\sigma}{1 - \sigma} \lambda_t \quad (40)$$

which is similar to (3). This wage equation can also generate a large volatility of unemployment, through a similar mechanism, if  $\varpi$  is large.

#### 4.4.4 A Cyclical Fair Wage

Finally, we consider the case where

$$w_t^{ref} = w_t^{fair} s_t^{1 - \varpi_1} \quad (41)$$

where  $\varpi_1$  measures how the reference wage varies around the normal fair wage across the business cycle. Here, a wage offer that exceeds the cyclically adjusted fair wage is seen as generous. The optimal wage is then

$$w_t = \frac{1}{1 - \sigma} w_t^{fair} s_t^{1 - \varpi_1} + \frac{\sigma}{1 - \sigma} \lambda_t \quad (42)$$

This is similar to (4), the wage equation used by Blanchard and Gali (2007) and Michaillat (2012, 2014). This model can generate a large volatility of unemployment if  $\varpi_1$  is sufficiently large.

## 5 Simulation Results

In this section we present simulation evidence to complement the analysis in previous sections. We calibrate the model, as discussed below. The model comprises the equations for labour market dynamics in (5)-(9), the production function in (12) (for the exogenous search model) or (25) (for the behavioural search model), the optimality condition in (17), and either the equation for the Nash bargained wage in (19) and one of the exogenous wage equations in section 2) (for exogenous rigidity); or the effort function in (24), the fair wage in (32) and one of the behavioural search wage equations in section 4.4). This model is



linearised and solved numerically; it is then simulated and key statistics generated.

We do a series of pairwise comparisons of the four variants of the exogenous wage rigidity model with the corresponding variant of the behaviour search model. Thus we compare the model that uses the fixed wage equation in (1) with the model implied by the fixed fair wage equation in (36); we compare the model implied by (2) with the model implied by the adaptive fair wage equation in (38), and so on. We also compare the model implied by Nash wage bargaining without wage rigidity with the model implied by the fair wage equation in (34).

## 5.1 Calibration Strategy

We normalize a time period to be one month. We calibrate our parameters using widely used values in the existing literature. The discount rate is set as  $r = 0.42\%$ , equivalent to an annual discount rate of 5%. We follow Hall and Milgrom (2008) and assume that the average opportunity cost of employment is  $z = 0.71$ . Chodrow-Reich and Karabarounis (2016) report a range of empirical estimates of the opportunity cost of employment, between 0.47 and 0.96, based on alternative specifications of the flow value of non-work; the mid-point of this range is also  $z = 0.71$ . For the matching function, we set  $\alpha = 0.4$ ; this is the mid-point of the range of estimates obtained by Petrongolo and Pissarides (2001). We calibrate the remaining structural parameters to hit a series of calibration targets, outlined in Table 2). We target the persistence and volatility of US productivity growth for 1951-2004 as reported in Hagedorn and Mankovskii (2008); to meet these targets, we set  $\rho^s = 0.765$  and  $\sigma_s = 0.0084$ . We also target  $u = 0.059$ ; the average value of the US unemployment rate, 1948-2016, and  $\theta = 0.72$ , the value for average labour market tightness reported by Pissarides (2009). For the model with exogenous wage rigidity, we calibrate the bargaining power of workers to meet the target for the average rate of unemployment. This gives  $\eta = 0.482$ . We then calibrate  $\gamma$  so that the model matches  $\theta = 0.716$ . This gives  $\gamma = 0.38$ ; this value lies in the range of calibrated values of  $\gamma$  in the literature<sup>6</sup>. We calibrate the monthly job separation rate as  $\tau = 0.036$ <sup>7</sup>. Since  $fu = \tau(1 - u)$ , our values for  $\tau$  and  $u$  imply the average job-finding rate is  $f = 0.573$ ; this is close to Shimer (2005b)'s estimate of  $f = 0.594$ . We then calibrate  $m$  to satisfy the relationship  $f = m\theta^\alpha$ ; for these values of  $f$  and  $\theta$ ; this implies  $m = 0.70$ .

For the behavioural search model, we retain the calibrated parameters above, with the exception of  $\eta$ . The key parameter in this model is the elasticity of the effort function,  $\sigma$ . To calibrate this we use estimates of an effort function similar to (24) in Della Vigna and Pope (2016). Della Vigna and Pope (2016) use data on the behaviour of 10,000 participants in an experiment using the

<sup>6</sup>The value of  $\gamma$  is contentious. Shimer (2005) uses a quarterly vacancy cost of 0.213. Hagedorn and Manovskii (2008) use a weekly vacancy cost of 0.584. Hall (2005) assumes a monthly cost of 0.986 while Pissarides (2009) assumes 0.356.

<sup>7</sup>In the literature, monthly values of  $\tau$  vary between 0.03 (Hall and Milgrom, 2008) and 0.036 (Pissarides, 2009).

Mechanical Turk platform. They estimate a very low elasticity of the effort function. Based on their estimates, we calibrate  $\sigma = 0.02$ . We follow Danthine and Kurmann (2010) in setting the elasticity of  $d(e_t)$  to  $1 + \chi = 0.75$ ; this implies  $\chi = -0.25$ . These calibrated values for  $\sigma$ , and  $\chi$  imply  $\varphi = 49.75$ . We set  $\omega = 0.755$  and  $\kappa = 0.0093$ . Although there are no prior studies or other evidence to guide our calibrations of these parameters, the simulated volatilities are not sensitive to the specific values chosen. With this calibration, the utility cost of effort and the utility benefits of reciprocation are equal to 1.5% and 1.2% respectively of output in steady-state. We set  $\mu = 1.092$  to ensure output equals unity in steady-state. Given these, we calibrate  $\nu$  to match the average value of unemployment in US data, similar to the calibration of  $\eta$ . Doing so results in  $\nu = 0.423$ . The fact that this is slightly lower than the calibrated value of  $\eta$  is consistent with our model since  $\eta$  is the share of the surplus workers are able to obtain, while  $\nu$  is the smallest share of the surplus to which they feel entitled. Our calibrated parameter values are summarised in Table 1).

Table 1— Calibrated Parameters

Parameter	Interpretation	Value
$\rho^s$	Persistence of Supply Shock	0.765
$\sigma_s$	Volatility of Supply Shock	0.0084
$\tau$	Separation Rate	0.036
$r$	Discount Rate	0.0042
$z$	Average Opportunity Cost of Employment	0.71
$\gamma$	Vacancy Cost	0.38
$m$	Matching Coefficient	0.7
$\alpha$	Matching Elasticity	0.4
$\eta$	Wage bargaining Power of Workers	0.482
$\nu$	Entitlement Share of Workers	0.423
$\sigma$	Elasticity of $e(\cdot)$	0.02
$\varphi$	Elasticity of $d(\cdot)$	49.74
$\chi$	Elasticity of $c(\cdot)$	-0.25
$\omega$	Cost of Effort Function	0.755
$\kappa$	Reciprocity Function	0.0093
$\mu$	Production Function	1.092

With these calibrations, both the exogenous wage rigidity and the behavioural search models match our calibration targets closely; see Table 2).

Table 2— Calibration Targets

Parameter	Interpretation	(i)	(ii)	(iii)
		U.S Data	Exog. Rigidity	Behav. Search
$\sigma_s$	Volatility of US Productivity Growth	0.013	0.013	0.013
$\rho^s$	Persistence of US Productivity Growth	0.765	0.765	0.765
$\theta$	Average Labour Market Tightness	0.72	0.716	0.722
$u$	Average Unemployment Rate	0.059	0.059	0.059

## 5.2 Simulation Results

We assess our models through their ability to match the volatilities of unemployment, labour market tightness and vacancies and the correlations between unemployment and vacancies and between unemployment and labour market tightness, as reported by Hagedorn and Manovskii (2008) for the US, 1951-2004<sup>8</sup>. These are detailed in the first row of Table 3). Row (2a) present results for the case where the wage is equal to the Nash bargained wage in (19), while row (2b) presents results for the case where the reference wage equals the fair wage, in (34). The results are very similar. Neither model comes close to matching the volatilities of unemployment vacancies and labour market tightness in US data. The correlations between these variables are essentially the same in both models. The correlation between unemployment and labour market tightness comes quite close to matching the correlation in the data; the correlation between unemployment and vacancies is strongly negative but does not match the observed value<sup>9</sup>. The relative failure of the model where wages are set through Nash bargaining has been familiar since Shimer (2005). The failure of the model where wages are equal to the fair wage is more novel. It highlights the argument that there is nothing intrinsic in behavioural models that generates the level of wage rigidity that is required for a model to match the data.

Rows (3a) and (3b) presents results for the models where the wage is fixed, as in (1), and for the behavioural search model with a fixed reference wage, as in (36). Both models are able to match observed volatilities closely, especially for labour market tightness and unemployment. The results in row (3a) are not surprising, as they essentially repeats the findings of Hall (2005). However the results for the behavioural search model in row (3b) are more novel; they demonstrate that a behavioural search model can match the data as well as existing models of exogenous wage rigidity<sup>10</sup>. The correlations between the variables are again very similar to each other and to the correlations in row (2). These correlations reflect Beveridge Curve mechanisms that generate a negative correlation between unemployment and the other variables. These mechanisms

<sup>8</sup>In doing so, we choose to assess these alternative models in terms of their ability to match labour market data. Several of the models discussed in section 2) have a wider focus and consider the impact of the models on wider macroeconomic issues, for example the discussion in Krause and Lubik (2007) on the in ability of this type of mode to generate a realistic Phillips Curve trade-off between output and inflation. These interesting issues are beyond the scope of this paper

<sup>9</sup>The correlations between productivity shocks and unemployment and vacancies are similar for all the pairs of models that we consider. The simulated correlations are larger than the correlations observed in the data; this is a well-known shortcoming of search frictions models.

<sup>10</sup>The ability of the model in (1) to generate unemployment volatility has been interpreted by Ljungqvist and Sargent (2017) in terms of a small value of the "Fundamental Surplus". A similar argument can be used to explain why (36) also generates a large unemployment volatility. Since the firm sets the wage, the fundamental surplus is  $FS = y - w$ . As the wage can be written as  $w = w^{fair} + \sigma y$ , the firms optimality condition can be written as  $(1 - \sigma)y = w^{fair} + \lambda$ . Implicitly differentiating this and using the definition of the fundamental surplus, we obtain  $\varepsilon_{\theta,y} = \frac{1-\sigma}{\alpha} \frac{y}{y-w}$  or  $\varepsilon_{\theta,y} = \frac{1-\sigma}{\alpha} \frac{y}{FS}$  where  $\varepsilon_{\theta,y}$  is the elasticity of labour market tightness with respect to output. Our calibration implies a small value for the Fundamental Surplus.

reflect the flows of workers into unemployment following job separation and out of unemployment as a result of a job match. These flows are modelled using the assumed constant rate of job separation and the matching function. The parameters of these are common to all the models we consider. The alternative wage equations in rows (2) and (3) do not affect the dynamic worker flows that underlie the Beveridge Curve mechanism, leading to the same correlations being generated by the different models.

Rows (4a) and (4b) present results for the models of partial wage adjustment in (2) and in (38). For (2), we use  $\phi = 0.9$  to calibrate the degree of wage rigidity. The model in (2) is less able to match the data as the volatilities are lower. For the endogenous search model in (38), we use the same degree of rigidity as in (2) and so calibrate  $\varpi = 0.9$ . The results are similar. The correlations are also similar in rows (4a) and (4b); they are slightly different to the other models as the dynamics of the wage adjustment process interact with the dynamics of worker flows. Rows (5a) and (5b) present results for the models of partial wage adjustment in (3) and in (40). For (3), we again use  $\phi = 0.9$  to calibrate the degree of wage rigidity and assume the same for the behavioural search model in (29), so  $\varpi = 0.9$ . These models give similar results and are able to match the volatilities well, although they are somewhat smaller than in row (3), reflecting the lesser degree of wage rigidity. The correlations are similar to those in rows (2)-(3). Finally, rows (6a) and (6b) present results for the models of partial wage adjustment in (4) and (42), where we use  $\phi = \varpi = 0.9$ . Again, these models give similar results and are able to match the volatilities well.

In summary, Table 3) shows that models derived from a behavioural search model give similar results to widely-used models of exogenous wage rigidity in the literature, as they imply similar volatilities of unemployment, vacancies and labour market tightness and similar correlations between these variables. Thus our proposed model can match the data as closely as the existing literature but without the disadvantage of assuming exogenous and ad hoc forms of real wage rigidity.

Table 3—Simulation Results

Wage Equation		$\sigma_u$	$\sigma_v$	$\sigma_\theta$	$\rho_{u,v}$	$\rho_{u,\theta}$	
(1)	US Data	0.123	0.139	0.259	-0.919	-0.977	
(2a)	(19)	0.047	0.029	0.047	-0.696	-0.894	
(2b)	(34)	0.025	0.034	0.054	-0.696	-0.894	
(3a)	(1)	0.119	0.162	0.259	-0.696	-0.894	
(3b)	(36)	0.117	0.160	0.256	-0.696	-0.894	
(4a)	(2)	$\phi = 0.9$	0.043	0.079	0.111	-0.633	-0.837
(4b)	(38)	$\varpi = 0.9$	0.042	0.077	0.109	-0.632	-0.835
(5a)	(3)	$\phi = 0.9$	0.095	0.130	0.207	-0.696	-0.894
(5b)	(40)	$\varpi = 0.9$	0.096	0.130	0.203	-0.696	-0.894
(6a)	(4)	$\phi = 0.9$	0.107	0.146	0.222	-0.696	-0.894
(6b)	(42)	$\varpi = 0.9$	0.106	0.144	0.223	-0.696	-0.894

## 6 Conclusions

In this paper, we have attempted to unify the diverse literature on real wage rigidity in models with search frictions using a behavioural search framework in which firms post wages and workers decide how much effort to exert. Using this, we derived models of real wage rigidity that resemble the widely-used models of exogenous wage rigidity in the literature and that can match the large volatility of unemployment observed in the data. The mechanism for generating unemployment volatility is the same for both types of model: following a positive productivity shock, firms post an increased number of vacancies, resulting in increased labour market tightness and a reduction in unemployment. In response to a negative shock, firms post fewer vacancies, resulting in an increase in unemployment and a reduced marginal cost of hiring, again satisfying (18). This mechanism is stronger when wage rigidity suppresses offsetting fluctuations in the wage.

In our model, real wage rigidity arises through stickiness of the reference wage. Recent experimental studies in Behavioural Economics, including Kahneman et al (1986), Fehr et al (2009) and Cohn et al (2014), provide some evidence of this. However we do not as yet have a large body of evidence on how worker's reference wages adjust across the business cycle. Hopefully, evidence on this will emerge, allowing us to determine which of the alternative models of endogenous real wage rigidity proposed in this paper is best able to explain the volatility of unemployment.

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