Job Reallocation, Unemployment and Hours in a New Keynesian Model*

Richard W. P. Holt
Economics,
University of Edinburgh

This version September 2007, First version August 2005.

Abstract

This paper focusses on the reallocation of labour resources in a New Keynesian environment with labour market search and endogenous separations. We show that introduction of variation in hours per worker alters the incentives for intertemporal substitution in a way that generates a more steeply downward sloping Beveridge curve and reduces the tendency to synchronise gross job flows. This also enables the New Keynesian model to capture the interaction of hours and employment at business cycle frequencies. We show that the impact of labour supply elasticity on the slope of the Beveridge curve and the correlation of gross job flows is determined primarily by variation in the response to monetary shocks. When hours variation is suppressed the comovement of job creation with job destruction and of unemployment with vacancies are strongly positive in response to monetary shocks. Whereas with variation in hours both measures of reallocation take on the correct negative sign.

* I am grateful to Jozsef Sakovics, Stuart Sayer, Jonathan Thomas and seminar participants at the Centre For Dynamic Macroeconomics Workshop 2005, Royal Economics Society Conference 2006, ESRC Money, Macroeconomics and Finance Research Group Conference 2006, University of Birmingham and University of Hull for advice and encouragement. Earlier versions of this paper have circulated under the titles "Unemployment, Job Flows and Hours in a New Keynesian Model" and "Unemployment, Labour Market Dynamics and the New NeoClassical Synthesis". I am responsible for any errors. Correspondence should be addressed to Richard Holt, Economics, University of Edinburgh, William Robertson Building, 50 George Square, Edinburgh, EH8 9JY, Scotland; E-mail: Richard.Holt@ed.ac.uk .

1 Introduction.

Recent research extends the New Keynesian paradigm to incorporate labour market search, motivated by the explicit account it provides of unemployment.[1] Following Shimer (2005) and Hall (2005), who argue that unemployment dynamics are driven by fluctuations in outflows not inflows, the bulk of the literature holds the inflow (separation) rate constant.[2] Yet, subsequent empirical evidence indicates that inflows variation also plays an important role in unemployment dynamics.[3] This makes a model with endogenous separations a natural starting point. The Mortensen Pissarides (1994) features endogenous separation of the least productive matches to provide a Schumpeterian explanation of microeconomic restructuring and the reallocation of resources to more productive activities that underlies economic growth and fluctuations, see Davis et al. (1998). In the literature on restructuring the slope of the Beveridge curve (correlation of unemployment with vacancies) and the synchronisation of gross job flows (correlation of job creation with job destruction) are critical measures of the reallocation process. Both are negative in US data. Suppressing inflow variation, i.e. following Shimer (2005), avoids the synchronisation of job flows and generates a downward sloping Beveridge curve. However, it does so by assuming away reallocation decisions. The Schumpeterian perspective on business cycles suggests that recessions are the best time to undertake microeconomic restructuring, since the opportunity costs of doing so are low. Mortensen and Pissarides (1993) show that a temporary shock to profitability produces strong positive correlation of gross job flows and an upward sloping Beveridge curve, in the context of a (constrained) efficient equilibrium labour market search model with endogenous separations (one which satisfies the Hosios condition).[4] Krause and Lubik (2007) find a similar effect in a New Keynesian framework when, as in the Mortensen-Pissarides model, labour input varies on

[1] Authors have examined the role played by labour market search, and wage rigidities in determining dynamic behaviour of unemployment, output and inflation. In so doing they address the amplification and persistence puzzles highlighted by Shimer (2005), Chari, Kehoe and McGrattan (2000), Cogley and Nason (1995).

[2] These include Moyen and Sahuc (2005), Christoffel and Linzert (2005), Christoffel et al. (2006), Jung and Kuester (2006), Trigari (2006), Faia (2007), Kuester (2007) and Thomas (2007).

[3] Elsby et al. (2007) show that Shimer's result that unemployment inflows are invariant over the cycle is overstated even using his own data and methodology. Davis et al. (2006) and Fujita and Ramey (2006) present evidence from job flows and other data sources to support the view that inflows are an important component of unemployment dynamics at business cycle frequencies, accounting for up to a third of the variation in unemployment.

[4] Suppressing inflow variation avoids the synchronisation of job flows and generates a downward sloping Beveridge curve. However, it does so by assuming away reallocation decisions.

the extensive margin(s) only. It is possible to reconcile models of reallocation and restructuring with the facts while adhering to the Hosios condition by incorporating additional features into firms' decision problems so as to alter the incentives for intertemporal substitution. For example, Mortensen (1994) achieves this by introducing on-the-job search and distinguishing between job and worker flows, while Den Haan et al. (2000) do so by including capital accumulation.

This paper examines the reallocation of labour resources in a New Keynesian environment with labour market search and endogenous separations. We show that introduction of variation in hours per worker alters the incentives for intertemporal substitution in a way that generates a downward sloping Beveridge curve and reduces the tendency to synchronise gross job flows. This also enables the New Keynesian model to capture the positive comovement of hours and employment at business cycle frequencies.[5] The New Keynesian framework imposes the discipline of general equilibrium on our analysis. It introduces frictions in price setting which permits meaningful discussion of the impact of both productivity and monetary shocks.[6] We show that the effect of labour supply elasticity on the slope of the Beveridge curve and the correlation of gross job flows is determined primarily by changes in the response to monetary shocks. Specifically, under inelastic hours the comovement of job creation with job destruction and of unemployment with vacancies are strongly positive in response to monetary shocks, whereas under elastic hours both measures of reallocation take on the correct negative sign. The volatility of unemployment is relatively high with or without hours variation. The introduction of hours variation raises the variation of unemployment, but reduces that of vacancies. Variation in hours reduces the variability of wages, but this remains too high. Moreover, vacancies fail to exhibit sufficient persistence and are too strongly correlated with job creation.

The mechanism by which hours per worker affects reallocation is relatively straightforward. Variation of hours per worker allows existing matches to adjust labour input to shocks by varying

5 Fluctuation in hours per worker accounts for a substantial proportion of the variation in labour input at business cycle frequencies, Cho and Cooley (1994). Despite its role in labour input variation hours per worker is frequently omitted from models with labour market search, presumably on grounds of parsimony.

6 Shimer (2005) notes that an upward sloping Beveridge curve arises when *exogenous* shocks to the (aggregate) job destruction rate are permitted - this may be interpreted as an aggregate reallocative shock. It is possible that a suitable choice of correlation of reallocative shocks and productivity shocks could generate a Beveridge curve with the appropriate slope. However, Davis and Haltiwanger (1999) are unable to find a clear and important role for such aggregate reallocative shocks. For this reason it is more interesting to examine whether a negatively sloped Beveridge curve can arise when job destruction varies endogenously in response to aggregate productivity and money supply growth disturbances, which are standard in a New Keynesian setting.

hours as well as through separations - firms equate marginal costs of factor adjustment across each margin. This extra flexibility alters rents, and as a consequence the incentives both to dissolve existing matches and to create new ones. Labour adjustment on the extensive margin is attenuated and the tendency to synchronise creation and destruction activity is also reduced.[7] One potential problem is that variation on the intensive margin may substitute for variation on the extensive margin and attenuate fluctuations in unemployment - worsening the volatility puzzle highlighted by Shimer (2005). In practice, holding other parameters constant, the effect on unemployment is relatively small. In addition, our calibration strategy adjusts parameters to maintain the standard deviation of job destruction constant across experiments, so that unemployment variation remains roughly constant regardless of the use of the intensive margin. However, the volatility of job creation and vacancies is reduced by realistic hours variation.

The sensitivity of reallocative measures to variation in hours is enhanced by the presence of monetary shocks. It is costly to dissolve existing matches or create new matches in response to transitory shocks, yet hours variation within existing matches does not entail long-run considerations. Since monetary shocks are less persistent than productivity shocks, the introduction of hours variation has its greatest effect on the response to monetary shocks. Nonetheless, even for productivity shocks, realistic hours variation alters the incentives for intertemporal substitution sufficiently to produce a negative job flows correlation.

A small collection of papers incorporate endogenous separations into the New Keynesian treatment of unemployment, Krause and Lubik (2007), Trigari (2005), Braun (2006), Walsh (2005), Andres et al. (2006). These authors all provide the same rationale and broadly address the same issues as considered in the literature which assumes a constant separation rate (see footnotes (1) and (2)). For the most part, they do not address questions on the timing of reallocation that we consider and that a model with endogenous job destruction is designed to answer. In particular, the joint behaviour of the Beveridge curve and the correlation of gross job flows is considered only by Krause and Lubik (2007), who find both measures of reallocation to be positive, in an

[7] With the intensive margin suppressed, a rise in unemployment occurs through a *rise* in job creation and an *even bigger rise* in job destruction. This reflects the relatively low cost of altering the rate of job destruction (relative to that of job creation). It gives rise to a (counterfactual) positive correlation of job creation and job destruction. Since job creation tends also to be high when the number of vacancies open is high, the Beveridge curve is flatter and may become positive in the absence of hours variation.

environment with endogenous job destruction and labour input variation on the extensive margin only.[8]

The combination of endogenous hours along with endogenous job destruction that we discuss below was first considered by Trigari (2005). Our principal contribution is to demonstrate the effect of realistic hours variation on measures of reallocative activity. We also illustrate the role of different shocks in determining the effect of hours variation on reallocation. Trigari does not directly consider the correlation of gross job flows, nor does she attempt to match the behaviour of unemployment or vacancies. Nonetheless her impulse response analysis is likely to be consistent with the effects of hours variation on reallocation that we outline here.[9] We use a simplified version of Trigari's model and use it to contrast the behaviour of measures of reallocation obtained under different assumptions about labour supply elasticity. Our focus on contrasting the impact of particular (implicit) assumptions on hours variation in a relatively simple New Keynesian model leads us to calibrate rather than estimating the elasticity of hours directly. It also means that we take a stand on the shocks that affect the economy and match unconditional moments. Although not imune from criticism this strategy faciltates comparison with Krause and Lubik (2007) and Walsh (2005); Trigari (2005) considers the (conditional) response to monetary shocks alone.[10]

Of the other three papers, Walsh (2005) was the first to integrate New Keynesian model with labour market search and endogenous job destruction. Following from Den Haan et al. he does not allow variation in hours per worker and does not consider measures of reallocation at all. Andres et al. (2006) extend Walsh's model and use it to examine the variability of unemployment, vacancies and labour market tightness.[11] Although they do not compute the slope of the Beveridge curve, it can be inferred from the results they present. For the version of their model (without capital and distortionary taxation) which most closely approximates ours, it is -0.08: negative but much smaller than in US data, just as we find when we suppress variation in hours. They do not display

[8] They find that the introduction of (complete) wage rigidity can produce a downward-sloping Beveridge curve, but they are unable to avoid positively correlated gross job flows. Indeed, they are unable to match the Beveridge curve if wage rigidity is set to match observed wage variability.

[9] Trigari (2005) estimates key parameters so as to match the impulse responses of job flows, employment, hours inflation and output to an interest rate shock.

[10] In principle one might then estimate the model using a Bayesian approach, as in the treatment of a model with exogenous job destruction provided by Jung and Kuester (2007). However, our calibration suggests that the present model is too simple to be taken to the data in this way, so we leave this for future work.

[11] Their benchmark model also allows for habit persistence, capital accumulation and distortionary taxes.

any data for the volatility of gross job flows or related measures of reallocation.[12] Our analysis suggests that because they suppress variation in hours per worker the correlation of gross job flows would be positive but that this can be corrected by allowing hours variation. Andres et al. (2006) find a role for price rigidity in determining the variability of unemployment vacancies and labour market tightness. Our analysis extends theirs to an environment in which hours per worker can both vary and allows for monetary as well as productivity shocks. Braun (2006) applies Trigari's methodology to worker flows rather than job flows; she considers a New Keynesian framework with capital accumulation.

We consider a New Keynesian model without capital accumulation. While capital can help discipline model calibration, much work in the New Keynesian tradition both for structural modelling and policy analysis suppresses this margin, see Gali (2003), Woodford (2003), as do models with unemployment, Blanchard and Gali (2006), Christoffel and Linzert (2005), Faia (2007a), Trigari (2006). The main justification (often implicit) for this simplification appears to be the limited role played by capital accumulation.[13] The omission of capital accumulation and other intertemporal features, such as habit persistence, serves to highlight the role of the intensive margin.[14]

The model is outlined in Section 2. Calibration and solution method are discussed in Section 3. Section 4 presents and discusses the results and assess the contribution of various features in accounting for US business cycles facts. Section 5 concludes. An appendix contains details of the data used, and the calibration strategy.

2 Model

The economy contains four types of agent: intermediate good producers, final goods producers, households and a government. Production of the intermediate good requires labour. Labour can

[12] In addition, direct comparison between our results and those of Andres et al. (2006) is complicated by the fact that they appear only to calibrate idiosyncratic shocks and the properties of the productivity shock in the benchmark case, and proceed to allow the variability of job destruction and output to vary across experiments.

[13] In the literature on unemployment dynamics, Hagedorn and Manowskii (2005) point out that match-level profits are an important determinant of the amplitude of fluctuations in unemployment and vacancies. Krussell et al. (2005), surveying developments in the literature, comment that the calibration of this critical profit share parameter could be improved if capital accumulation were incorporated as a disciplining device, but Jung (2005) demonstrates that the introduction of capital accumulation does not overturn the insight of Hagedorn and Manowskii (2005).

[14] An earlier version of this paper, Holt (2006), adopted a framework with capital accumulation. The results on the role of hours variation are similar to those displayed below. Hence a New Keynesian environment capital accumulation does not alter incentives sufficiently to generate a negative job flows correlation, contrary to the real business cycle based analysis of Den Haan et al (2000).

be varied on both extensive and intensive margins. Hours are determined through Nash bargaining rather than unilaterally by individual consumers. The strength of variation on the intensive margin is determined by the elasticity of labour supply (preferences over leisure). The model structure is based on that of Trigari (2005). We simplify her model in several ways in order to highligt the role of hours variation and facilitate comparison with the literature. We omit habit persistence to simplify the dynamic structure of the model and thereby highlight the role of hours. We target the BLS estmate of average unemployment (6%) rather than the high (25%) unemployment she uses, which acts to stabilise the unemployment pool and hence vacancies in response to shocks. In the light of evidence of instability of the Taylor rule over the sample period we follow Krause and Lubik (2007) and adopt a money supply growth rule. We also adopt idiosyncratic production costs rather than idiosyncratic preference shocks, which is slightly more intuitive in the light of our interest in reallocation based on profitability. Finally we specify preferences over leisure, following Andolfatto (1995) rather than hours worked as is common in the New Keynesian literature.

Below we discuss in turn the decision problem of households, the specification of goods and labour markets and the equilibrium characterisation of the economy.

2.1 Households

Assume that the economy contains a continuum of identical households of unit mass. Each household is a family with a continuum of members. In equilibrium some members are employed while others are unemployed. Each member i, of household h has the following period utility function defined over consumption, C, money balances $\frac{M}{P}$ and hours,H,

$$\frac{\left(C_{i,t}^{h}\right)^{1-\phi}}{1-\phi}+\frac{\Upsilon_{\frac{M}{P}}}{1-\xi}\left(\frac{M_{i,t}^{h}}{P_{t}}\right)^{1-\xi}+\left(1-I_{t}^{U}\right)\Upsilon_{H}\frac{\left(1-H_{i,t}^{h}\right)^{1-\varphi}}{1-\varphi}+I_{t}^{U}\frac{\left(1-e\right)^{1-\varphi}}{1-\varphi}$$

Here $\Upsilon_{\frac{M}{P}}$, the relative weight on money balances in the utility function, Υ_H, the relative weight on leisure in the utility function, ϕ, the inverse of the elasticity of intertemporal substitution, φ, the elasticity of substitution of hours per worker, e time spent undertaking search and ξ are all positive constants. I_t^U is an indicator function taking the value 1 if the individual is unemployed and zero otherwise. To avoid the distributional issues that arise through differing employment histories, we assume that family members perfectly insure each other against (cross-section) variation in the marginal utility of consumption. Separability of the individual's utility in consumption, money balances and leisure ensures that family members have identical consumption and money holdings. Under these simplifying assumptions, household member's decisions can be analysed in terms of a representative household.[15] The representative household chooses consumption and money balances to maximise expected utility of its members over their lifetimes:

$$E_0\left[\sum_{t=0}\beta^t\left[\frac{(C_t)^{1-\phi}}{1-\phi}+\frac{\Upsilon_{\frac{M}{P}}}{1-\xi}\left(\frac{M_t}{P_t}\right)^{1-\xi}+\Upsilon_H\int_0^{1-U_t}\frac{(1-H_{i,t})^{1-\varphi}}{1-\varphi}di+U_t\frac{(1-e)^{1-\varphi}}{1-\varphi}\right]\right].$$

Here β, is the discount factor and U_t represents the fraction of the household membership which is unemployed (we suppress the household superscript for convenience). Hours of work are determined through bargaining between the individual worker and the firm rather than being unilaterally determined by the household.

Households own all retail and wholesale firms. They can save by holding 1-period interest bearing bonds, or non-interest bearing money balances. The representative household maximises expected lifetime utility subject to the following sequence of constraints

$$P_tC_t+R_t^nB_t+M_t=\mathcal{I}_t+B_t+M_{t-1}+P_tT_t,\qquad t\geq 0. \tag{1}$$

Here B_t represents holdings of a nominal 1 period bond, and R_t^n represents the gross nominal interest rate on this bond. M_t represents holdings of nominal money balances at the end of period t, P_tT_t represents lump-sum nominal transfers. C_t is a composite index of final goods consumption. $\mathcal{I}_t$ is the household's nominal income (household labour income, plus the household's share of firms' profits net of expenditures on vacancies).[16]

The solution to the representative household's problem is characterised by first-order conditions for bond holdings, B_t, consumption C_t, money balances M_t. Substituting the first order condition for the shadow value of wealth using the marginal utility of consumption in the remaining conditions we have:

$$1=\beta R_t^nE_t\left[\frac{P_t}{P_{t+1}}\left(\frac{C_t}{C_{t+1}}\right)^{\phi}\right]. \tag{2}$$

[15] This sort of assumption is a common simplification in the literature on business cycle fluctuations under labour market search designed to facilitate tractability, see e.g. Andolfatto (1996), Merz (1995).

[16] Given the representative family assumption, all families hold the same share of firms' profits, so in equilibrium this share is one at all dates.

$$\Upsilon_{\frac{M}{P}}\left(\frac{M_t}{P_t}\right)^{-\xi} - C_t^{-\phi} = \beta E_t\left[C_{t+1}^{-\phi}\frac{P_{t+1}}{P_t}\right] \tag{3}$$

2.2 Goods and Labour Markets

2.2.1 Labour Market Flows

The match specific production, bargaining and separation decisions described below depend on the probability that unemployed workers find jobs and the probability that vacancies are filled. Here we define these probabilities and the associated labour market flows.

Define the number of matches at the beginning of period t as $N_t \in [0,1]$. Following the literature, we allow some job destruction in the form of quits which are taken as exogenous and independent of the match-specific profitability. We capture this by allowing a fraction, λ^x, of matches to separate prior to the realisation of period t shocks. Subsequently, shocks are realised, including an idiosyncratic cost shock, X, drawn from distribution $F(X)$ and a match may choose to break up if the value of the match surplus is negative. Let the $\bar{X}_t$ denote the threshold value of the cost shock, so that higher realisations of idiosyncratic costs cause matches to separate. Endogenous separation thus occurs with probability $\lambda^n\left(\bar{X}_t\right) = 1 - \int^{\bar{X}_t} dF(X) = 1 - F\left(\bar{X}_t\right)$, where $dF(\cdot)$ is the probability density function over X. The overall separation rate in period t is

$$\lambda_t = \lambda^x + (1-\lambda^x)\left(1 - F\left(\bar{X}_t\right)\right). \tag{4}$$

We model matching frictions using an aggregate matching function. Matching occurs at the same time as production. Assume that there is a continuum of potential firms, with infinite mass, and a continuum of workers of unit mass. Unmatched firms choose whether or not to post a vacancy and incur a cost κ per period. Free entry of unmatched firms determines the size of the vacancy pool. Define the mass of firms posting vacancies in period t as V_t. Let the mass of searchers, unmatched workers, be U_t. All unmatched workers may enter the matching market in period t - even if their match dissolved at the start of period t, so

$$U_t = 1 - (1-\lambda_t) N_t. \tag{5}$$

New matches in date t begin production in date $t+1$, while unmatched workers remain in the worker matching pool. The flow of successful matches created in period t is given by the constant returns matching function

$$\mathcal{M}_t = \mathfrak{M} U_t^{\gamma} V_t^{1-\gamma}. \tag{6}$$

where $\gamma \in (0,1)$ and $\mathfrak{M} > 0$. The number of employed workers at the start of period $t+1$ is

$$N_{t+1} = (1 - \lambda_t) N_t + \mathcal{M}_t. \tag{7}$$

Denote the probability that a vacancy is filled in date t as

$$p_t^V = \frac{\mathcal{M}_t}{V_t}, \tag{8}$$

and the probability that an unemployed worker enters employment in period t as

$$p_t^U = \frac{\mathcal{M}_t}{U_t}. \tag{9}$$

The gross job destruction rate is the number employment relationships that separate less exogenous separations that rematch within period as a fraction of current employment

$$JD_t = \frac{\lambda_t N_t - p_t^V \lambda^x N_t}{N_t} = \lambda_t - p_t^V \lambda^x. \tag{10}$$

Gross job creation is the flow of new matches (as a fraction of existing employment) less matches due to firms filling vacancies that resulted from exogenous separations

$$JC_t = \frac{\mathcal{M}_t - p_t^V \lambda^x N_t}{N_t} = \frac{\mathcal{M}_t}{N_t} - p_t^V \lambda^x. \tag{11}$$

2.2.2 The Intermediate sector

Production Production of intermediate goods takes place in matched firm-worker pairs - or, for notational ease, *matches*. Each match consists of one worker and one firm, who together engage in production until the employment relationship is terminated. By assumption, both firms and workers are restricted to a single employment relationship at any given time. Matches are subject to aggregate productivity and idiosyncratic cost shocks, Z_t and X_t respectively.[17] Following Den Haan et al. (2000) assume that idiosyncratic cost disturbances are serially uncorrelated. Date t

[17] Cost shocks are a natural way to model heterogenous productivity underlying the process of creative destruction at the heart of the model. Trigari (2005) adopts an formally equivalent but arguably less intuitive approach in which the idiosyncratic disturbances affect the utility derived from leisure.

production occurs after realisation of the date t shocks. At date t an ongoing match (one facing idiosyncratic shock $X_t < \bar{X}_t$) produces

$$Y^I(X_t) = AZ_t H(X_t) + \mathcal{F} - X_t$$

units of intermediate good.[18] The parameters A and $\mathcal{F}$ are positive constants. Matches are price takers and sell their homogeneous intermediate output at (nominal) price P_t^I. The formal separation of the job-destruction and price-setting decision problems is maintained for tractability, but is consistent with the view that prices are not set at the level of an individual match. Current profits of an ongoing match are

$$\Pi^I(X_t) \equiv \frac{AZ_t H(X_t)}{\mu_t} + \frac{\mathcal{F} - X_t}{\mu_t} - \frac{W(X_t) H(X_t)}{P_t}, \tag{12}$$

where $\mu_t = \frac{P_t}{P_t^I}$ is the markup of the index of final goods prices over the price of the intermediate good (the reciprocal of marginal cost) and $W(X_t)$ is the match specific (nominal) wage.

Value Functions Next we describe the value functions for firms' and workers' decision problems.

In equation (13) V_t^U, the date t value of unemployment, expressed in final goods, comprises the consumption value of utility from search, the discounted present value of ongoing unemployment next period, V_{t+1}^U, and the difference between the value of employment, $V^W(X)$, and that of unemployment in the event that the worker matches this period (with probability p_t^U) and the match survives to produce next period (with probability $(1-\lambda^x) F(\bar{X}_{t+1})$):

$$V_t^U = \frac{(1-e)^{1-\varphi}}{1-\varphi} C_t^\phi + \beta E_t \left[\frac{C_t^\phi}{C_{t+1}^\phi} \left[V_{t+1}^U + p_t^U (1-\lambda^x) \int^{\bar{X}_{t+1}} \left[V^W(X) - V_{t+1}^U \right] dF(X) \right] \right]. \tag{13}$$

Matching and production occur simultaneously, so that a match which is formed in period t cannot produce until period $t+1$, after aggregate and idiosyncratic shocks have been realised. As a result a new match survives with probability $(1-\lambda^x) F(\bar{X}_{t+1})$.

Let $V^W(X_t)$ denote the date t value, expressed in terms of consumption goods, to a worker of employment in an ongoing match with idiosyncratic cost shock X_t.

$$\begin{aligned} V^W(X_t) \quad = \quad & \frac{W(X_t) H(X_t)}{P_t} + \Upsilon_H \frac{(1 - H(X_t))^{1-\varphi}}{1-\varphi} C_t^\phi \\ & + \beta E_t \left[\frac{C_t^\phi}{C_{t+1}^\phi} \left[V_{t+1}^U + (1-\lambda^x) \int^{\bar{X}_{t+1}} \left[V^W(X) - V_{t+1}^U \right] dF(X) \right] \right]. \end{aligned} \tag{14}$$

[18] An additive idiosyncratic shock avoids wide variation of hours across matches, Cooley and Quadrini (1999).

The worker supplies $H(X_t)$ hours of labour to the firm for real hourly wage $\frac{W(X_t)}{P_t}$. Both wage and hours are outcomes of a bargaining process - described below. Hours worked generates income, but hours spent in the workplace reduce utility. These concerns are captured in the first two terms in (14). The remainder of the date t value to an employed worker from the ongoing match is the discounted present value, $\beta E_t \left[\frac{C_t^{\phi}}{C_{t+1}^{\phi}} V_{t+1}^U\right]$, of unemployment plus the difference between the value of employment, $V^W(X)$, and that of unemployment in the event that the match continues to produce next period (where we sum across values of X which do not lead to termination prior to date $t+1$ production).

The date t value, $V^J(X_t)$, of a firm that forms part of an ongoing match with current match specific shock X_t, consists of current profits plus the appropriately discounted value to the firm of the sum of a date $t+1$ vacancy, V_{t+1}^V, in the event that the match terminates prior to production in period $t+1$ (where termination occurs with probability $\lambda_{t+1} = \lambda^x + (1-\lambda^x)\left(1 - F\left(\bar{X}_{t+1}\right)\right)$) and the expected value in the event that the match continues to produce in $t+1$;

$$V^J(X_t) = \Pi^I(X_t) + \beta E_t \left[\frac{C_t^{\phi}}{C_{t+1}^{\phi}} \left[\lambda_{t+1} V_{t+1}^V + (1-\lambda^x) \int^{\bar{X}_{t+1}} V^J(X)\, dF(X)\right]\right].$$

We assume vacancy posting costs κ per period. Then the value in date t of a firm with an unfilled vacancy, V_t^V, reflects the cost of posting that vacancy plus the value of firm, V_{t+1}^V, in the event that the firm fails to fill the vacancy by date $t+1$ or else the event that the vacancy is filled but the match is terminated prior to production in period $t+1$ (this occurs for a sufficiently adverse realisation of the idiosyncratic shock), plus the value $V^J(X)$ in the event that the vacancy is filled and the period $t+1$ idiosyncratic cost shock takes a value X, that does not lead to termination

$$V_t^V = -\kappa + \beta E_t \left[\frac{C_t^{\phi}}{C_{t+1}^{\phi}} \left[\left(1 - p_t^V (1-\lambda^x) F\left(\bar{X}_{t+1}\right)\right) V_{t+1}^V + p_t^V (1-\lambda^x) \int^{\bar{X}_{t+1}} V^J(X)\, dF(X)\right]\right].$$

The free entry condition on vacancies drives the value of a vacancy to zero, $V_t^V = 0$, $\forall t$, so the Bellman equations for $V^J(X_t)$, and V_t^V become

$$V^J(X_t) = \Pi^I(X_t) + (1-\lambda^x)\beta E_t \left[\frac{C_t^{\phi}}{C_{t+1}^{\phi}} \int^{\bar{X}_{t+1}} V^J(X)\, dF(X)\right] \tag{15}$$

$$\kappa = p_t^V (1-\lambda^x)\beta E_t \left[\frac{C_t^{\phi}}{C_{t+1}^{\phi}} \int^{\bar{X}_{t+1}} V^J(X)\, dF(X)\right]. \tag{16}$$

Moreover, using (15), we can re-write (16) as a Bellman equation for p_t^V:

$$\frac{\kappa}{p_t^V} = \beta\left(1-\lambda^x\right)E_t\left[\frac{C_t^\phi}{C_{t+1}^\phi}\int^{\bar{X}_{t+1}}\left[\Pi^I\left(X\right)+\frac{\kappa}{p_{t+1}^V}\right]dF\left(X\right)\right]. \tag{17}$$

Bargaining: Hours and Wages We assume that for each match engaged in production, the firm and worker adopt Nash bargaining over hours worked and the hourly wage. Given the full consumption insurance against unemployment risk provided by our family structure some care is required to ensure that this problem is well defined. We discuss this issue first before turning to the outcome of the bargaining process.

Assume that workers evaluate the consequences of their actions on the basis of the contributions these make to their family's lifetime utility. Then the worker's surplus from employment, $V^W\left(X_t\right)-V_t^U$ is the same as the value (in terms of consumption goods) of the change in the family's utility from having one more additional member in employment, $\frac{\partial\Omega_t}{\partial(1-U_t)}\cdot C_t^\phi$. That is $V^W\left(X_t\right)-V_t^U = \frac{\partial\Omega_t}{\partial(1-U_t)}\cdot C_t^\phi$, where Ω_t is the representative family's value function. To check this note that we can write Ω_t recursively as

$$\Omega_t = \frac{\left(C_t\right)^{1-\phi}}{1-\phi}+\frac{\Upsilon_{\frac{M}{P}}}{1-\xi}\left(\frac{M_t}{P_t}\right)^{1-\xi}+\Upsilon_H\int_0^{1-U_t}\frac{\left(1-H\left(X_{i,t}\right)\right)^{1-\varphi}}{1-\varphi}di+U_t\frac{\left(1-e\right)^{1-\varphi}}{1-\varphi}+\beta E_t\left[\Omega_{t+1}\middle| X\leq\bar{X}_{t+1}\right]$$

subject to the date t constraint in (1), and the evolution equation for the number of individuals engaged in production

$$1-U_{t+1} = \left[1-\lambda_{t+1}\right]\left[1-U_t\right]+p_t^U\left[1-\lambda_{t+1}\right]U_t.$$

Computing the derivative with respect to $(1-U_t)$ we find

$$\frac{\partial\Omega_t}{\partial\left(1-U_t\right)}\cdot C_t^\phi = \begin{array}{c}\frac{W(X_t)H(X_t)}{P_t}-\Upsilon_H\frac{(1-H(X_t))^{1-\varphi}}{1-\varphi}C_t^\phi+\frac{(1-e)^{1-\varphi}}{1-\varphi}C_t^\phi\\ +\left(1-p_t^U\right)\beta\left(1-\lambda^x\right)E_t\left[\frac{C_t^\phi}{C_{t+1}^\phi}\int^{\bar{X}_{t+1}}\left[V^W\left(X\right)-V_{t+1}^U\right]dF\left(X\right)\right]\end{array}.$$

Using equations (13) and (14) we find that this equals $V^W\left(X_t\right)-V_t^U$, as required. Thus the worker's threat point in the bargaining process is clearly defined in terms of household welfare.

Given that the bargaining problem for the worker is well defined, the division of the match surplus

$$S\left(X_t\right) = V^W\left(X_t\right)-V_t^U+V^J\left(X_t\right)-V_t^V = V^W\left(X_t\right)-V_t^U+V^J\left(X_t\right), \tag{18}$$

is determined on a period by period basis as:

$$\max_{W(X_t),H(X_t)} \left[V^W(X_t) - V_t^U\right]^\eta \left[V^J(X_t) - V_{t+1}^V\right]^{1-\eta}.$$

The first order conditions for hours and wages respectively are

$$\eta V^J(X_t)\left[\frac{W(X_t)}{P_t} - \Upsilon_H \frac{(1-H(X_t))^{-\varphi}}{C_t^{-\phi}}\right] = -\left\{\begin{array}{c}(1-\eta)\left(V^W(X_t) - V_t^U\right)\cdot \\ \left[\frac{AZ_t}{\mu_t} - \frac{W(X_t)}{P_t}\right]\end{array}\right\}, \tag{19}$$

$$\eta V^J(X_t) = (1-\eta)\left(V^W(X_t) - V_t^U\right). \tag{20}$$

Optimal hours worked are thus

$$\Upsilon^H \frac{(1-H(X_t))^{-\varphi}}{C_t^{-\phi}} = \Upsilon^H \frac{(1-H_t)^{-\varphi}}{C_t^{-\phi}} = \frac{AZ_t}{\mu_t} \qquad \forall X_t \leq \bar{X}_t. \tag{21}$$

Equation (21) says that, under Nash bargaining, the marginal rate of substitution between consumption and hours worked is equal to the marginal product of labour. Hours per worker in ongoing matches are decreasing in the markup, but increasing in aggregate productivity. Variation in hours per worker is decreasing in φ, so choice of φ can be used to shut down the intensive margin in our experiments. Hours per worker are independent of the match specific shock: $H(X_t) = H_t$.

Recall that the worker's surplus from employment is

$$V^W(X_t) - V_t^U = \begin{array}{c}\frac{W(X_t)H_t}{P_t} + \Upsilon_H \frac{(1-H_t)^{1-\varphi}}{1-\varphi} C_t^\phi - \frac{(1-e)^{1-\varphi}}{1-\varphi} C_t^\phi \\ + \left(1-p_t^U\right)\beta(1-\lambda^x) E_t\left[\frac{C_t^\phi}{C_{t+1}^\phi}\int^{\bar{X}_{t+1}}\left[V^W(X) - V_{t+1}^U\right] dF(X)\right].\end{array}$$

Using (20) and (16) it follows that

$$V^W(X_t) - V_t^U = \frac{W(X_t)H_t}{P_t} + \Upsilon_H \frac{(1-H_t)^{1-\varphi}}{1-\varphi} C_t^\phi - \frac{(1-e)^{1-\varphi}}{1-\varphi} C_t^\phi + \frac{\eta}{1-\eta}\left(1-p_t^U\right)\frac{\kappa}{p_t^V}.$$

Lastly, combining (15) and (16)

$$V^J(X_t) = \frac{AZ_t H_t}{\mu_t} + \frac{\mathcal{F} - X_t}{\mu_t} - \frac{W(X_t)H_t}{P_t} + \frac{\kappa}{p_t^V}.$$

So the optimal wage for a match with idiosyncratic cost realisation X_t becomes

$$\frac{W(X_t)H_t}{P_t} = \eta\left[\frac{AZ_t H_t}{\mu_t} + \frac{\mathcal{F} - X_t}{\mu_t} + \kappa\frac{p_t^U}{p_t^V}\right] + (1-\eta)\left[\frac{(1-e)^{1-\varphi}}{1-\varphi}C_t^\phi - \Upsilon_H \frac{(1-H_t)^{1-\varphi}}{1-\varphi}C_t^\phi\right].$$

Define aggregate labour income as $\frac{W_t H_t}{P_t} = H_t \int^{\bar{X}_t} \frac{W(X_t)}{P_t} dF(X)$. Then

$$\frac{W_t H_t}{P_t} = \left\{\begin{array}{c}\eta\left[\frac{AZ_t H_t}{\mu_t} + \frac{1}{\mu_t}\left[\mathcal{F} - \frac{\int^{\bar{X}_t} X\, dF(X)}{F(\bar{X}_t)}\right] + \kappa\frac{p_t^U}{p_t^V}\right] \\ + (1-\eta)\left[\frac{(1-e)^{1-\varphi}}{1-\varphi}C_t^\phi - \Upsilon_H \frac{(1-H_t)^{1-\varphi}}{1-\varphi}C_t^\phi\right]\end{array}\right\} F\left(\bar{X}_t\right). \tag{22}$$

The first term within the first square brackets on the right hand side of equation (22) represents the workers' share of the market value of production, the second term reflects the market value of idiosyncratic costs (relative to steady state), and the third term reflects the impact of labour market tightness. The remaining term reflects the worker's reservation wage.

Separation For values of the idiosyncratic cost shock above a certain threshold level, $\bar{X}_t$, separation occurs. The condition $S\left(\bar{X}_t\right) = 0$, pins down this threshold value of the match specific shock. Combining (18) and (20), $V^J\left(X_t\right) = (1-\eta)\, S\left(X_t\right)$. So $\bar{X}_t$ is determined by the condition $V^J\left(\bar{X}_t\right) = 0$:

$$\frac{AZ_tH_t}{\mu_t} + \frac{\mathcal{F} - \bar{X}_t}{\mu_t} - \frac{W\left(\bar{X}_t\right)H_t}{P_t} + \frac{\kappa}{p_t^V} = 0.$$

This equation indicates that a job is destroyed when costs are sufficiently high that the value of production net of idiosyncratic cost shock and wage equals the (expected) cost of posting a vacancy. Substituting for the match specific wage, the threshold value $\bar{X}_t$ is determined by

$$(1-\eta)\left[\frac{AZ_tH_t}{\mu_t} + \frac{\mathcal{F} - \bar{X}_t}{\mu_t} - \left[\frac{(1-e)^{1-\varphi}}{1-\varphi}C_t^{\phi} - \Upsilon_H\frac{(1-H_t)^{1-\varphi}}{1-\varphi}C_t^{\phi}\right]\right] - \eta\kappa\frac{p_t^U}{p_t^V} + \frac{\kappa}{p_t^V} = 0. \quad (23)$$

2.2.3 Final Goods Sector

Assume that there is a continuum of final goods producers, with unit mass. Final good firm z acquires the wholesale good at price P_t^I and costlessly transforms it into the divisible final good z which is then sold directly to households at price $p_t\left(z\right)$. Define $P_t = \left(\int_0^1 p_t\left(z\right)^{1-\varepsilon} dz\right)^{\frac{1}{1-\varepsilon}}$ as the utility based price index associated with the consumption composites. The market for final goods is characterised by monopolistic competition - ε represents the elasticity of substitution across varieties of final good. Aggregate demand for the final good z in period t is $y_t\left(z\right) = c_t\left(z\right)$, where $c_t\left(z\right)$ represents consumption demand for final good z output. The optimal choice of consumption expenditures on final good z is then $c_t\left(z\right) = \left(\frac{p_t(z)}{P_t}\right)^{-\varepsilon} C_t$, where aggregate consumption, $C_t = \left(\int_0^1 c_t\left(z\right)^{\frac{\varepsilon-1}{\varepsilon}} dz\right)^{\frac{\varepsilon}{1-\varepsilon}}$ and aggregate final good output $Y_t = \left(\int_0^1 y_t\left(z\right)^{\frac{\varepsilon-1}{\varepsilon}} dz\right)^{\frac{\varepsilon}{1-\varepsilon}}$ are composite indices of final goods.

Final goods prices exhibit nominal rigidities which follow a hybrid Calvo-style adjustment scheme. With probability $(1-\omega)$ a final good producer can set the price of its output in period

t. This probability be independent of when the firm last adjusted price. Then the average price for final goods producers who do not adjust their price is simply P_{t-1}. Define the average price set by firms who do adjust price as $\bar{p}_t$. Since pure forward-looking price adjustment schemes seem not to account adequately for observed inflation dynamics, we employ a hybrid scheme (following Gali and Gertler (1999)). Assume that a fraction $(1-\tau)$ of the final goods producers are forward-looking and set prices optimally (to maximise expected discounted profits given the probability of future adjustment). Define the price set by forward-looking producer z at date t as $p_t(z)$. Since all forward-looking firms setting price at date t face the same expected future demand and cost conditions they choose the same price, so $p_t(z) = p_t^*$, where

$$p_t^* = \frac{\varepsilon}{1-\varepsilon} \frac{E_t \sum_{s=0}^{\infty} \omega^s \beta^s \frac{C_t^{\phi}}{C_{t+s}^{\phi}} \left(\frac{p_t^*}{P_{t+s}}\right)^{1-\varepsilon} Y_{t+s} P_{t+s}^I}{E_t \sum_{s=0}^{\infty} \omega^s \beta^s \frac{C_t^{\phi}}{C_{t+s}^{\phi}} \left(\frac{p_t^*}{P_{t+s}}\right)^{1-\varepsilon} Y_{t+s}} \tag{24}$$

The remaining fraction, τ, of firms which reset price in period t are assumed to set a price equal to the average of the prices reset in the previous period, corrected for inflation, π_{t-1}:

$$p_t^b = \bar{p}_{t-1}\pi_{t-1}. \tag{25}$$

The average price set in period t is $p_t = \left[(1-\tau)(p_t^*)^{1-\varepsilon} + \tau\left(p_{t-1}^b\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$, and the aggregate retail price index evolves according to

$$P_t^{1-\varepsilon} = (1-\omega)(\bar{p}_t)^{1-\varepsilon} + \omega P_{t-1}^{1-\varepsilon}. \tag{26}$$

2.3 Monetary and Fiscal Policy and Exogenous Driving Processes

We set government spending to zero and assume that the government maintains a balanced budget by rebating seigniorage revenues to households in the form of lump-sum transfers. The government budget constraint is thus $P_t T_t = M_t - M_{t-1}$,where M_t is the aggregate money stock. Monetary policy is specifed by

$$M_t = M_{t-1}e^{\upsilon_t} \tag{27}$$

where υ_t evolve according to the AR(1) process

$$\upsilon_t = \rho_{\upsilon}\upsilon_{t-1} + \varepsilon_{\upsilon,t}. \tag{28}$$

The logarithm of aggregate productivity also follows an AR(1) process:

$$\ln Z_t = \rho_Z \ln Z_{t-1} + \varepsilon_{Z,t} \tag{29}$$

where $\varepsilon_{\nu,t}$ and $\varepsilon_{Z,t}$ are independent mean zero processes.

2.4 Equilibrium

Under the representative consumer framework, household choices (superscript h) are common across householdsand in equilibrium $M_t^h = M_t$ etc, in (1) to (3). Aggregate income, $\mathcal{I}_t$ comprises labour income, plus profits of final goods producers, plus profits of intermediate goods producers net of vacancy posting costs $\mathcal{I}_t = (1-\lambda^x) N_t W_t H_t + P_t \Pi_t^F + P_t \Pi_t^I$. Here, nominal final goods profits are $P_t \Pi_t^F = \int p_t(z) y_t(z) dz - P_t^I \int y_t(z) dz = P_t Y_t - P_t^I Y_t^I$, and

$$Y_t^I = (1-\lambda^x) N_t \int_0^{\bar{X}_t} [A Z_t H_t + \mathcal{F} - X] \, dF(X) - \kappa \mu_t V_t \tag{30}$$

denotes aggregate intermediate output net of vacancy posting costs.[19] Nominal intermediate good producers' profit can be written as the sum of output net of vacancy costs, less aggregate wage payments: $P_t \Pi_t^I = P_t^I Y_t^I - (1-\lambda^x) N_t W_t H_t$. Using these insights and cancelling terms we find $\mathcal{I}_t = P_t Y_t$. In equilibrium, when combined with the government budget identity, the household budget constraint reduces to the aggregate (final) goods market equilibrium condition

$$Y_t = C_t \tag{31}$$

Thus the system of equations governing equilibrium in the economy consists of the numbered equations (1) - (12), (17) and (21) - (31).

3 Calibration & Model Solution Method

We log-linearise the model about its (zero-inflation, zero growth) steady state and use dynamic simulations to tease out the dynamic structure of the economy. Model solution requires choice of several parameters governing steady state values of labour and goods market variables; nominal rigidity, and household preferences. We also specify the processes governing idiosyncratic costs,

[19] Note $Y_t^I = \int_0^1 y_t(z) dz$. Using the demand function for final good z: $y_t(z) = \left(\frac{p_t(z)}{P_t}\right)^{-\varepsilon} Y_t$, we have $Y_t^I = \int_0^1 \left(\frac{p_t(z)}{P_t}\right)^{-\varepsilon} Y_t dz = \left(\frac{P_t}{\tilde{P}_t}\right)^{\varepsilon} Y_t$, where $\tilde{P}_t = \int_0^1 p_t(z)^{-\varepsilon} dz$, is an auxilliary price index.

aggregate productivity and money supply growth. The parameter values are summarised in Table 1, Appendix A contains discussion of the rationale for these choices.

Table (1) here.

4 Results

In this section we discuss evidence on the impact of variation in hours per worker on the strength and timing of reallocative activity and on other standard macroeconomic aggregates.

We contrast the behaviour of a model variant in which hours variation is suppressed (which represents the standard approach in models of labour market search with endogenous job destruction) with an equivalent set up in which the elasticity of labour supply, governed by the parameter ψ, is selected to match the variation of hours in the data. To provide a fair basis of comparison across variants of the model, we hold constant across experiments both the standard deviation of simulated output and the standard deviation of simulated job destruction relative to simulated output. To do this, we adjust the standard deviation of productivity shocks to allow the standard deviation of (Hodrick-Prescott filtered) model output to match the variability of output in US data (Hodrick-Prescott filtered US NIPA GDP), which is 1.69%. We hold the autocorrelation of productivity shocks, both standard deviation and serial correlation of money supply growth shocks constant across these experiments. The standard deviation of idiosyncratic cost shocks is varied in order to match the volatility of job destruction relative to that of GDP. These dimensions cannot be used for falsification. Instead, we examine the ability of the model to capture two key aspects of the strength and timing of reallocative behaviour: i) the Beveridge curve and ii) the correlation of gross job flows. We also consider the operation of the labour market as captured by the correlation of hours with employment, the behaviour of job creation and vacancies and standard macroeconomic aggregates such as unemployment and inflation. We explain the mechanism by which variation in hours per worker improves the treatment of labour reallocation, consider the role played by different shocks and examine the robustness of the results to plausible variation in labour supply elasticity.

4.1 Reallocation and Hours Variation

Table (2) illustrates the role of labour supply elasticity (variation in hours) in determining the nature of reallocation. Column (1) of Table (2) displays properties of US Data. The other columns of Table (2) correspond to a particular model variant.[20] For column (X >1), the entry in the row labelled output indicates the variability of output in column (X) relative to the variability of output in US data. The other entries in column (X) (except the final 8) correspond to the variability relative to that of output generated by model (X). The final two entries in each column are serial correlation statistics for output and inflation, while the penultimate six entries are simple correlation statistics capturing aspects of labour market activity.

Table (2) here.

Labour supply elasticity, ϵ_H, is $\frac{1}{\psi}\left[\frac{1-H}{H}\right] = \frac{2}{\psi}$, since in steady state $H = 1/3$. In the limit as $\psi \to \infty$, $\epsilon_H \to 0$, and variation in hours is eliminated. Column (2) reports results for the model where labour supply elasticity is set to a low value, 0.01, using $\psi = 200$. This suppresses hours variation allowing our model to approximate the framework used by Krause and Lubik (2007). Column (5) displays simulation results when labour supply elasticity is set to match the variability of hours observed in US data. This enables our model to approximate the model of Trigari (2005). The other columns are discussed in Section (4.3).

Without hours variation it is not possible to generate the patterns of reallocation found in the data. The Beveridge curve is almost flat and the correlation of gross job flows is positive. This mirrors the finding of Krause and Lubik (2007). This is exactly the effect that one would expect, in the light of the wider literature on reallocation under socially efficient search, Mortensen and Pissarides (1993).[21] Once realistic variation in hours is permitted the model is much better able to capture the direction of reallocation. However, the strength of the relationship between unemployment and vacancies is not captured as the Beveridge curve, while downward sloping, is

[20] All statistics (for model simulations and data) are computed from Hodrick-Prescott filtered data, expressed as percentage deviations from steady state (or trend in the case of the data). The business cycle statistics for model variants are computed by averaging across 200 simulations. Each simulation contains 250 data points but the first 50 are omitted when undertaking detrending and computing moments.

[21] It appears to confirm the difficulties of allowing for endogenous job destruction outlined by Shimer (2005) even though here movements in job destruction are driven by aggregate productivity and monetary disturbances rather than the reallocative shocks to exogenous job destruction that he discusses.

not as steep as that in the data, see Columns (1), (2) and (5).

It is worth spending some time trying to understand the mechanism by which variation in hours alters the incentives to create and destroy jobs. To do so we contrast the model's response to a shock that raises unemployment under inelastic hours and then under elastic hours.

First notice that from an accounting viewpoint, a rise in unemployment can be achieved in a variety of ways including a rise in job destruction and a fall in job creation, or by one of these in isolation with no change in the other, by a fall in job creation combined with a *smaller* fall in job destruction or even by a *rise* in job creation combined with a *larger rise* in job destruction. The first of these would tend to give rise to a negative contemporaneous correlation of job creation and job destruction. The first case describes the data, as is well documented Davis et al. (1998). It also applies to the case with elastic hours. The first case describes the data, as is well documented Davis et al. (1998). It also applies to the case with elastic hours. The last (two) of cases would tend to produce a positive contemporaneous correlation of job creation with job destruction. Under inelastic hours a rise in unemployment occurs through a *rise* in job creation combined with a *larger rise* in job destruction. Second, since the correlation of gross job flows is a flow measure of reallocation while the Beveidge curve is (at least in part) is a stock measure, it is not clear that there should be a strong association between the correlation of gross job flows and the slope of the Beveridge curve. The relationship between the two will depend on the extent to which high levels of vacancies are strongly associated with periods of above average job creation and to the extent that above average job destruction is associated with periods of above average unemployment.

Consider the case where variation in hours is suppressed. Separations are efficient and job destruction facilitates the socially efficient creation of jobs, so the optimal time to create jobs is at the point at which the opportunity cost of doing so is at its lowest, namely when match level profits (rents) are low. This makes job creation and job destruction move together, Column (2). As Column (2) shows, job creation and vacancies also move together very closely with hours variation suppressed - whereas in US data these variables appear virtually uncorrelated, so a decline in rents for ongoing matches (following a shock) drives up job destruction, which is positively correlated with unemployment, although the correlation is weaker than in US data. Such a shock also leads to a sharp rise in job creation, which is strongly associated with a rise in vacancies. So with hours variation suppressed unemployment and vacancies are less strongly associated than in the data because in the model job destruction is relatively weakly associated with changes in unemployment, despite the strong correlation of vacancies with job creation, and of job creation with job destruction. This demonstraes the difficulties of accounting for reallocative behaviour under the standard (implicit) assumption that labour input can only be varied on the extensive margin. It also provides and example of an environment in which the correlation of gross flows takes a different sign to the slope of the Beveridge curve.

Next consider the environment in which ψ is set to match the variability of hours in US data, σ_H/σ_Y (to achieve this we set $\psi = 2.25$ as in Column (5)). With realistic variation in hours, the model generates a positive correlation between hours per worker and employment (albeit weaker than that in the data). So hours per worker will be above average in an expansion, as unemployment rises, and below average in a recession as unemployment falls. Variation in hours per worker reduces the extent to which rents vary in response to shocks (as a result of the convexity of the match level rents in hours per worker.

Increased variation in hours per worker is likely to reduce the variation on the extensive margin. The response of job destruction to shocks will, other things equal, be more muted when hours can vary and insulate the economy from the full reallocative effects of any shock. As a direct result of this reduced response of job destruction, the incentives for vacancy and job creation (in response to a shock that raises unemployment) will be attenuated for two reasons. Firstly, the reduced response of job destruction will leave a larger number of ongoing matches, which will reduce the potential rents available to new matches and consequently reduce job creation and vacancy creation. Secondly the response of job creation will be attenuated because the probability of filling an open vacancy will fall, due to the reduction in the size of the pool of unemployed workers (which follows from the more muted response of job destruction). Finally the job creation response is likely to be attenuated, independently of any variation in job destruction, since the flexibility of hours allows ongoing matches to respond to improved conditions (as the economy moves back towards steady state following a shock).

Now, in practice, our calibration strategy holds the variability of job destruction constant across experiments at the value observed in US data, σ_{JD}/σ_Y. This places greater emphasis on the final effect described in the previous paragraph. Columns (2) and (5) confirm that greater elasticity of hours reduces the variability of job creation as would be expected under the latter effect. By attenuating the use of the extensive margin (job creation) in response to shocks, hours variation alters the correlation of gross job flows. So, in response to a shock that leads to an increase in unemployment, job creation rises when job destruction falls, as in the data, despite the fact that we require the economy to satisfy the Hosios condition. Vacancies are less variable when variation in hours is introduced which is consistent with the idea that variation in hours attenuates use of the extensive margin. Vacancies remain positively correlated with job creation when hours can vary (Column (5)) but the correlation is weaker than with hours variation suppressed (Column (2)). By contrast, the correlation of job destruction with unemployment is stronger under the variable hours environment than with hours variation suppressed. It is the combination of the stronger correlation between job destruction and unemployment, and the reduction in the correlation of job creation with vacancies that permits the negative correlation of job creation and job destruction together with a negatively sloped Beveridge curve. Although, the Beveridge curve remains shallower than required by the data.

While a model with hours variation offers an improved treatment of many aspects of reallocation, the joint behaviour of vacancies with job creation is one area in which the variation of hours does not really get close to the data. In US data there is virtually no relationship between the job creation and the number of open vacancies, yet with realistic hours variation the model generates a positive correlation between vacancies and job creation (the association is even greater when hours variation is suppressed). This reflects the lack of persistence in vacancies (not displayed in Table (2)): in US data the first order serial correlation coefficient for vacancies is 0.92, while in the model with hours variation it takes the value 0.08.

4.2 Hours Variation and Other Macroeconomic Aggregates

It is important to ensure that the improvement in the account of reallocative activity provided by the model does not compromise other aspects of model performance. Here we provide a brief summary of the other properties of the model. As indicated in the introduction, some of these issues have been discussed by Trigari (2005) for the model with elastic hours variation and Walsh (2005), Krause and Lubik (2007) and Andres et al. (2006) for the case where variation is suppressed. As a result, rather than repeat their detailed analysis of the mechanisms present, we highlight the impact of hours variation and the behaviour of aspects of the model that are not considered elsewhere. In particular, we discuss the impact of variable hours on the volatility of unemployment, vacancies and labour market tightness as the behaviour of these variables was not explicitly considered by Trigari (2005).[22]

In contrast to the results of Shimer (2005) (who finds that the volatility of unemployment is only one tenth of that in US data), we find that the model generates unemployment volatility that is around 80% of that in the data. This is true regardless of the elasticity of hours per worker. Andres et al. (2006) argue that this mainly reflects the presence of nominal rigidities in the New Keynesian model. If one were to hold the standard deviation of idiosyncratic shocks (and other parameters) constant (rather than adjusting parameters to hold the standard deviation of job destruction constant), then as Walsh (2005) notes an increase in nominal price setting frictions raises the amplitude and persistence of output fluctuations. Put simply the introduction of noinal rigidities flattens the supply curve and raises the output response to shocks at the expense of price adjustment. Since the volatility of unemployment will increase with that of output it follows that unemployment will exhibit greater volatility. This explains the impact of price stickiness on unemployment poited out by Andres et al. (2006). However, in their analysis **i)** the standard

[22] Trigari (2005) and Walsh (2005) discuss the role of labour market search and matching frictions in enhancing the persistence of inflation and output in response to shocks (compared to a standard New Keynesian framework with a frictionless Walrasian labour market). Trigari (2005) outlines the impact of variation on the extensive margin for the behaviour of marginal cost, while Walsh (2005) demonstrates that output and inflation persistence can be enhanced by the introduction of habit persistence in consumption and by increasing the strength of frictions in nominal price setting using a hybid Calvo price-setting scheme. Krause and Lubik (2007) provide evidence that the unemployment-vacancy-tightness variability puzzle identified by Shimer (2005) can be resolved by incorporating real wage rigidity through an ad hoc wage norm. Andres et al. (2006) argue that (in conjunction with habit persistence in consumption, capital accumulation and distortionary taxation) the frictions in price setting in a New Keynesian model make it possible to solve the unemployment - vacancy - tightness variability puzzle without resort to either wage rigidity, as in Shimer (2005), or departures fron the Hosios condition as in Hagedorn and Manowskii (2005).

deviation of output varies across experiments and **ii)** the standard deviation of job flows appears to be calibrated only in the benchmark case so that it too can vary across experiments. So this mechanism can not explain the somewhat surprising rise in unemployment volatility as variation in hours is introduced in our model (see Columns (2) and (5)), since both output and job destruction variability are held constant across our experiments. Instead the change in unemployment reflects the fact that unemployment is less strongly correlated with job destruction in the latter case, while the volatility of job destruction is held constant across experiments. The decline in the use of the extensive margin that we anticipate associated with the introduction of variable hours therefore shows up as a reduction in the volatility of vacancies (and also in the volatility of job creation). The volatility of labour market tightness is unaffected. These results suggest that, if we insist on adjusting parametrs to hold the volatility of job destruction constant, there may be some role for more standard resolutions of the unemployment-vacancies-tightness puzzle: wage rigidity and departures from the Hosios condition in matching these moments.

The serial correlation properties of output is not greatly affected by the introduction of hours variation and is close to its value in US data. Model-based inflation displays greater persistence than US data once realistic hours variation is admitted. The variability of inflation is closer to the value in US data when hours per worker can exhibit realistic variation than when this is suppressed. To understand the variability of inflation, notice that the first order condition for optimal hours equation (21) is common across experiments (since we do not suppress hours variation completely, we only approximate the standard inelastic hours case):

$$\Upsilon^H \frac{(1-H_t)^{-\varphi}}{C_t^{-\phi}} = \frac{AZ_t}{\mu_t}$$

This can be rearranged to give an expression for marginal cost $= \mu_t^{-1}$, as a function of hours worked (consumption and productivity). Given our assumptions on the structure of price adjustment, inflation depends on the discounted present value of future marginal costs. In the inelastic case, $\psi = 200$, so even though hours do not vary a great deal, the size of ψ makes marginal cost and hence inflation sensitive to small variation in hours. This leads inflation to be more variable with hours variation suppressed. The same is true for wages. The wage equation reflects variation in

μ_t^{-1} as well as an effect through the term in the disutility of hours worked $(1 - H_t)^{1-\varphi}$ which again exhibits substantial variation for high values of ψ. However, even with elastic variation in hours per worker, wages are three times more variable than in the data. This may leave scope for the introduction of wage rigidity.

Overall, regardless of whether realistic variation in hours per worker is introduced, the extent of variation on the extensive margin is insufficient to account for the puzzles identified by Shimer (2005). Nonetheless, the New Keynesian framework, even without capital, offers a substantial improvement in the account of unemployment volatility, and this is robust to the introduction of realistic variation in hours per worker.

4.3 Robustness to Alternative Labour Supply Elasticities

A labour supply elasticity of 0 is implicit in studies in the labour market search literature that rely only on the extensive margin for adjusting labour input. Our preferred model is calibrated to a labour supply elasticity of 0.9 (corresponding to $\psi = 2.25$) in order to match the volatility of hours per worker. Given the structure of the model this is the "correct" ψ. However, a range of $\psi \in [0, 1]$, are supported by empirical evidence, Blundell and McCurdy (1999). Here we briefly consider the sensitivity of our measure of reallocative and other macroeconomic activity in our model to alternative values of ψ. We consider values of $\epsilon_H \in [0.01, 1]$. Our results are summarised in Figure (1).[23] Panel (a) displays measures of reallocation and other correlations relating to labour market flows. The improvement in these metrics associated with the introduction of variation in hours per worker relies upon a relatively elastic parameterisation of labour supply. Panels (b), (c) and (d) show the volatility of unemployment, labour market tightness, job creation and vacancies. For the aspects of the model displayed in these panels, the effects of hours variation only emerges for relatively elastic hours per worker, around the value used in the experiment described in Table (2).

[23] In constructing Figure (1) we adjust the standard deviation of productivity shocks to hold the volatility of output constant and adjust the standard deviation of idiosyncratic shocks to hold the volatility of job destruction constant at their respective values observed in US data.

4.4 The Effect of Real and Nominal Shocks

Finally consider Columns (3), (4), (6) and (7) in Table (2), which decomposes the effect of the variation in labour supply by the source of shocks. We deliberately avoid re-calibrating to match features of the data, as our aim is to show the contribution of individual shocks to the overall response.[24] Figures (2) and (3) document impulse response functions for output, inflation and hours (panels (a) and (d)), vacancies and unemployment (panels (b) and (e)) and job creation and destruction (panel (c) and (f)) to monetary and productivity impulses. These offer an alternative means to picture the dynamic adjustment in the face of shocks.

Notice that in our calibration monetary shocks exhibit less persistence than productivity shocks. From Columns (3) and (6) we see that monetary shocks also account for a lower fraction of output variation with inelastic hours than in the case of elastic hours. In the inelastic hours environment, the intensive margin cannot be used to adjust to shocks, and firms are reliant on the extensive margin, see Figure (2), panels (c) and (d) and Columns (3) and (4). So, to respond to shocks, long-run relationships must either be created or destroyed. This means that it is particularly costly to adjust to temporary shocks in the inelastic hours case, so that monetary shocks account for a relatively small component of output fluctuations. Also, in the short-run, firms tend to make greater use of job destruction rather than job creation to respond to shocks since the latter activity is more costly, see Figure (2). Now, for the inelastic hours case, consider a monetary shock that leads to a fall in job destruction and unemployment. This does not greatly raise the value of creating a new match, because the lack of persistence of the shock generates a small, temporary deviation from steady state, see Figure (2). On the other hand, the fall in the fraction of unemployed workers reduces the probability of filling a match. Taking these effects together, vacancies and job creation will be below average at the very point in time when job destruction and unemployment are low, see Figure (2) panels (d) and (f). This will generate a positively sloped Beveridge curve and a positive correlation (synchronisation) of gross job flows as in Column (3). By contrast, when hours can vary, this margin can be used to adjust to shocks. This enables

[24] An alternative to our calibration approach would be to estimate the relative importance of the shocks using a full information approach, to impose the discipline of formal statistical criteria. Given the difficulties of matching the behaviour of vacancies we adopt the simpler calibration based strategy, recognising its limitations.

transitory monetary shocks to play a greater role in accounting for output variability than in the inelastic case. For example, compare the output responses in panel (b) of Figures (2) and (3). As discussed above, the response to monetary shocks under elastic hours affects rents in a way that reduces the economy's reliance on the extensive margin, desynchronises job flows and generates a downward sloping Beveridge curve, see Column (6). This insight is confirmed in Figure (3) panel (b).

With frictions in nominal price setting, a positive productivity shock raises unemployment in the short run. Yet poductivity shocks are persistent, so a shock which raises unemployment is likely to temper the tendency to open vacancies and create jobs in the short-run. Consider the inelastic hours case in Figure (2) panel (c). In the short-run unemployment and vacancies both rise in the face of a positive productivity shock. Thereafter, as the price level adjusts unemployment declines. Nonetheless, high rents due to the persistence of the productivity shock leads to persistently high vacancies. So in the inelastic case it is the long-run behaviour of unemployment and vacancies which generates a downward sloping Beveridge curve. Of course, since the search environment satisfies the Hosios condition, seperations are efficient, so job creation and job destruction are positively correlated. To reconcile the behaviour of the Beveridge curve and the correlation of gross job flows, note that job destruction is only weakly correlated with unemployment in Table (2). The impact variable hours on the response to a productivity shock is to reduce the degree of synchronisation of job flows, to see this compare panel (e) in Figures (2) and (3). In the elastic case, the responses to a productivity shock are more muted (than in the inelastic case).

Figures (2) and (3) confirm the relative lack of persistence of the effects of a monetary shock in comparison to a technology shock, and highlight the role of hours per worker in adjustment to shocks. The impulse response functions also illustrate the strong degree of association of vacancies and job creation and the comparative lack of persistence in these two variables in the elastic hours case.

5 Conclusions

In this paper we show that one simple modification, the introduction of realistic variation in hours per worker, allows a New Keynesian model with labour market search and endogenous job destruction to account for the direction and to some extent the strength of reallocative activity (measured by the Beveridge curve and the correlation of gross job flows). We also show that the impact of hours variation is enhanced by temporary shocks. These results are interesting for two reasons. Firstly, because there is considerable evidence that reallocative activity and microeconomic restructuring underlie business cycles and growth, yet is almost completely ignored in the New Keynesian literature on unemployment even in those papers which allow endogenous job destruction. Secondly because they provide a simple example of a situation in which incentives for intertemporal substitution can resolve the difficulty of capturing measures of reallocation based on gross job flows while satisfying the Hosios condition.

At the same time realistic variation in hours leads predominantly to plausible behaviour of other more traditional macroeconomic aggregates. Our strategy of adjusting parameters to maintain the variability of job destruction and of output across experiments allows us to confirm, using a different methodology from Andres et al. (2006), that a New Keynesian model with frictions in price setting captures a large part of the volatility of unemployment, and in the inelastic case vacancies also. Unfortunately while the amplitude of unemployment fluctuations increases towards that observed in the data once we allow for realistic hours variation, the amplitude of vacancy fluctuations declines. In addition vacancies lack persistence once realistic hours variation is permitted and is too strongly associated with job creation. Since we deem an account of reallocative activity important this leaves a role for other solutions to the unemployment-vacancy-tightness volatility puzzle such as wage rigidity or departures from the Hosios condition suggested by Shimer (2005) and Hagedorn and Manowskii (2005) respectively. One possible solution to the absence of vacancy persistence might be to introduce fixed costs of posting a vacancy, as in Fujita and Ramey (2007b), into our monetary model with endogenous job destruction. This is the subject of ongoing research.

Nevertheless, the success of the model in capturing the behaviour of unemployment and measures of reallocation while including endogenous job destruction may offer a suitable starting point for monetary policy analysis - quantitative difficulties in relation to vacancies and wages notwithstanding.

.

References

[1] Andolfatto, D., (1996), 'Business Cycles and Labour Market Search', *American Economic Review*, **86** (1), pp. 112-132.

[2] Andres, J,. R. Domenech, and J. Ferri, (2006), 'Price Rigidity and the Volatility of Vacancies and Unemployment', University of Valencia, Institute of International Economics, Working Paper #601.

[3] Bils, M. and P. Klenow, (2004), 'Some Evidence on the Importance of Sticky Prices', *Journal of Political Economy,* **112** (5), pp. 947-85.

[4] Blanchard, O. J. and J. Gali, (2006), 'A New Keynesian Model with Unemployment', National Bank of Belgium, Research Series, #2006-10.

[5] Blundell, R., and T. MaCurdy, (1999), "Labour Supply: A Revire of Alternative Approaches", in O. Ashenfelter and D. Card (eds.), *Handbook of Labour Economics*, Vol. 3.1. North Holland, Amsterdam.

[6] Braun, H., (2006), '(Un)employment Dynamics: The Case of Monetary Policy Shocks', mimeo.

[7] Chari V. V., P. J. Kehoe, E. R. McGrattan, (2000), 'Sticky Price Models of The Busienss Cycle: Can The Contract Multiplier Solve the Persistence Problem ', *Econometrica*, **68**, (5), pp. 1151-1179.

[8] Cho J-O,and T. F. Cooley, (1994), "Employment and Hours over the Business Cycle", *Journal of Economic Dynamics and Control*, **18**, pp 411-432.

[9] Christiano, L., M. Eichenbaum and C. Evans (2005), "Nominal Rigidities and the Dynamic Effects of Shock to Monetary Policy.", *Journal of Political Economy*, **113**, pp 1-45.

[10] Christiano, L. M., (2006), 'The Response of Hours to a Technology Shock: Evidence Based on Direct Measures of Technology', NBER Working Paper, #10254.

[11] Christoffel, K. and T. Linzert, (2005), 'The role of real wage rigidity and labor market frictions for unemployment and inflation dynamics', ECB Working Paper #556.

[12] Christoffel, K., T. Linzert and K. Kuester, (2006), 'Identifying the Role of Labor Markets for Monetary Policy in an estimated DSGE model', ECB Working Paper #635.

[13] Cogley, T. and J. Nason, (1995), 'Output Dynamics in Real Business Cycle Models', *American Economic Review*, **85**, pp. 492-511.

[14] Cooley, T. F. and G. Hansen, (1989), 'Inflation Tax in a Real Business Cycle Model', *American Economic Review*, **79** (4), pp. 733-748.

[15] Cooley, T. F. and V. Quadrini (1999), 'A Neoclassical model of the Phillips Curve Relation', *Journal of Monetary Economics*, **44**(2), pp.165-193.

[16] Davis, S. J., R. J. Faberman, and J. C. Haltiwanger, (2006), 'The Flow Approach to Labor Markets: New Data Sources and Micro-Macro Links', *Journal of Economic Perspectives*, **20** (3) pp.

[17] Davis, S. J. and J. C. Haltiwanger, (1999), 'On the Driving Forces Behind the Cyclical Movements in Employment and Job Reallocation', *American Economic Review,* **89** (5), pp. 1234-1258.

[18] Davis, S. J., J. C. Haltiwanger and S. Schuh (1998), *Job Creation and Destruction*, MIT Press, Cambridge MA.

[19] Den Haan, W. J., G. Ramey and J. Watson, (2000), 'Job Destruction and the Propagation of Shocks', *American Economic Review*, **90** (3) pp. 482-498.

[20] Elsby, M., R. Michaels, and G. Solon (2007), 'The Ins and Outs of Cyclical Unemployment', NBER Working Paper #12853.

[21] Faia, E., (2007), 'Optimal Monetary Policy Rules with Labour Market Frictions', Forthcoming *Journal of Economic Dynamics and Control*.

[22] Fujita, S. and G. Ramey, (2007a), 'Reassessing the Shimer Facts', Federal Reserve Bank of Philadelphia, Working Paper #07-02.

[23] Fujita, S., and G. Ramey, (2007b), 'Vacancy Persistence', *Journal of Economic Dynamics and Control*, **31** (11), pp. 3671-3698.

[24] Gali, J., (1999), 'Technology Shocks, Employment and The Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations?', *American Economic Review*, **89** (1), pp.249-271.

[25] Gali, J., (2003), 'New Perspectives on Monetary Policy, Inflation and the Business Cycle', in M. Dewatripont, L. Hansen and S. Turnovsky (Eds.), *Advances in Economic Theory*, Cambridge University Press, Cambridge, UK.

[26] Gali, J., and M. Gertler, (1999), 'Inflation Dynamics: A Structural Econometric Analysis', *Journal of Monetary Economics*, **44**, pp. 195-222.

[27] Hagedorn, M. and I. Manowskii, (2005), 'The Cyclical Behaviour of Unemployment and Vacancies Revisited', mimeo University of Pennsylvania.

[28] Hall, R. E., (2005), 'Employment Fluctuations and Equilibrium Wage Stickiness', *American Economic Review*, **95**, (1), pp. 50-65.

[29] Holt, R. W. P., (2006), 'Whither Job Destruction? Unemployment, Job Flows and Hours in a New Keynesian Model', Edinburgh School of Economics Discussion Paper #146.

[30] Jung, P., (2005), 'Capital, Unemployment and Hours - on the Quantitative Peformance of a DGE Labour Market Model', mimeo, Goethe University.

[31] Jung, P., and K. Kuester, (2006), 'Unemployment Fluctuations with Complete and Incomplete Insurance', mimeo, Goethe University.

[32] Kuester, K., (2007), 'Real Price and Wage Rigidities in a Model with Matching Frictions', ECB Working Paper #720.

[33] Klein, P., (1997), 'Using the Generalised Schur form to solve systems of linear Expectational Difference Equations', *Journal of Economic Dynamics and Control,* **24**, pp 1405-1423.

[34] Krause, M. and T. A. Lubik, (2007), 'The (Ir)relevance of Real Wage Rigidity in the New Keynesian Model with Search Frictions', *Journal of Monetary Economics*, **54**, (3), pp. 706-727.

[35] Krussell, P., A. Hornstein and G. l. Violante, (2005), 'Unemployment and Vacancy Fluctuations in the Matching Model: Inspecting the Mechanism', *Federal Reserve ank of Richmond Quarterly*, **91**(3)**,** pp. 19-51.

[36] Mankiw, N. G. and L. H. Summers, (1986), 'Money Demand and The Effects of Fiscal Policies', *Journal of Money Credit and Banking*, **18** (4) pp. 415-429.

[37] B. T. McCallum (1999), 'Solutions to Linear Rational Expectations Models: A Compact Exposition', *Economics Letters,* **61**, pp 143-147.

[38] Merz, M., (1995), 'Search in the Labour Market and the Real Business Cycle', *Journal of Monetary Economics*, **36**, (2), pp. 269-300.

[39] Mortensen, D. T., (1994), 'The Cyclical Behaviour of Job and Worker Flows', *Journal of Economic Dynamics and Control,* **18**, (6), pp. 1121-1142.

[40] Mortensen, D. T. and C. A. Pissarides, (1993), 'The cyclical behavior of job creation and job destruction', in: J.C. Ours, G.A. Pfann and G. Ridder, Editors, *Labour Demand and Equilibrium Wage Formation*, North-Holland, Amsterdam.

[41] Mortensen, D. T., and C. A. Pissarides, (1994), 'Job Creation and Job Destruction in the Theory of Unemployment', *Review of Economic Studies*, **61**, pp. 397-415.

[42] S. Moyen and J-G. Sahuc, (2005), 'Incorporating Labour Market Frictions into an Optimising Monetary Model', *Economic Modelling,* **22**, (1), pp. 159-186.

[43] Reichling, F., (2007), 'Optimal Unemployment Insurance in Labour Market Equilibrium when Workers can Self-insure', mimeo, Stanford University.

[44] Shimer, R., (2005), 'The Cyclical Behaviour of Unemployment and Vacancies', *American Economic Review*, **95**, (1), pp. -49

[45] Thomas, C., (2006), 'Search and Matching Frictions and Optimal Monetary Policy', CEP Discussion Paper #2006-12.

[46] Trigari, A., (2005), 'Equilibrium Unemployment, Job Flows and Inflation Dynamics', mimeo, IGIER.

[47] Trigari, A., (2006), 'The Role of Search Frictions and Bargaining for Inflation Dynamics', IGIER Working Paper No. 304.

[48] Walsh, C. E., (2005), 'Labour Market Search, Sticky Prices and Interest Rate Policies', *Review of Economic Dynamics,* **8,** (4) pp. 829-49.

[49] Woodford, M., (2003), *Interest and Prices,* Princeton University Press.

6 Appendix: Data, Calibration and Model Solution Method

6.1 Data

We attempt to match the second moments of seasonally adjusted quarterly US macroeconomic and labour market data. Unless otherwise indicated, the data used are available on the BEA and BLS websites. Our sample period, 1972:2-1993:4, in common with other studies, is limited by the availability of published job flows data, see Davis, Haltiwanger and Schuh (1998). We use real GDP data from NIPA as our measure of output. To express this in per capita terms we deflate by the BLS civilian population over 16. Inflation is the percentage change in the seasonally adjusted NIPA implicit GDP deflator. US M1 money supply, used to estimate the properties of the exogenous money supply process, is taken from OECD Main Economic Indicators. The Conference-Board-Help-Wanted Index is used as our measure of vacancies. The unemployment rate is the official BLS unemployment rate for those over 16. The rates of gross job creation and job destruction relate to the manufacturing sector only, see Davis et al. and are available from Haltiwanger's website. Because of the sector-specific nature of the job flows data, we use data for employment, wages and hours per worker that pertain specifically to US manufacturing.[25]

6.2 Calibration

The parameters of the model are summarised in Table (1). We begin with a number of relatively uncontroversial parameters. The discount factor, β, is set to 0.99 to target an annual real interest rate of 4%. The elasticity of substitution between goods in the final goods sector is set at $\varepsilon = 21$ to give a markup of 5%, as in Jung and Kuester (2006). The value of ε is at the upper end of those found in the New Keynesian literature. It implies profits attributable to final goods producers are low, consisent with the NIPA compensation data.

The severity of nominal price-setting frictions is governed by the parameters τ and ω. The first, τ, represents the fraction of those firms which set prices in any given period that do so in a

[25] In relation to the data the main source of controversy concerns data for total hours worked per capita. Economy wide data appear to exhibit a trend. If the hours per capita data contain a unit root, then authors may use of differenced data in analysing the economy's response to a technology shock. This choice may determine the sign of the response to a technology shock, see Christiano et al. (2006), Gali (1999) for further discussion. However, the data (and the model simulated series) we use are HP-filtered which removes any (unwanted) trend before moments are calculated so this debate is of less direct relevance except in as much as it affects the choice series. In addition, the use of manufacturing industry data sidesteps controversies since hours worked appear to be stationary.

backward-looking manner. The second, ω, represents the probability with which any given final good producer gets the opportunity to reset the price of the good. This determines the average duration of a newly set price. While we could set ω to whatever value is required to match inflation volatility, the implied price durations would be unreasonable. Instead we set $\omega = 0.8$, which indicates that on average a newly set price lasts for 5 quarters before being reset. This is within the range of values considered reasonable by Gali and Gertler (1999), from estimates of the underlying price adjustment model with aggregate data. Recent evidence from micro data, Bils and Klenow (2004), has suggested that prices may change more frequently, on average once every six months. This is difficult to rationalise in environments, such as ours, where the price setting and factor adjustment decisions are separated.[26] Given the separation assumption that we make it is more appropriate to target the price duration estimates. Following the evidence of Gali and Gertler (1999) and Christiano et al. (2005) and others we set $\tau = 0.5$. The deviation between model generated inflation and the data, gives an indication of model fit along this dimension.

We follow the standard approach in the literature and set the autocorrelation of aggregate productivity innovations in quarterly data to $\rho_Z = 0.95$. We allow the standard deviation, σ_Z, of aggregate productivity shocks to vary across our experiments in order to target the standard deviation of output in the data over our sample period: $\sigma_Y = 0.0168$. In relation to money supply growth, we adopt the approach of Krause and Lubik (2007) and model growth in M1 as a $AR1$ process. These authors use the estimates provided by Cooley and Hansen (1989). For our sample period the estimate of the autocorrelation coefficient, $\rho_v = 0.5$, as in Cooley and Hansen (1989), while the standard deviation of the innovation process is slightly lower, $\sigma_v = 0.004$. We set the elasticity of money demand with respect to consumption, $\xi = 1$, consistent with the estimates provided by Mankiw and Summers (1986). Then $\Upsilon_{\frac{M}{P}} = \frac{M}{PY}$ is set at 17, to target average income velocity of money over the sample period.

Next we turn to labour market parameters, we begin with relatively uncontroversial parameters concerning labour market flows and the parameters of the matching function. The average job

[26] Altig (2005) and others have made progress in reconciling the new micro price adjustment evidence with observed aggregate inflation dynamics by extending the standard New Keynesian model to allow for firm specific capital adjustment decisions. Kuester (2007) integrates price setting, production and factor adjustment decisions in a single sector, but he only allows for exogenous job destruction.

destruction rate is set at 10% per quarter, $\lambda = 0.1$, following the evidence of Den Haan et al. (2000), Shimer (2005). We follow, Shimer, (2005), Jung (2005) and others in targeting a steady state employment rate of $N = 0.94$, consistent with BLS estimates of the average unemployment rate.[27] To achieve that target, we set the probability of finding a job $p^U = 0.61$.[28] We follow Den Haan et al. (2000) in calibrating the probability of filling a vacancy, $p^V = 0.7$ to match US data. The scaling parameter of the matching function, $\mathfrak{M} = 0.654$ is chosen to target a matching function exponent of $\gamma = 0.5$. This lies within the range of plausible values discussed by Petongolo and Pissarides (2001) who suggest $\gamma \in [0.3, 0.5]$. Following Den Haan et al. (2000), the fraction of jobs destroyed exogenously in steady state is set at $\lambda^x = 0.068$ to target a steady state job creation rate of 0.052, as estimated from plant level data by Davis et al. (1998). The rate of job destruction and job creation will equal in steady state. There is little formal evidence to guide the properties of the distribution of idiosyncratic shocks. We follow Dean Haan et al. in assuming that idiosyncratic shocks are log-normally distributed, with mean $\mu_X = E[\ln X]$ and standard deviation σ_X. Rather than allow both μ_X and σ_X to vary across experiments, we follow the standard approach in the literature and fix μ_X. We allow the standard deviation of idiosyncratic shocks, σ_X, to vary across experiments so as to match the variability of job flows in the data relative to that of output, σ_{JD}/σ_Y. Increases in μ_X raise σ_X. At low $\mu_X \approx 0$ the numerical integration over X that we use sometimes do not converge so here we set $\mu_X = -1.5$, but our results do not depend on this particular choice. Given μ_X , σ_X, λ and λ^x we the job destruction threshold, $\bar{X}$, and then determine $\mathcal{F} = F\left(\bar{X}\right)^{-1} \int_0^{\bar{X}} X f(X)\, dX$.[29]

There has been considerable discussion over the calibration of worker bargaining power, the match surplus (the profits over which both parties in a match bargain), and the value of a worker's outside option. Hagedorn and Manowskii (2005) argue that the results of Shimer (2005) on

[27] Some authors, Andolfatto (1995), Trigari (2006) employ much lower values of steady state employment, 0.54 and 0.75 respectively. One justification for this approach is that it implicitly allows for the presence of transitions from employment to out of the labour force. However, it is then difficult to argue that one can match the properties of unemployment data. In addition, this approach may distort the cyclical properties of the model by allowing the size of the pool of unemployed individuals to remains relatively stable in the face of shocks.

[28] This is higher than in Shimer (2005), Jung (2005). The reason is that in discrete time models with endgenous job destruction, following Den Haan et al. (2000), job destruction occurs prior to search and the number of searchers in steady state is given by $1-(1-\lambda)N$ rather than $1-N$ aswith exogenous destruction.

[29] We allow idiosyncraic shocks to enter firms' profit functions additively, so we include the constant $\mathcal{F}$ to eliminate the effect of cost shocks on aggregate profits. In Krause and Lubik (2007), Walsh (2005) this does not arise because idiosyncraic shocks enter multiplicatively. We avoid the latter structure as it generates unreasonable idiosyncratic hours. In Trigari (2006) this concern does not arise because additive idiosyncratic shocks enter the utility function.

the failure of the canonical Mortensen-Pissarides model are sensitive to his calibration of these features.[30] Hagedorn and Manowskii (2005) show that the volatility of unemployment, vacancies and labour market tightness, key problems identified by Shimer, can be rectified by assigning a low value to the match surplus, a low bargaining power for workers as captured by η and a high value for the outside option (due implicitly to home production and the utility value of nonwork) so as to give a small difference between the value of work and non-work. By contrast Shimer adopts the standard Hosios condition $\eta = \gamma$ and assumes that a worker's outside option comprises only the value of unemployment benefits, then to obtain sufficient variability in unemployment and vacancies, he introduces wage rigidity in an ad hoc manner.

For worker bargaining power, since we wish to examine the effect of hours variation on the slope of the Beveridge curve and the correlation between gross job flows in a constrained efficient environment, we assume that worker bargaining power satisfies the Hosios condition $\eta = \gamma = 0.5$. The free entry condition links the cost of vacancy creation to the match surplus (or more precisely the profit share attributable to matches). Jung (2006) argues that unlike the vacancy posting cost this profit share is directly observable, at least in principle (from NIPA compensation data). In his model, which lacks monopolistic competition, he suggests sensible values lie in the range $[0.002, 0.05]$. In our New Keynesian environment, with monopolistic competition, a figure of less than 1% seems plausible. This is consistent with the estimates of Jung and Kuester (2006). Consequently we set vacancy costs, κ, to target a profit share attributable to matches of 0.5%. In our framework, with endogenous job destruction, vacancy posting costs vary across experiments as the standard deviation of idiosyncratic shocks is varied to match σ_{JD}/σ_Y.

Shimer (2005) adopts a value for the outside option of 40% of labour income, based on the role of benefits alone. Krussell et al. (2005) argue that such a value is likely to overstate the value of unemployment benefits. They suggest that the evidence favours an upper bound of 20% of labour income. As Hagedorn and Manowskii (2005), Jung (2005) argue, rather than the replacement ratio implied by benefits per se, it is the difference between the value of work and of non-work that is of

[30] Jung (2006) generalises Hagedorn and Manowskii's analysis to a real business cycle framework with capital, risk averse agents and hours choice. Both Hagedorn and Manowskii (2005) and Jung (2006) follow Shimer (2005) and suppress the endogenous job destruction that is key to our analysis.

critical importance for the amplitude of unemployment fluctuations. The value of non-work may include comprises formal unemployment benefits and the value of home production and leisure. Jung (2005) shows that realistic unemployment variation may arise despite relatively low formal unemployment benefits. Our approach implicitly sets tbenefits equal to zero and allows the value of leisure to determine the worker's outside option.

When individuals are risk averse and hours of employment can vary, then the parameters ϕ and ψ, governing the intertemporal and intratemporal elasticities of substitution can affect the value of a workers outside option. To avoid the use of ϕ, the inverse of the elasticity of substitution, as a free parameter, we normalise $\phi = 1$. This is consistent with the fact that we use σ_Z to pin down the variability of output and equilibrium requires that $C_t = Y_t$. This case, utility logarithmic in consumption, is easily justifiable as a target on the basis of microeconometric and macroeconomic evidence. Reichling (2007) claims that unemployed workers spend on average as litttle as three minutes per week engaged in job search. We set hours worked as a fraction of the time endowment as $H = 0.33$. We set $e = 0.01H$ which means search occupies around 5 minutes. Then we vary ψ across experiments and allow the value of leisure to vary as a result, with the first order condition for hours determining Υ_H .

6.3 Model Solution Method

The log-linearsied approximation to the system of equations, (12), (17) and (21) - (31), is stacked in the form

$$\mathcal{A}E_t\left[\mathcal{Y}_{t+1}\right] = \mathcal{B} \cdot \mathcal{Y}_t + \mathcal{C} \cdot \mathcal{Z}_t$$

Where $\mathcal{Z}_t$ is a vector of exogenous state variables ($\hat{z}_t$ and $\hat{v}_t$) and $\mathcal{Y}_t$ is a vector of endogenous jump ($\hat{y}_t$,$\hat{h}_t$, $\hat{u}_t$, $\hat{v}_t$, $\hat{\jmath}c_t$, $\hat{\jmath}d_t$, $\hat{p}_t$, $\hat{w}_t$, $\hat{\mu}_t$, $\hat{\pi}_t$, $\hat{r}_t^n$, $\hat{m}_t$, $\hat{p}_t^V$, $\hat{x}$) and state ($\hat{n}_t$, $\hat{\pi}_{t-1}$, $\hat{m}_{t-1}$, $\hat{p}_{t-1}$) variables, and $\mathcal{A}$, $\mathcal{B}$ and $\mathcal{C}$ are conformable matrices of coefficients.[31] The system is solved with MATLAB, 7.0.1, using McCallum's (1998) undetermined coefficients approach based on Klein's (1997) generalised Schur decomposition method.

[31]The full system, $\mathcal{Y}_t$, includes a definition of the inflation rate $\hat{\pi}_t = \hat{p}_t - \hat{p}_{t-1}$, updating equations for $\hat{c}_{t-1}$, $\hat{\pi}_{t-1}$, $\hat{m}_{t-1}$ and $\hat{p}_{t-1}$, and additional auxilliary variables including labour market tightness $\hat{\theta}_t = \hat{v}_t - \hat{u}_t$ and real wages.

Parameter	**Meaning**	**Value**
β	Rate of time preference	0.99
ε	Elasticity of substitution between goods	21
ω	Probability of price non-adjustment	0.8
τ	Fraction of backward-looking firms	0.5
ρ_Z	Productivity shock autocorrelation	0.95
ρ_v	Monetary shock autocorrelation	0.5
σ_v	Monetary shock standard deviation	0.004
ξ	(Income) Elasticity of money demand	1
$\Upsilon_{\frac{M}{P}}$	Scaling factor: utility of real balances	17
λ	Separation rate	0.1
p^U	Probability of finding employment	0.61
p^V	Probability of filling a vacancy	0.7
$\mathfrak{M}$	Scaling factor: matching function	0.654
λ^x	Exogenous separation rate	0.068
JD	Job destruction rate	0.052
η	Worker bargaining power	0.5
ϕ	Elasticity of Intertemporal substitution	1
H	Hours per worker / total time endowment	0.33
e	Hours of search per unemployed worker	0.0033

Table 1: Calibration: Parameters and Targets

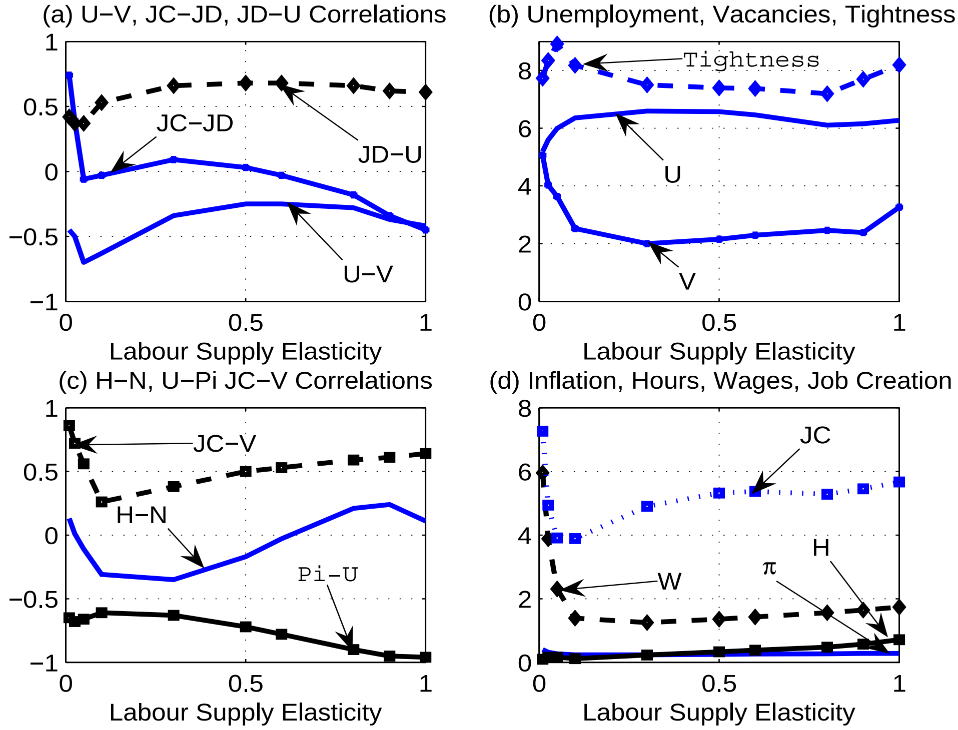

Figure 1: Role of Labour Supply Elasticity

.

Statistic	**Data**	**Inelastic Labour** ψ : 200 σ_X: 0.80 σ_Z: 0.009			**Elastic Labour** ψ : 2.25 σ_X: 0.57 σ_Z: 0.021		
Shock	**Data**	**Both**	**M**	**Z**	**Both**	**M**	**Z**
Col. No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Standard Deviations							
Output	1.00	1.00	0.29	0.95	1.00	0.52	0.86
Inflation	0.21	0.40	0.72	0.34	0.28	0.21	0.31
Wage	0.52	5.95	13.31	4.48	1.65	1.64	1.66
Hours / worker	0.73	0.10	0.24	0.08	0.57	0.34	0.65
Employment	0.66	0.67	0.57	0.68	0.76	0.55	0.82
Unemployment	7.21	5.19	7.11	4.93	6.15	4.36	6.62
Vacancies	8.04	5.06	5.06	5.04	2.88	2.08	3.14
Job Creation	5.09	7.26	10.94	6.70	5.45	3.80	8.29
Job Destruction	8.97	8.87	20.33	6.53	8.89	6.19	5.91
Tightness	15.02	7.73	2.67	8.08	7.69	5.54	9.69
Correlations							
Unemployment - Vacancies	-0.94	-0.15	0.96	-0.32	-0.37	-0.41	-0.36
Job Creation - Job Destruction	-0.41	0.74	0.90	0.71	-0.34	-0.39	-0.34
Hours - Employment	0.89	0.13	-0.11	0.21	0.24	0.08	0.24
Unemployment - Inflation	-0.65	-0.65	-0.97	-0.56	-0.95	-0.95	-0.95
Vacancies - Job Creation	-0.03	0.86	0.98	0.86	0.61	0.61	0.62
Unemployment - Job Destruction	0.67	0.42	0.88	0.25	0.62	0.62	0.63
Autocorrel'ns							
Output	0.87	0.89	0.47	0.94	0.87	0.65	0.95
Inflation	0.57	0.59	0.49	0.64	0.84	0.84	0.84

Table 2: Business Cycle Statistics
All statistics computed from HP detrended series, smoothing parameter 1600.
All model statistics are averaged across 100 simulations. Data : 1972:2 - 1993:4.

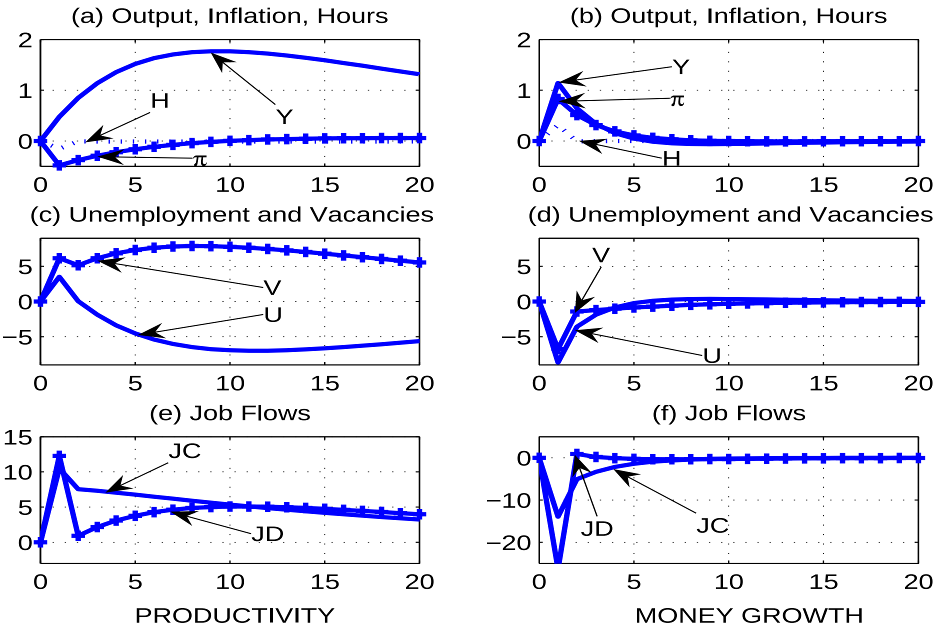

Figure 2: Impulse Responses: Inelastic Hours

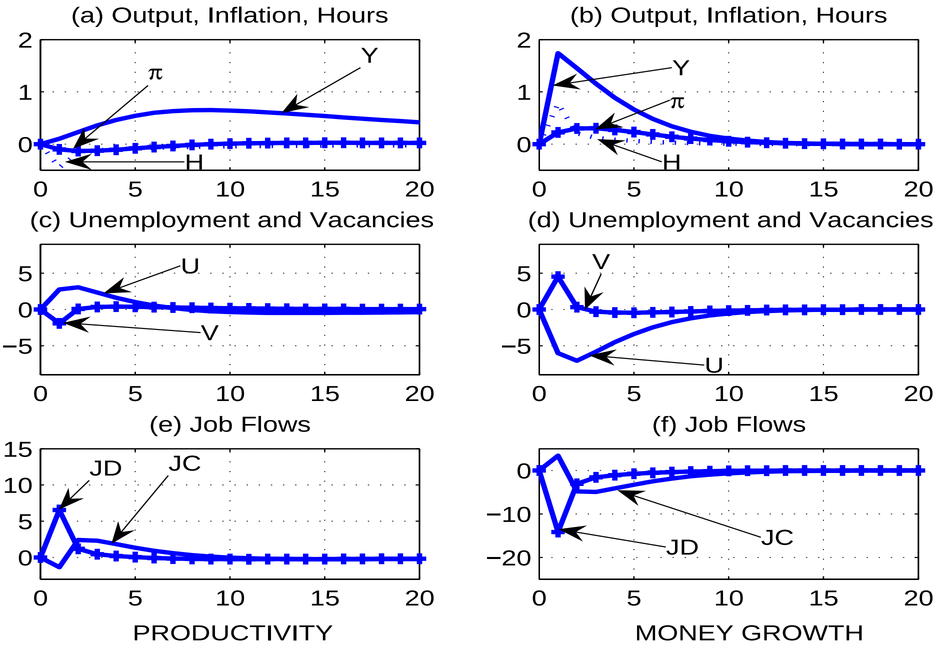

Figure 3: Impusle Responses: Elastic Hours