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**Working Paper**

## Evaluating the search and matching model with sticky wages

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# Working Papers

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Evaluating the search and matching  
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by Christopher Phillip Reicher

No. 1674 | December 2010

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Several authors have proposed staggered wage bargaining as a way to introduce sticky wages into search and matching models while preserving individual rationality. I evaluate the quantitative implications of such an approach. I feed through a series of estimated shocks from US data into a search and matching model with sticky prices and wages. I compare the implications of how the sticky wages enter into the hiring decision, and there seems to be a tradeoff between generating business cycle volatility and matching the lack of a long-run relationship between vacancy creation and inflation. With regard to wages, the sticky wage model unconditionally does a better job at matching wages than the flexible wage model.

Keywords: Sticky wages, sticky prices, staggered Nash bargaining, inflation, new hires, search and matching, business cycles.

JEL classification: E24, E25, E32, J23, J31, J63.

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\* I wish to thank Henning Weber and Christian Merkl as well as seminar participants in Kiel for their helpful advice. All errors are naturally my own.

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# Evaluating the performance of the search and matching model with sticky wages

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**This version: December 15, 2010**

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Several authors have proposed staggered wage bargaining as a way to introduce sticky wages into search and matching models while preserving individual rationality. I evaluate the quantitative implications of such an approach. I feed through a series of estimated shocks from US data into a search and matching model with sticky prices and wages. I compare the implications of how the sticky wages enter into the hiring decision, and there seems to be a tradeoff between generating business cycle volatility and matching the lack of a long-run relationship between vacancy creation and inflation. With regard to wages, the sticky wage model unconditionally does a better job at matching wages than the flexible wage model.

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## 1. Introduction

In this paper I evaluate the performance of the search and matching model with sticky prices and wages when confronted with the data, by feeding through a series of estimated shocks from US postwar data. It seems that there is a tradeoff between matching the volatility present in short run data and matching the lack of a long-run relationship between inflation and vacancy creation. In that sense, this paper contributes to the ongoing debate as to whether sticky wages are allocational or not with regard to new hires. I also find that including sticky wages in a search and matching model helps to match the cyclical behavior of wages; labor's share of income is countercyclical in reality and in sticky wage models but procyclical in most New Keynesian models.

The Diamond-Mortensen-Pissarides search and matching model appended to another business cycle model has become the workhorse model for macroeconomists who wish to discuss cyclical labor market dynamics. Attention has turned toward adding sticky wages to these models in an attempt to reconcile the model with two basic facts. The first fact concerns volatility. Shimer (2005) and Hall (2005) argue that sticky real wages can amplify shocks by reducing the profitability of new hires after a negative productivity shock. Gertler and Trigari (2009) set up a model with staggered Nash bargaining over real wages, and Gertler, Sala, and Trigari (2008) introduce bargaining over nominal wages. In modeling sticky wages this way, these authors preserve individual rationality at the match level and are not subject to the Barro (1977) critique. The model predicts a strong relationship between inflation and vacancy creation, since new hires are paid the going wage. The second fact concerns the behavior of wages themselves. Yashiv (2006) finds that a richly parameterized version of the basic search and matching model with stochastic exogenous separations can match certain aspects of the labor market but fails at matching the behavior of labor's share.

I investigate these related issues by setting up a sticky wage search and matching model and feeding through an array of well-motivated business cycle shocks estimated from postwar US

data. First, I compare a version of the model where wages for new hires are allocative (as argued by Gertler and Trigari (2009) and Martins, Snell, and Thomas (2009)) with a version of the same model where sticky wages are not allocative for new hires (as argued based on micro evidence by Haefke, Sonntag, and van Rijns (2009), Pissarides (2009), and Rudanko (2009)).<sup>1</sup> I find that the nonallocative model matches the lack of comovement between vacancies and inflation over the long run, while the allocative model predicts a strong relationship which does not exist. There is a tradeoff between the higher volatility provided by the allocative model and the ability to match the longer-run aspects of the data. Secondly, adding sticky wages to a model without sticky wages strongly improves that model's ability to fit labor's share. I find that labor's share is strongly countercyclical and weakly correlated with inflation; a model with sticky prices alone cannot match either of these facts. Sticky wages do improve the search and matching's model ability to match wages even if they have no other economic effect.

I also investigate the shocks themselves and simulate their effects on observed aggregates, and I find that none of the commonly-discussed shocks provides a credible source of business cycle impulses. This is not a completely new finding in the literature (Balleer (2009) provides evidence from a vector autoregression) but it deserves attention since I investigate a broader class of shocks than she does. By not forcing a reduced-rank model to fit every aspect of the data, I find the dimensions along which this model actually does not fit the data. As a business cycle model, the model still suffers from a problem of the "missing shock". Including monetary shocks and government spending shocks does not seem to help the model to generate realistic business cycles; Taylor rule shocks in particular come with their own problems.

Much work has already gone into evaluating the empirical performance of search and matching models along different dimensions. Most notably, Gertler, Sala, and Trigari (2008) estimate a large scale version of their sticky wage search and matching model using the Bayesian

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<sup>1</sup> These arguments concern themselves with the cyclicalities of new hires' wages in micro data, which is a very daunting task given the different types of heterogeneity one encounters in such data. This paper, by contrast, investigates what happens when one looks at the macro data.

methods of Smets and Wouters (2007). I look at a much simpler model than they do, and I employ a very different estimation strategy which does not require the model to fit the data. Christoffel, Küster, and Linzert (2007), Krause and Lubik (2007), Beauchemin and Tasci (2008), Krause, Lopez-Salido, and Lubik (2008), Costain and Reiter (2008), Ríos-Rull and Santaeulàlia-Llopis (2009), Balleer (2009), Faccini and Ortigueira (2010), and Choi and Ríos-Rull (forthcoming) have looked at more specific aspects of search and matching models (generally without sticky wages), while Christoffel, Costain, de Walque, Küster, Linzert, Millard, and Pierrard (2009) look at inflation dynamics under sticky wages. In general the literature has focused on model's inability to generate realistic movements in employment and in labor's share and its difficulty in generating a Beveridge Curve. Finally, Yashiv (2006) looks at a simple real model with a carefully calibrated microeconomic structure of hiring costs. He finds that conditional on a set of persistent exogenous separation shocks, his model does well at matching some key aspects of the data (most notably the Beveridge Curve) but not the behavior of wages. I find that sticky wages improve the fit of the search and matching model to wages, as he conjectures. In short, sticky wages seem to improve some of the deficiencies previously pointed out by other authors, whether or not they matter for vacancy creation.

## **2. The data**

I use thirteen model-consistent detrended series, covering the United States from 1947 through 2009. The first series is price inflation based on the NIPA PCE deflator. The second series is labor productivity in PCE terms, linearly detrended based on the BLS's nominal business-sector labor productivity series. The third series is the civilian employment-population ratio for those 16 and over from the CPS, retroplated using a ratio splice for 1947 using the old series for those 14 and over. The series is 2% above trend in the first quarter of 1947, then at trend in the third quarter of 1955, the third quarter of 1963, the third quarter of 1970, the third quarter of 1978, the third quarter of 1987, the third quarter of 1996, and the third quarter of 2005.

Unemployment appeared to be roughly stable at its medium-run trend on these dates, and the resulting gaps accord well with the CBO's estimates of the employment gap. The fourth series is growth in M1, taken from the St. Louis Fed for the period after 1959 and Friedman and Schwartz (1963) for the period before 1959. The fifth series is the three-month treasury bill rate, and the sixth series is labor's share of gross income from corporate business.

The seventh series is the vacancy-employment ratio which is mostly based on the Conference Board's Help Wanted Index normalized by employment from the BLS's establishment survey. Before 1957 the data come from the Met Life Help Wanted Index, spliced to the latter series as explained by Zagorsky (1998). After 1995 the data come from Barnichon (forthcoming) who adjusts the help wanted index for growth in online advertising. The eighth and ninth series are the job destruction and creation rates published from the BED (now called the BDM by the BLS). They are extended back using the manufacturing-based data produced by Faberman (2006), by regressing the economywide totals on the composite manufacturing-based ones. I use these instead of the CPS-based measures used by others because the CPS data only begin in 1976 and suffer from a great deal of short-term measurement noise. These series are not perfect but they still offer information about job and worker flows from the establishment side which can be hard to get from other sources. The tenth series is the share of government consumption and gross investment in output, and the eleventh is the gross private investment share of output, both taken from the NIPA. The twelfth series is the linearly detrended real price of equipment, structures, and software. This is constructed as a Törnqvist index using the NIPA deflator for gross private investment excluding equipment and software and using the Cummins and Violante (2002) quality-adjusted deflator for equipment and software, extended and interpolated using the NIPA deflator.<sup>2</sup>

The last series is the 10-to-20-year constant-maturity forward rate on treasury securities. This is intended as a measure of expected long-term interest rates (and inflation, based on the

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<sup>2</sup> I wish to thank Gianluca Violante for graciously making these data available electronically.



Fisher condition). The series has two gaps. The first gap is from 1987 to 1993, and this is interpolated by approximating the changes in the 10-to-20 year rate with changes in the 10-to-30-year rate and then correcting linearly for the error of closure. The other gap is the period before 1953. The NBER has series on 20-year treasury yields and 3-to-5-year treasury yields end in 1961. Luckily, this is a period of low and stable long-term interest rates. Regressing the post-1953 forward rate on these two yields gives an accurate predicted 10-to-20-year forward rate.

### **3. The model**

Walsh (2002, 2005), Trigari (2009), and Cooley and Quadrini (1999) present different models of job creation and destruction in the presence of nominal rigidities, building upon the search and matching model of Mortensen and Pissarides (1994) and den Haan, Ramey, and Watson (2000). I follow Gertler and Trigari (2009) in modeling wage determination according to staggered Nash bargaining. To avoid complicating things too much, I introduce their bargaining mechanism into an otherwise standard individualistic search and matching model with endogenous separations and sticky prices. I also carefully account for the structure of hiring costs as suggested by Yashiv (2006).

The model has five interesting structural disturbances: Disturbances to government spending, total factor productivity, investment-specific productivity, long-run interest rates, and short-run interest rates. On the household side, there is a continuum of infinitely lived consumers. Production and hiring take place in a firm-worker match, with wages reset in a staggered manner. A retail sector aggregates output from the wholesale sector and resets retail prices in a staggered manner. The monetary authority follows a Taylor rule, augmented to account for nonstationary interest rates and for out-of-model shocks to inflation. Government spending and fixed investment, with variable utilization, round out the model.

### 3.1 The household sector

Individuals within households, indexed by  $j$ , supply labor inelastically; they either work for a set number of hours per week or do not work at all. They also have the choice between consuming in a given period and saving in nominal bonds to consume in the future. They each seek to maximize the objective function:

$$E_t \sum_{i=0}^{\infty} \beta^i \left[ \ln(C_{j,t+i}) - (n_{j,t+i} + \gamma_{t+i} v_{j,t+i} (v_{t+i})^t) A \right], \quad (1)$$

where  $C_{j,t+i}$  equals the household's period-by-period real consumption;  $n_{j,t+i}$  is the proportion of workers in the household who work at the end of a given period; and  $v_{j,t+i}$  is the number of job vacancies supplied by the household. For the sake of tractability, households are large and pool consumption efficiently. The term containing aggregate vacancies  $v_{t+i}$  reflects congestion in the vacancy-posting market as modeled by Yashiv (2006) in a large-firm setting. The term  $\gamma_t$  is a time-varying vacancy posting cost. The vacancy-posting process has a microeconomic structure and will be discussed in more detail below.

Markets operate in three stages per period. In the first stage, after shocks are realized, financial markets open. People trade bonds and withdraw money in order to make their consumption purchases. In the second stage, the goods market opens and these purchases happen; and cash is exchanged. In the third stage, income from the second stage is realized and factor payments are made. This delay introduces a cost channel of monetary transmission into the model. This makes it possible for low nominal interest rates to directly stimulate production, since the opportunity cost of using money for transactions has fallen. Walsh (2005) discusses this issue in some detail.

The traditional quantity equation, which is normally motivated by forcing people and firms to finance a portion of their spending with cash holdings, states that nominal consumption must not exceed end of period money holdings:

$$P_t Y_t \leq M_{t+1}. \quad (2)$$

In reality, the observed velocity of money is not constant. In a New Keynesian model such as this one, nominal spending is endogenously determined by interest rate policy, neutralizing any shocks to money demand. If one wishes to include money as an observable variable to track nominal output, it is necessary to include money demand shocks since money growth does not equal nominal output growth in reality.

The household's budget constraint is the usual one with a couple of additions.  $B_t$  equals the number of bonds that households can buy; households also can hold money, consume, or invest out of beginning-of-period wealth and after-tax gross income  $Q_t$ . Bonds earn the gross nominal interest rate  $R_t$ .  $T_t$  equals the level of net taxes paid by the household, with a Ricardian fiscal policy:

$$M_{t+1} + B_{t+1} + P_t C_t + P_t I_t = P_t Q_t + R_{t-1} B_t + M_t - P_t T_t.$$

(3)

The household's first-order conditions also end up looking familiar. Optimization in bonds generates the usual intertemporal asset pricing relationship:

$$\lambda_t = E_t \beta R_t \frac{P_t}{P_{t+1}} \lambda_{t+1}, \quad (4)$$

where the household's marginal utilities of consumption and wealth are equal:

$$\frac{1}{C_t} - \lambda_t = 0. \quad (5)$$

Because of market clearing, output (which equals total production minus vacancy costs) equals consumption plus investment and government spending, all in consumption units:

$$Y_t = C_t + G_t + I_t, \quad (6)$$

and the stochastic quantity equation holds, with the extra velocity term needed to match the data:

$$P_t Y_t = V_t M_{t+1}. \quad (7)$$

### 3.2 The retail sector and sticky prices

Monopolistically competitive retailers buy output competitively from the wholesale sector and resell it at a markup. They aggregate it according to a Dixit-Stiglitz aggregator. Retailers buy their products  $y_{jt}$  competitively from wholesale producers who produce homogeneous intermediate goods. The aggregate level of output equals:

$$Y_t = \left[ \int_0^1 y_{jt}^{\frac{\theta-1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}}, \quad (8)$$

for some substitutability parameter  $\theta$  greater than one. From this expression, each individual retail firm faces a demand curve:

$$y_{jt} = \left( \frac{P_{jt}}{P_t} \right)^{-\theta} Y_t, \quad (9)$$

where the aggregate price level  $P_t$  equals the CES price index:

$$P_t = \left[ \int_0^1 p_{jt}^{1-\theta} dj \right]^{\frac{1}{1-\theta}}. \quad (10)$$

The retailers buy unfinished output from the wholesalers at a price  $P_t^W$  and sell it at an aggregate markup  $\mu_t \equiv P_t / P_t^W$ . Each retailer, in the spirit of Calvo (1983), can only change its price with a probability  $1 - \omega$ . Those firms that change their price in a given period do so symmetrically and reset their prices to  $p_t^*$ . They maximize expected discounted profits. Letting  $D_{i,t+i}$  equal the discount factor  $\beta^i(\lambda_{t+i}/\lambda_{t+i})$ , the objective function for the price-changers equals:

$$E_t \sum_{i=0}^{\infty} \omega^i D_{i,t+i} \left[ \left( \frac{p_t^*}{P_{t+i}} \right)^{1-\theta} - \mu_{t+i}^{-1} \left( \frac{p_t^*}{P_{t+i}} \right)^{-\theta} \right] Y_{t+i}. \quad (11)$$

Long-run profit maximization results in the first order condition:

$$\left(\frac{P_t^*}{P_t}\right) = \left(\frac{\theta}{\theta-1}\right) \frac{E_t \sum_{i=0}^{\infty} \omega^i D_{i,t+1} \mu_{t+i}^{-1} \left(\frac{P_{t+i}}{P_t}\right)^\theta Y_{t+i}}{E_t \sum_{i=0}^{\infty} \omega^i D_{i,t+1} \left(\frac{P_{t+i}}{P_t}\right)^{\theta-1} Y_{t+i}}, \quad (12)$$

with the aggregate retail price index given by:

$$P_t^{1-\theta} = (1-\omega)(p_t^*)^{1-\theta} + \omega P_{t-1}^{1-\theta}. \quad (13)$$

Current prices are a weighted nonlinear function of lagged prices and the prices set by those firms that could adjust. Conditions (12) and (13), when linearized and combined, give a standard New Keynesian Phillips Curve relationship between markups and present and future expected inflation.

### 3.3 The wholesale sector

The wholesale sector produces and distributes output originating from a set of worker-firm matches. Workers and firms separate for both exogenous and endogenous reasons, and firms search for workers based on expectations of future profitability. Using standard notation,  $U_t = I - N_t$  equals the number of workers searching for a job at the beginning of the period with the population normalized to one. There is a constant probability  $\rho^x$  that a match will end exogenously. The remaining  $(I - \rho^x)N_t$  matches experience an iid, temporary, idiosyncratic productivity shock  $a_{it}$  (with a distribution function  $F$ ) and a systematic permanent productivity shock  $z_t$ , all of which the worker and firm observe at the beginning of the period. Based on their realizations, the worker and firm efficiently decide whether to continue the relationship or to separate. If the relationship continues, the match produces  $y_{it} = (a_{it} z_t)^{1-\alpha} (k_{it} / p_t^k)^\alpha$  which is sold at the competitive wholesale price  $P_t^w$  to the retailers. If the relationship separates, production equals zero; the job is destroyed; and the worker becomes unemployed.

Matches rent capital (priced in terms of consumption units but entering the production function in real units) in a competitive rental market at a rate  $\rho_t^k$ , after all shocks are realized. Denoting the retailer's gross markup  $\mu_t$  as  $P_t / P_t^w$ , the surplus of a match at period  $t$  equals the real value of the match's product in time  $t$ , minus the disutility of work in product terms,<sup>3</sup> plus the expected discounted continuation value of the match (denoted by  $q_{it}$ ), minus the match's capital rental payments. Income payments are discounted by the nominal interest rate because of the monetary friction:

$$s_{it} = \frac{(a_{it}z_t)^{1-\alpha}(k_{it}/p_t^k)^\alpha}{\mu_t R_t} - \frac{A}{\lambda_t} + q_{it} - \frac{\rho_t^k k_{it}}{R_t}.$$

The value of  $k_{it}$  is determined optimally by the match, so that:

$$\frac{k_{it}}{p_t^k} = (a_{it}z_t) \left[ \frac{\alpha}{\mu_t \rho_t^K p_t^k} \right]^{\frac{1}{1-\alpha}}. \quad (14)$$

Firms and workers bargain efficiently over the worker's marginal product:

$$s_{it} = \frac{(1-\alpha)(a_{it}z_t)^{1-\alpha}(k_{it}/p_t^k)^\alpha}{\mu_t R_t} - \frac{A}{\lambda_t} + q_{it},$$

so substituting in the firm's capital demand, one can find the reduced form of the surplus:

$$s_{it} = \frac{(1-\alpha)(a_{it}z_t)}{\mu_t R_t} \left[ \frac{\alpha}{\mu_t \rho_t^K p_t^k} \right]^{\frac{\alpha}{1-\alpha}} - \frac{A}{\lambda_t} + q_{it}.$$

After consolidating terms some more, one obtains the expression:

$$s_{it} = \frac{(1-\alpha)(a_{it}z_t)}{\mu_t^{1-\alpha} R_t} \left[ \frac{\alpha}{p_t^k \rho_t^K} \right]^{\frac{\alpha}{1-\alpha}} - \frac{A}{\lambda_t} + q_{it}. \quad (15)$$

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<sup>3</sup> Parameterizing the outside option this way ensures balanced growth. Gertler, Sala, and Trigari (2008) simply make the outside option proportional to the capital stock.

For a match to have positive surplus and continue, it will require that  $a_{it}$  exceed a certain cutoff  $\tilde{a}_t$ . Since the shock  $a_{it}$  is iid, the continuation value  $q_{it}$  will equal the same value  $q_t$  across matches. Setting (15) to zero gives the value of this cutoff:

$$\tilde{a}_t = \frac{\mu_t^{\frac{1}{1-\alpha}} R_t (A / \lambda_t - q_t)}{z_t (1-\alpha)} \left[ \frac{\rho_t^K p_t^K}{\alpha} \right]^{\frac{\alpha}{1-\alpha}}.$$

(16)

If  $a_{it}$  has the distribution  $F$ , then the endogenous separation probability  $\rho_t^n$  equals  $F(\tilde{a}_t)$ , and the aggregate separation rate  $\rho_t$  and the match survival rate  $\varphi_t$  are given by:

$$\rho_t = \rho^x + (1 - \rho^x) F(\tilde{a}_t), \quad (17)$$

and

$$\varphi_t = (1 - \rho^x) [1 - F(\tilde{a}_t)] = (1 - \rho_t). \quad (18)$$

In most models of this sort, workers and firms bargain every period. This model instead has sticky nominal wages as observed in the micro data. As in Gertler and Trigari (2009), workers and firms determine wages through staggered Nash bargaining. With probability  $1 - \nu$ , wages are bargained such that the worker receives a share  $\eta$  of the bilateral surplus, and the firm receives the remainder. Otherwise, the nominal wage does not change. As part of this contract, firms and workers separate only when it is efficient to do so; otherwise they stay together through side payments if necessary. I look at two major cases: An “allocative” case where new workers receive the prevailing wage and this is priced into vacancy demand (as in the original Gertler and Trigari model), and a “nonallocative” case where the wages of new hires are not allocative, and workers receive a share  $\eta$  of the initial match surplus by way of a signing bonus. In the allocative situation, shocks get propagated through the economy through their direct effect on the profitability of making a new hire. In the nonallocative situation, no such channel exists, and vacancy posting will be determined based purely on the size of future surpluses.

Entrepreneurs operating out of households' garages can post vacancies at a marginal cost  $p_t^v$  but face no other barriers to entry. These vacancies get filled at a gross rate  $k_t^f$ . A firm's portion of the surplus at any given date is denoted  $s_{it}^f$ . Free entry in vacancies equates the present surplus value of a vacancy with the cost of vacancy posting. For the allocative model this equates vacancy posting costs with the average firm's portion of the surplus:

$$p_t^v = (1 - \rho^x) k_t^f \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \int_{\tilde{a}_{t+1}}^{\infty} s_{it+1}^f dF(a_{it+1}). \quad (19A)$$

For the version of the model with non-allocative wages, this is given by the new firm's share of the overall surplus which it bargains for with the newly matched worker:

$$p_t^v = (1 - \rho^x) k_t^f \beta E_t \frac{\lambda_{t+1}}{\lambda_t} (1 - \eta) \int_{\tilde{a}_{t+1}}^{\infty} s_{it+1} dF(a_{it+1}). \quad (19N)$$

The probability of an unemployed worker actually finding a match equals  $k_t^w$ . After doing some algebra, the continuation value of the surplus for both cases is given by:

$$q_t = (1 - \rho^x) \beta E_t \frac{\lambda_{t+1}}{\lambda_t} (1 - k_t^w) \int_{\tilde{a}_{t+1}}^{\infty} s_{it+1} dF(a_{it+1}) + \frac{k_t^w p_t^v}{k_t^f}. \quad (20)$$

In equilibrium the price of a vacancy, in output units, equals:

$$p_t^v = \frac{\gamma_t A}{\lambda_t} (v_t)^t. \quad (21)$$

I follow Yashiv (2006) and set up a small-firm version of his hiring cost function. The parameter  $t$  reflects external congestion effects in the market for vacancy posting. It takes time and effort to find a task for a potential employee to do, and it is not unrealistic to assume that vacancy creation is subject to diminishing returns like most other enterprises. In a large-firm setting, this is equivalent to saying that a firm might benefit greatly from hiring a new janitor, but it might benefit only slightly more from a two new janitors. Congestion effects make vacancy posting less responsive to aggregate conditions than they otherwise would be.



Vacancy posting costs have two components. The first component is a standard search cost, which is paid whenever a vacancy is posted. The second component is a hiring cost, which is only paid by the vacancy poster if a new hire is made. Combined, the expected marginal cost of posting a vacancy takes the following form:

$$\gamma_t = \gamma_0 + \gamma_1 k_t^f. \quad (22)$$

In most search and matching models,  $\gamma_1$  is zero, but microeconomic evidence suggests that hiring costs are much larger than search costs in the aggregate. In equilibrium this makes hiring less sensitive to labor market tightness and more sensitive to surpluses, and it helps certain versions of the model to match the Beveridge curve.

Turning to aggregation, the firms' surplus in the aggregate is given by the present value of profits, expressed as a difference equation:

$$\int_{\tilde{a}_t}^{\infty} \left( s_{it}^f - \frac{(1-\alpha)(a_{it}z_t)^{1-\alpha} (k_{it} / p_t^k)^\alpha}{\mu_t R_t} + \frac{w_{it}}{R_t} \right) dF(a_{it}) = \\ + (1-\rho^x) \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \int_{\tilde{a}_{t+1}}^{\infty} s_{it+1}^f dF(a_{it+1}). \quad (23)$$

The total number of unemployed in a period equals the starting stock of unemployed plus those who separate at the beginning of the period. Abstracting from labor force entry and exit, this comes out to

$$u_t \equiv U_t + \rho_t N_t = 1 - (1 - \rho_t) N_t. \quad (24)$$

Given a constant-returns Cobb-Douglas matching function  $m(u_t, v_t) = \zeta u_t^a v_t^{1-a}$ , the vacancy-filling rate equals:

$$k_t^f = \frac{m(u_t, v_t)}{v_t}, \quad (25)$$

and the worker's job-finding rate is given by:

$$k_t^w = \frac{m(u_t, v_t)}{u_t}. \quad (26)$$

The number of matches evolves according to the accounting identity:

$$N_{t+1} = (1 - \rho_t)N_t + m(u_t, v_t), \quad (27)$$

and the gross output of the matched firms and workers is given by:

$$Q_t = \frac{(1 - \rho_t)N_t z_t \left[ \int_{\tilde{a}_t}^{\infty} a_{it} dF(a_{it}) \right]}{1 - F(\tilde{a}_t)} \left[ \frac{\alpha}{\mu_t \rho_t^k p_t^k} \right]^{1-\alpha}. \quad (28)$$

Income equals gross product:

$$Y_t = Q_t. \quad (29)$$

To solve for the rebargained real wage, one could note that those firms which pay the rebargained wage  $W_t^*$  have an average surplus of  $(1 - \eta)s_t$  from Nash bargaining. It turns out that the rebargained real wage is the same as the one which would arise from period by period Nash bargaining:

$$\int_{\tilde{a}_t}^{\infty} \left( (1 - \eta)s_{it} - \frac{(1 - \alpha)(a_{it} z_t)^{1-\alpha} (k_{it} / p_t^k)^\alpha}{\mu_t R_t} + \frac{W_t^*}{R_t} \right) dF(a_{it}) = \\ + (1 - \rho^x) \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \int_{\tilde{a}_{t+1}}^{\infty} (1 - \eta)s_{it+1} dF(a_{it+1}). \quad (30)$$

The average nominal wage rate is given by:

$$P_t W_t = v P_{t-1} W_{t-1} \left( \frac{P_{t-1}}{P_{t-2}} \right)^x + (1 - v) P_t W_t^*, \quad (31)$$

where  $W_t$  is the average wage rate across all matches. To keep things simple, I assume that observed wages in both the allocative and nonallocative models both follow this form, with the difference made up by a lump-sum signing bonus.

The price of capital in consumption units equals  $p_t^k$ , which in equilibrium equals the inverse of the level of investment-specific productivity. Capital depreciates at a rate  $\delta(N_t^K)^\phi$ , which reflects a positive relationship between depreciation and variable utilization. Capital pricing comes from the household's optimal choice of investment:

$$1 = \beta E_t \frac{p_{t+1}^k \lambda_{t+1}}{p_t^k \lambda_t} \left[ 1 + \frac{\rho_{t+1}^K N_{t+1}^K - \delta(N_{t+1}^K)^\phi}{R_{t+1}} \right]. \quad (32)$$

Finally, optimal utilization is given by:

$$\rho_t^K = \delta \phi (N_{t+1}^K)^{\phi-1}, \quad (33)$$

and the capital accumulation equation in consumption units is given by:

$$\frac{K_{t+1}}{p_{t+1}^k} = \left( 1 - \delta(N_t^K)^\phi \right) \frac{K_t}{p_t^k} + \frac{I_t}{p_t^k}. \quad (34)$$

### 3.4 Shocks to technology and government spending

Labor-specific productivity grows in the long run at rate  $\Gamma^z$ , and it follows a highly persistent AR(1) on top of that trend:

$$\ln(\bar{z}_t) - \Gamma^z t = \rho_z \left[ \ln(\bar{z}_{t-1}) - \Gamma^z (t-1) \right] + \varepsilon_t^z. \quad (35)$$

The level of government spending,  $G_t$ , follows a highly persistent AR(1) which corrects toward the level of output (thus ensuring balanced growth):

$$\ln(G_t) = (1 - \rho_G) \ln\left(\frac{G}{Y}\right) + (1 - \rho_G) \ln(Y_t) + \rho_G \ln(G_{t-1}) + \varepsilon_t^G. \quad (35)$$

The price of capital, in consumption units, also follows a highly persistent AR(1):

$$\ln(p_t^k) - \Pi^K t = \rho_{PK} \left[ \ln(p_{t-1}^k) - \Pi^K (t-1) \right] + \varepsilon_t^{PK}. \quad (36)$$

The observed velocity of money follows a random walk with drift:

$$\Delta \ln(V_t) = \Gamma^V + \varepsilon_t^V. \quad (37)$$

### 3.5 The monetary authority

The monetary authority follows a Taylor rule based on observed data. It has a long-run inflation (and interest rate) target which follows a highly persistent AR(1):

$$\pi_t^* = (1 - \rho_{\pi^*})\bar{\pi} + \rho_{\pi^*}\pi_t^* + \varepsilon_t^{\pi^*}. \quad (38)$$

One can think of this as capturing the longer-term changes in inflation expectations which came from the end of Bretton Woods and the subsequent fall in trend inflation throughout the 1980s and 1990s. Goodfriend (1993) discusses how rises in the long-term interest rate reflected shocks to longer-run inflation expectations during that time. He interprets these episodes as “inflation scares” during which long-run inflation expectations became unanchored. More generally, this moving target is intended to capture the apparent nonstationarity of interest rate and inflation targets.

The Fed follows a Taylor rule with a slow adjustment toward the target interest rate. The Taylor rule itself follows the form:

$$r_t = (1 - \rho_r)\left(r + \pi_t^* + \rho_{\pi}(\pi_t^{OBS} - \pi_t^*) + \rho_Y(\ln(Y_t^{OBS}) - \ln(Y_{t-1}^{OBS}) - \ln(\Gamma))\right) + \rho_r r_{t-1} + \varepsilon_t^r. \quad (39)$$

This is similar to the Taylor Rule used by Bordo, Erceg, Levin, and Michaels (2007) in their discussion of the Volcker disinflation. The monetary authority responds to observed inflation and output and not to their theoretical deviations from an efficient equilibrium.<sup>4</sup> The rule contains output growth instead of levels in order to offer a clean interpretation of  $\pi_t^*$  as the long-run component of inflation and interest rates. The exogenous term  $\varepsilon_t^r$  represents a Taylor rule error.<sup>5</sup>

The Fed adjusts interest rates with persistence  $\rho_r$ .

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<sup>4</sup> See Cochrane (2010) for why it matters to have authorities respond to a full rank of in-equilibrium rather than out-of-equilibrium values. Basically, out-of-equilibrium values are not observed and therefore policy rules are not identified from the data.

<sup>5</sup> Orphanides (2003) discusses the Taylor rule residual in the context of omitted variables.

### 3.6 Observation shocks

The structural model has a reduced rank in comparison to the data; there are not enough shocks in the model (six shocks) to generate a set of observables of full rank (thirteen observables). Gertler, Sala, and Trigari (2008) solve this problem by introducing extra shocks to, for instance, preferences and markups. Instead, I model the unexplained movements in the data as driven by persistent observation errors. In this spirit, the model must match the data on labor productivity, capital prices, government spending as a share of observed output, short and long term interest rates, and the velocity of money. The additional variation in the data comes from AR(1) observation errors on inflation, employment (equal to the error on output), labor's share, vacancies, the job creation and destruction rates, and investment.

This exercise answers the question: Given what we observe about the usual driving processes in our models, how does the model perform at matching other aspects of the data? Rather than viewing the model as a complete data generating process (as the structural DSGE estimation literature has done), I treat the model as a mapping from assumptions to observable implications (as the early RBC theorists did) but with a likelihood-based evaluation procedure that goes well beyond matching a few second moments. Looking at the likelihood puts a greater emphasis on comovement and on longer-run fluctuations, making it possible to investigate along which lines various versions of the model succeed and fail.

### 3.7 Equilibrium

The aggregate household conditions (4) through (7), the New Keynesian retail conditions (12) and (13), the aggregated versions of (14) through (34) from the wholesale sector, the driving processes (35) through (39), and the appropriate transversality conditions constitute a rational expectations equilibrium for this economy. Based on a linearized version of this system, is possible to obtain feedback coefficients using the gensys.m program of Sims (2002). In this

particular situation, the equilibrium exists and is unique in the neighborhood around the steady state. Linearization also provides the convenient ability to express the system as a moving average and cleanly decompose fluctuations by their cause, which I proceed to do.

## 4. Estimation strategy

### 4.1 State space approach

Given a set of feedback rules and quarterly data on the variables of interest, it is fairly simple to use the Kalman Filter to estimate the underlying unobservable states. The filter also delivers the approximate Gaussian likelihood of the model, which I maximize in order to estimate the shock variances and observation error autocorrelations. The first half of the state space approach consists of deriving the underlying laws of motion of the model, including the observation errors:

$$x_t = A_1 x_{t-1} + B_1 \varepsilon_t, \quad (40)$$

The second half consists of the observation equation relating the model to the observed data, labeled as  $x_t^*$ . Algebraically, this can be represented by the observation equation:

$$x_t^* = D_1 x_t. \quad (41)$$

The errors belong to the system as members of  $x_t$ .

### 4.2 Calibrated and estimated parameter values

Table 1 contains a complete list of calibrated parameter values. Most of the parameter values follow the calibrated or estimated values used by Walsh (2002) or Gertler and Trigari (2009), unless the data clearly indicate another value. The real interest rate  $R$  equals 4.72 percent per year based on the average real interest rate in the data. Output per capita grows at a rate  $\Gamma$  of 1.87 percent per year, and real capital prices fall at 1.50 percent per year, so  $\beta$  equals 0.993. Investment (including residential structures but excluding consumer durables) is 16.1% of output

based on NIPA data; depreciation is 1.5% per quarter; and government spending is 20.2% of output based on NIPA data. Steady state utilization is normalized to 1.

Similarly to Walsh's calibration, the gross retail markup  $\mu$  equals 1.11, for a value of  $\theta$  of 10. In the baseline model, prices and wages have an average duration of one year for values of  $\omega$  and  $\nu$  of 0.75. This implies less flexibility than Bils and Klenow's (2004) estimate of about 0.5 and is more in line with the values often used in the business cycle literature. Gertler and Trigari use similar parameter values. Following Walsh and others, the exogenous job separation rate  $\rho^x$  equals 0.068 and the total job separation rate  $\rho$  equals 0.10 per quarter. These values imply a value of  $\rho^n = F(\tilde{a})$  equal to 0.0343 per quarter. The idiosyncratic process  $a_{it}$  is lognormal with an arithmetic mean of 1. The dispersion parameter  $\sigma_a$  and central location parameter  $\mu_a$  must be derived from the rest of the calibration.

Vacancy posting costs altogether equal 1.5 percent of output. Hairault (2002) and Andolfatto (1996) use a value of 1.0 percent, value while Hagedorn and Manovskii (2008) use a very small value which just includes search costs. Like Yashiv (2006) I am interested in a broader measure of hiring costs, so I turn to Barron, Berger, and Black (1997). They compile a number of different survey results concerning hiring activity in the United States. Roughly, the average new hire incurs about 16 hours of search and screening time per hire, while the average new hire incurs about 160 hours of training time. Given that the average employee works 450 hours in a quarter based on NIPA data for 2007, and given the number of new hires relative to total workers, this works out to about 1.39 percent of hours worked. This number is probably somewhat too low as a share of efficiency units of labor going toward recruiting activities, since human resources workers are typically better-paid than other workers. Therefore I round this number up to 1.5 percent, which is probably still a bit low. The larger value encompasses the direct cost of searching, screening, and orientation for new employees; it does not include indirect vacancy posting costs; and it still yields a small surplus. I follow Yashiv and set  $\iota$  to 1.

The unemployment share  $a$  of the matching function equals 0.4. Walsh cites Blanchard and Diamond (1989, 1991) who use postwar CPS data to derive an estimate of 0.4. This is what I get when I regress the log deviation in the job creation rate on the log deviation of labor market tightness. The steady-state unemployment rate  $u$  (after separations) equals 0.06 which is just above the average postwar CPS unemployment rate; this allows for some slight underreporting of unemployment on average. The worker-finding rate  $k^f$  equals 0.7 and the job-finding rate  $k^w$  equals 0.6, both from Walsh's calibration. These imply that there are 0.0514 vacancies  $v$  in the steady state, which is a bit more than in the data. Since vacancies here are considered a flow, this equals all of the vacancies which appear and disappear over the course of a given quarter. Workers have a bargaining power  $\eta$  of 0.5. The two long-run productivity processes, the government spending process, and the long-run inflation process have coefficients of one, approximated as 0.9999 for numerical reasons. I estimate the Taylor rule using one lag of the observables as an instrument. The Taylor rule has a coefficient of 1.142 on inflation, a coefficient of 0.310 on output growth, and a persistence coefficient of 0.938. This means that the nonexplosive equilibria of the model have a reduced rank, so I have to include an observation error on inflation to bring the model back to full rank.

I consider six different specifications in order to explore the observable implications of sticky prices and wages. The first is the baseline "allocative" specification or model (1), where nominal wages from preexisting matches are allocative in determining the profitability of making a new hire. The second specification (the baseline "nonallocative" model or model (2)) replaces equation (19A) with (19N); in this specification, newly matched firms and workers bargain individually. All of the specifications (3) through (6) which follow are based on the nonallocative model (2).

The third specification, the "flexible wage" model (3), involves setting the wage stickiness parameter  $\nu$  to 0. The fourth specification, the "flexible price" model (4), involves



setting the price stickiness parameter  $\omega$  to 0 and gross markups to one. The fifth specification, the “flexible price and wage” model (5), combines the previous two specifications. Apart from the cost channel in money holdings, this is equivalent to an RBC-style matching model. The sixth specification (the “elastic vacancy” model (6)) involves setting the vacancy-creation elasticity  $\iota$  to 0 as in the typical free-entry model.

## 5. Estimation results

### 5.1 The role of sticky wages on the job creation margin

Figure 1a and 1b show the estimated model variables, along with their observable counterparts, for the allocative-wage model. Figure 3 shows selected smoothed model-consistent data for the nonallocative model. Table 2 shows various simulated data from all specifications along with their counterparts from the data, HP-filtered with a smoothing parameter of 10,000. The nonallocative model has an overwhelmingly higher log likelihood than the allocative model—11,628 versus 11,170. The allocative model produces much more volatility, 2.02% for detrended employment, versus 0.68% for the nonallocative model. The ability for allocative sticky wage models to amplify shocks explains much of the appeal of these models. The allocative model also has a Beveridge Curve, with a correlation between vacancies and employment of +0.64, versus -0.67 for the nonallocative model and +0.87 for the data. In the short run, the allocative model performs fairly well when put up against certain moments. Both versions of the model do a decent job at matching the basic behavior of labor’s share and job destruction, matching the data with a correlation above +0.4 in the case of labor’s share and between +0.3 and +0.6 in the case of job destruction. Both versions of the model with sticky wages clearly capture some important features of the data.

In the long run, the allocative model runs into a large problem. A look at Figure 1a shows that the model predicts a very strong long-run relationship between vacancy creation and

inflation. High inflation results in a larger part of bargaining surpluses going to firms, since nominal wages are always a bit slow to catch up with reality. This acts as a strong incentive to post vacancies, which pushes up employment as well. The model predicts a very strong long-run Phillips curve which does not seem to show up in the data.<sup>6</sup> Figure 3 shows that this effect mostly disappears when sticky wages are nonallocative. There is a strong tradeoff between matching the volatility of the data and matching the joint long-run behavior of vacancies and inflation, and this comes from the mechanism behind job creation in the allocative model.

Figures 2 and 4 show the effects of the estimated shocks when fed into the model under both scenarios. To avoid too much clutter I group the various monetary shocks and productivity shocks together. Productivity shocks do not contribute much to the cycle in either specification, and government spending shocks contribute almost nothing at all to the cycle. In the allocative model (Figure 2), monetary shocks matter quite a lot. The 1970s and early 1980s should have had very low unemployment because inflation and interest rates were so high. In the nonallocative model, none of the candidate shocks seems to matter very much, except for some monetary influence in the episodes of 1948, 1980, and 2008. In general, it seems that accepting a model of sticky wages which is consistent with the long run data would come at the cost of saying that none of the commonly-used shocks in this class of models can explain business cycles.

## **5.2 The effect of wage stickiness on matching labor's share**

Figures 5 and 6 show selected model variables for the flexible wage model (model 3), which is the nonallocative model with the sticky wage component turned off. The only difference between models 2 and 3 is the behavior of labor's share to within a very small estimation difference. Without sticky wages, the markup dynamics of the sticky price model predict a very strong positive relationship between labor's share and inflation and a positive relationship

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<sup>6</sup> Gertler, Sala, and Trigari (2008) get around this by indexing wages strongly to inflation. Kahn (1997) shows that this does not happen in the micro data, and simulations suggest that indexation destroys much of the real effect of nominal wage stickiness, causing the allocative model to mimic the nonallocative model.

between labor's share and output. This is how off-the-shelf New Keynesian sticky price models work; a high labor share induces more effort or fewer separations depending on the context. Regression results in Table 2 show that in the data, labor's share is negatively related to output and positively related to inflation when estimated using a bivariate regression. The sticky wage model delivers a countercyclical labor share, but the model without sticky wages delivers the usual new Keynesian result which is sharply at odds with the data. As a result, the log likelihood of the flexible wage model is 11,356 versus 11,628 for the model with sticky wages. Sticky wages help to replicate the behavior of wages over the cycle, and they do so in a way consistent with what Nekarda and Ramey (2010) find at a detailed industry level. Even if sticky wages do not affect real allocations, they improve the fit of the model to the data on labor's share.

### **5.3 The effect of sticky prices**

Figures 7 and 8 show the simulated model variables for the sticky price model, model (4), which is the baseline sticky wage model (2) without monopolistic competition or sticky prices. The model exhibits very little volatility in employment (standard deviation of 0.41%) since now there is only a very weak channel for monetary propagation. Labor's share is now negatively related to inflation since a burst of inflation will drive down real wages with no markup dynamics to compensate for this. This is the one failure of the sticky wage model when confronted with the data, though a combination of sticky wages and sticky prices does match this feature fairly well.

The flexible price model does predict a good Beveridge Curve in relation to the other models, since slow-moving investment dynamics rather than fast-moving inflation dynamics drive the cycle. If the cycle is a slow-moving phenomenon and hiring costs do not fall very much in response to higher unemployment, then a negative shock results in a shrunken expected future surplus, and this in turn results in a fall in vacancy creation. A monetary shock under a Taylor rule, by contrast, results in a quick change in prices and markups (to avoid hyperinflation) that is mostly resolved by the next period, leaving surpluses unaffected. Because this does not fit the

data on persistence and vacancy creation, the flexible-price specification has the highest log likelihood out of the models examined, at 11,886. The data indicate that New Keynesian Taylor rule shocks do not appear to be an important driver of the cycle, even if New Keynesian markup dynamics and sticky wages help each other in their fitting the labor share.

Even if prices are flexible, sticky wages still improve the fit of the model with labor's share. The flexible price / flexible wage model (5) shows this. It behaves the same as the flexible-price model with sticky wages (4) in terms of real aggregates. It predicts almost no movement in labor's share, since bargaining surpluses are fairly small and wages adjust instantaneously. The fully flexible model has a log likelihood of 11,879 which makes it one million times less likely than the model with flexible prices but sticky wages. No matter whether prices are sticky or not, sticky wages do fit the data better than flexible wages.

#### **5.4 The structure of hiring costs and the Beveridge Curve**

Yashiv (2006) takes a richly parameterized model of search and hiring costs like this one and discusses the implications of various parameter choices. His model is a large-firm version of this model, calibrated to match some important facts about firm dynamics. The vacancy-posting elasticity parameter  $\iota$  matters quite a lot. The last column of Table 2 shows what happens when this parameter equals zero in the nonallocative model, and households can freely post vacancies as in most standard search and matching models. The model produces more volatility in all key labor market aggregates, especially vacancy creation and job creation. However, the model does a slightly poorer job at matching the Beveridge Curve, and thus the likelihood function prefers a value of  $\iota$  of 1. The model does not perform very differently, qualitatively. An alternative simulation, not shown, takes model (4), which has a good Beveridge Curve, and sets  $\iota$  to 0. That model still predicts a Beveridge Curve. The qualitative results in this paper seem robust to differing values of  $\iota$ , and the shocks and frictions in the other blocks of the model play a large

role in determining the shape and slope of the Beveridge Curve. The presence or absence of a Beveridge Curve in the data is very sensitive to the mixture of shocks and frictions present in the model.

The allocation of hiring costs between search and training matters more. Yashiv (2006) and Pissarides (2009) discuss this issue in detail, so I only mention it briefly. Taking away the lump sum portion of hiring costs and concentrating only on search costs, as in the standard formulation of the search model, has several effects. It reduces the predicted volatility of employment and output, since now hiring costs fall and hiring becomes much more responsive to unemployment. Models (4) and (5) lose their Beveridge Curve for the same reason. The structure of hiring costs does have a large effect on how the economy behaves. In general, the search and matching model itself does not have any robust predictions regarding the Beveridge Curve; the Beveridge Curve depends on the frictions and persistence properties of the shocks which appear elsewhere in the model.

## **6. Conclusion**

Sticky wages as they might appear in a matching model seem to show up in the macro data and can substantially improve the fit of search and matching models with the data on labor's share. As a transmission mechanism for nominal shocks, sticky wages require the modeler to make a major tradeoff. For sticky wages to affect employment in search and matching models with rational firms and workers, sticky wages would have to operate on new hires. However, this would imply that hiring indicators such as vacancies and job creation comove very strongly with trend inflation over time. This is not the case in the data. Vacancies and job creation rates do not show a trend which looks like the trend in inflation.

Sticky prices as modeled through the traditional New Keynesian aggregate supply channel also have a tradeoff associated with them. The data do not indicate that New Keynesian Taylor rule shocks play much of a role in postwar US macroeconomic fluctuations, outside of a

few possible episodes. Sticky prices do help slightly with the positive relationship between labor's share and inflation. The problem is that standard Taylor rule shocks do not have persistent effects on future bargaining surpluses, and this is the major driver of the Beveridge Curve in this class of models. Productivity and government spending shocks as estimated from the data do not seem to matter much at a business cycle except over the longer run. The current generation of search and matching models may suffer from a "missing shock" problem based on the lack of a plausible candidate shock in most commonly discussed models.

## References

- Andolfatto, D., 1996. "Business Cycles and Labor-Market Search." *American Economic Review* 86(1), 112-132.
- Balleer, A., 2009. "New Evidence, Old Puzzles: Technology Shocks and Labor Market Fluctuations." Manuscript, University of Bonn, October 2009.
- Barnichon, Regis, forthcoming. "Building a Composite Help Wanted Index." *Economics Letters*.
- Barro, R., 1977. "Long Term Contracting, Sticky Prices, and Monetary Policy." *Journal of Monetary Economics* 3(3), pages 305-316.
- Barron, J., Berger, M., Black, Dan, 1997. "Employer Search, Training, and Vacancy Duration," *Economic Inquiry* 35(1), pages 167-192.
- Beauchemin, K., Tasci, M., 2008. "Diagnosing labor market search models: a multiple-shock approach." *Federal Reserve Bank of Cleveland Working Paper* 08-013.
- Bils, M., Klenow, P., 2004. "Some Evidence on the Importance of Sticky Prices." *Journal of Political Economy* 112(5), 947-985.
- Blanchard, O., Diamond, P., 1989. "The Beveridge Curve." *Brookings Papers on Economic Activity* 1989(1), 1-60.
- Blanchard, O., Diamond, P., 1991. "The Aggregate Matching Function." *NBER Working Paper* 3175.
- Bordo, M., Erceg, C., Levin, A., Michaels, R., 2007. "Three Great American Disinflations." *Federal Reserve Bank of San Francisco Proceedings*, March.
- Calvo, G., 1983. "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics* 12(3), 383-398.
- Choi S., Ríos-Rull, J., forthcoming. "Understanding the Dynamics of Labor Share: The Role of Noncompetitive Factor Prices." *Annales d'Economie et de Statistique*.
- Christoffel, K., Costain, J., de Walque, G., Küster, K., Linzert, T., Millard, S., Pierrard, O., 2009. "Wage, Inflation, and Employment Dynamics with Labour Market Matching." *Documento de Trabajo* 0918, Banco de España.
- Christoffel, K., Küster, K., Linzert, T., 2007. "Identifying the Role of Labor Markets for Monetary Policy in an Estimated DSGE Model." *CFS Working Paper Series* 2007/07.
- Cochrane, J., 2010. "Determinacy and Identification with Taylor Rules: A Critical Review." *University of Chicago, Manuscript*.
- Cooley, T., Quadrini, V., 1999. "A Neoclassical Model of the Phillips Curve Relation." *Journal of Monetary Economics* 44(2), 165-193.

- Costain, J., Reiter, M., 2008. "Business cycles, unemployment insurance, and the calibration of matching models." *Journal of Economic Dynamics and Control* 32(4), 1120-1155.
- Cummins, J., and Violante, G., 2002. "Investment-Specific Technical Change in the US (1947-2000): Measurement and Macroeconomic Consequences." *Review of Economic Dynamics* 5(2), 243-284.
- Den Haan, W., Ramey, G., Watson, J., 2000. "Job Destruction and Propagation of Shocks." *American Economic Review* 90(3), 482-498.
- Faberman, R.J., 2006. "Job Flows and the Recent Business Cycle: Not All 'Recoveries' are Created Equal." Bureau of Labor Statistics Working Paper No. 391.
- Faccini, R., Ortigueira, S., 2008. "Labor-Market Volatility in the Search-and-Matching Model: The Role of Investment-Specific Technology Shocks." *Journal of Economic Dynamics and Control* 34(8), pages 1509-1527.
- Friedman, Milton, and Anna Jacobson Schwartz, 1963. *A Monetary History of the United States, 1867-1960*. Princeton: Princeton University Press.
- Gertler, M., Sala, L., Trigari, A., 2008. "An Estimated Monetary DSGE Model with Unemployment and Staggered Nominal Wage Bargaining." *Journal of Money, Credit and Banking* 40(8), 1713-1764.
- Gertler, M., Trigari, A., 2009. "Unemployment Fluctuations with Staggered Nash Wage Bargaining." *Journal of Political Economy* 117(1), 38-86.
- Goodfriend, M., 1993. "Interest rate policy and the inflation scare problem: 1979-1992." *Economic Quarterly*, Federal Reserve Bank of Richmond, Winter, pages 1-24.
- Haefke, C., Sonntag, M., and van Rijns, T., 2009. "Wage Rigidity and Job Creation." Kiel Working Paper 1504.
- Hagedorn, M., Manovskii, I., 2008. "The Cyclical Behavior of Equilibrium Unemployment and Vacancies Revisited." *American Economic Review* 98(4), 1692-1706.
- Hairault, J., 2002. "Labor-Market Search and International Business Cycles." *Review of Economic Dynamics* 5(3), 535-558.
- Hall, R., 2005. "Employment Fluctuations with Equilibrium Wage Stickiness." *American Economic Review* 95(1), 50-65.
- Kahn, S., 1997. "Evidence of Nominal Wage Stickiness from Microdata." *American Economic Review* 87(5), 993-1008.
- Krause, M., López-Salido, D., and Lubik, T., 2008. "Inflation Dynamics with Search Frictions: A Structural Econometric Analysis." *Journal of Monetary Economics* 55(5), 892-916.
- Krause, M., Lubik, T., 2007. "The (ir)relevance of real wage rigidity in the New Keynesian model with search frictions." *Journal of Monetary Economics*, 54(3), 706-727.



- Martins, P., Snell, A., and Thomas, J., 2009. "Real and Nominal Wage Rigidity in a Model of Equal-Treatment Contracting." IZA Discussion Paper 4346.
- Mortensen, D., Pissarides, C., 1994. "Job Creation and Job Destruction in the Theory of Unemployment." *Review of Economic Studies* 61(3), 397-415.
- Nekarda, C., Ramey, V., 2010. "The cyclical behavior of the price-cost markup," Manuscript, UC San Diego, June 2010.
- Orphanides, A., 2003. "Historical monetary policy analysis and the Taylor rule." *Journal of Monetary Economics* 50(5), 983-1022.
- Pissarides, C., 2009. "The Unemployment Volatility Puzzle: Is Wage Stickiness the Answer?" *Econometrica* 77(5), 1339-1369.
- Ríos-Rull, V., Santaeulàlia-Llopis, R., 2008. "Redistributive Shocks and Productivity Shocks." Manuscript, University of Minnesota, September 2009.
- Rudanko, L., 2009. "Labor market dynamics under long-term wage contracting." *Journal of Monetary Economics* 56(2), pages 170-183.
- Shimer, R., 2005. "The Cyclical Behavior of Equilibrium Unemployment and Vacancies." *American Economic Review* 95(1), 25-49.
- Sims, C., 2002. "Solving Linear Rational Expectations Models." *Computational Economics* 20(1-2), 1-20.
- Smets, F., Wouters, R., 2007. "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach." *American Economic Review*, 97(3), 586-606.
- Trigari, A., 2009. "Equilibrium unemployment, job flows and inflation dynamics." *Journal of Money, Credit and Banking*, 41(1), 1-33.
- Walsh, C., 2002. "Labor Market Search and Monetary Shocks." Working paper version. In: Altuğ, S., Chadha, J., Nolan, C. (Eds.), 2004. *Elements of Dynamic Macroeconomic Analysis*. Cambridge: Cambridge University Press.
- Walsh, C., 2005. "Labor Market Search, Sticky Prices, and Interest Rate Policies." *Review of Economic Dynamics* 8(4), 829-849.
- Yashiv, E., 2006. "Evaluating the performance of the search and matching model." *European Economic Review*, 50(4), 909-936.
- Zagorsky, J. 1998. "Job Vacancies in the United States, 1923 to 1994." *Review of Economics and Statistics* 80(2), 338-345.

Table 1 –Model calibration, different specifications, quarterly

Parameter	(1) Alloc	(2) Non- Alloc	(3) Flex Wage	(4) Flex Price	(5) Flex P, W	(6) Elastic v
Growth rate (in %) $\Gamma - 1$	0.46	0.46	0.46	0.46	0.46	0.46
Capital goods inflation (in %) $\Pi^k - 1$	-0.37	-0.37	-0.37	-0.37	-0.37	-0.37
Interest rate (in %) $R - 1$	1.16	1.16	1.16	1.16	1.16	1.16
Substitution parameter $\theta$	10	10	10	$\infty$	$\infty$	10
Price stickiness $\omega$	0.75	0.75	0.75	<b>0</b>	<b>0</b>	0.75
Wage stickiness $\nu$	0.75	0.75	<b>0</b>	0.75	<b>0</b>	0.75
Productivity dispersion $\sigma_a$	<b>0.361</b>	<i>0.517</i>	<i>0.517</i>	<i>0.517</i>	<i>0.517</i>	<i>0.517</i>
Total separation rate $\rho$	0.100	0.100	0.100	0.100	0.100	0.100
Exogenous separation rate $\rho_x$	0.068	0.068	0.068	0.068	0.068	0.068
Matching function elasticity $a$	0.4	0.4	0.4	0.4	0.4	0.4
Vacancy filling rate $k^f$	0.7	0.7	0.7	0.7	0.7	0.7
Job finding rate $k^w$	0.6	0.6	0.6	0.6	0.6	0.6
Unemployment rate $u$	0.060	0.060	0.060	0.060	0.060	0.060
Vacancies $v$	<i>0.051</i>	<i>0.051</i>	<i>0.051</i>	<i>0.051</i>	<i>0.051</i>	<i>0.051</i>
Bargaining power $\eta$	0.5	0.5	0.5	0.5	0.5	0.5
Vacancy posting congestion $\iota$	1	1	1	1	1	<b>0</b>
Vacancy search cost $\gamma_0$	<i>0.492</i>	<i>0.492</i>	<i>0.492</i>	<i>0.492</i>	<i>0.492</i>	<b>0.0253</b>
Hiring cost $\gamma_1$	<i>4.92</i>	<i>4.92</i>	<i>4.92</i>	<i>4.92</i>	<i>4.92</i>	<b>0.253</b>
Hiring cost share of total employment	0.015	0.015	0.015	0.015	0.015	0.015
Search cost share of hiring costs	0.091	0.091	0.091	0.091	0.091	0.091
Investment share of output	0.161	0.161	0.161	0.161	0.161	0.161
Government share of output	0.202	0.202	0.202	0.202	0.202	0.202
Depreciation rate $\delta$	0.015	0.015	0.015	0.015	0.015	0.015
Taylor rule coeff on inflation $\phi_\pi$	1.142	1.142	1.142	1.142	1.142	1.142
Taylor rule coeff on growth $\phi_y$	0.310	0.310	0.310	0.310	0.310	0.310
Taylor rule persistence $\rho_r$	0.938	0.938	0.938	0.938	0.938	0.938
Autocorrelation of inflation error	0.95	0.93	0.93	0.94	0.94	0.93
Autocorrelation of employment error	0.9999	0.999	0.999	0.95	0.95	0.9995
Autocorrelation of labor share error	0.97	0.97	0.81	0.98	0.94	0.97
Autocorrelation of vacancy error	0.97	0.97	0.97	0.97	0.97	0.95
Autocorrelation of job destruction error	0.81	0.77	0.78	0.85	0.85	0.82
Autocorrelation of job creation error	0.93	0.95	0.95	0.95	0.95	0.93
Autocorrelation of investment error	0.90	0.95	0.95	0.96	0.96	0.94
Sticky wages apply to new hires?	Yes	No	No	No	No	No

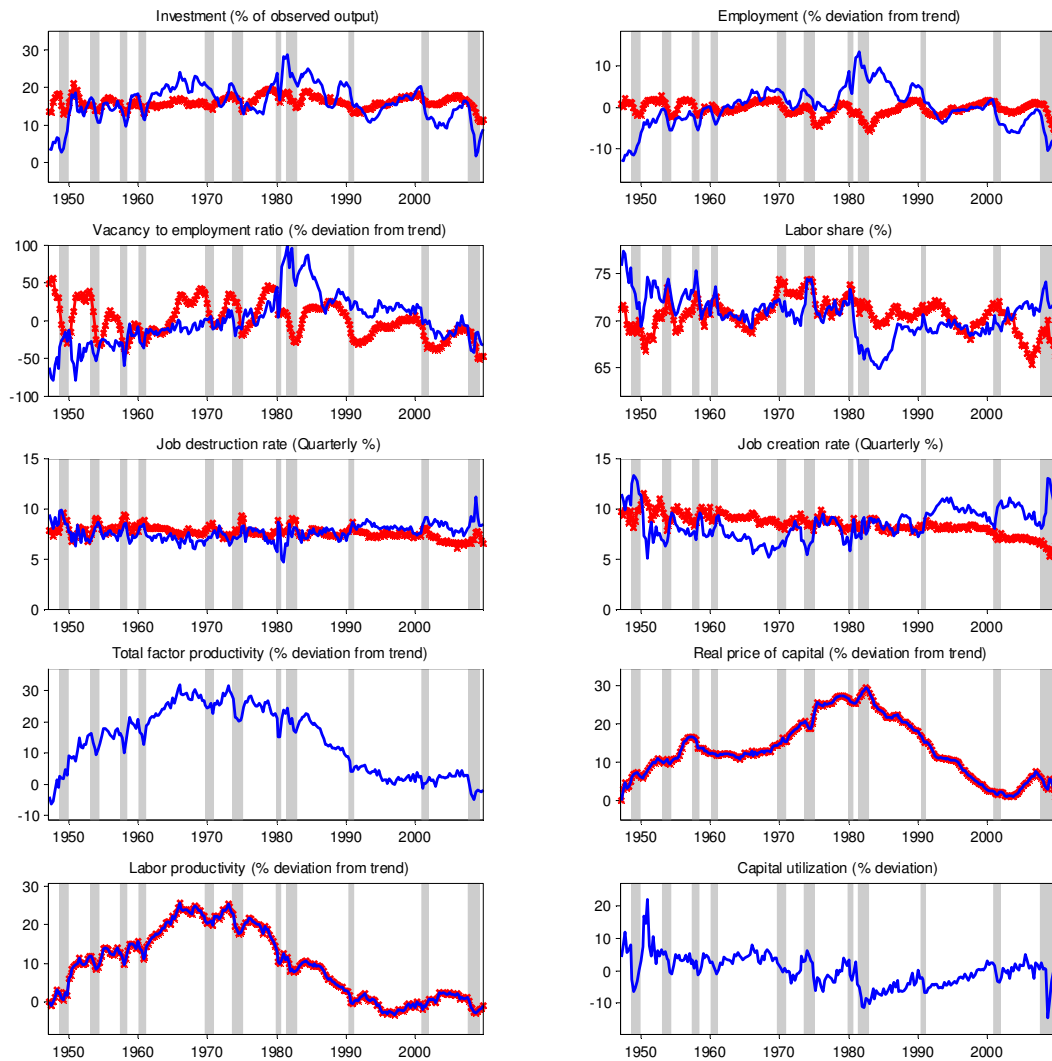
Items in bold differ from the baseline nonallocative model. Autocorrelations are estimated from the likelihood function, so they differ across all specifications. Items in *italics* are derived from the other calibrated values.

**Table 2 –Actual and simulated statistics of variables, data vs. model specifications**

<b>Sample Statistic</b>	<b>Data</b>	<b>(1) Alloc</b>	<b>(2) Non- Alloc</b>	<b>(3) Flex Wage</b>	<b>(4) Flex Price</b>	<b>(5) Flex P, W</b>	<b>(6) Elastic v</b>
Std Dev (Output)	2.26%	2.69%	1.84%	1.84%	1.77%	1.77%	1.94%
Std Dev (Employment)	1.29%	2.02%	0.68%	0.68%	0.41%	0.41%	0.98%
Std Dev (Vacancies)	17.71%	14.32%	1.97%	1.97%	0.62%	0.62%	19.64%
Std Dev (JD Rate)	5.87%	8.00%	4.09%	4.09%	1.42%	1.42%	8.33%
Std Dev (JC Rate)	5.26%	11.65%	6.01%	6.00%	2.61%	2.61%	19.48%
Std Dev (Labor Share)	1.52%	1.43%	1.52%	3.18%	1.14%	0.03%	1.33%
Std Dev (Inflation Rate)	0.48%	0.60%	0.67%	0.67%	0.63%	0.63%	0.66%
Std Dev (Interest Rate)	0.32%	0.32%	0.32%	0.32%	0.32%	0.32%	0.32%
Std Dev (Investment Share)	7.76%	7.67%	5.46%	5.46%	3.06%	3.06%	6.40%
Std Dev (Vac.)/Std Dev (Empl.)	13.73	7.09	2.90	2.90	1.51	1.51	20.04
Corr (Employment, Output)	0.72	0.81	0.52	0.52	0.52	0.52	0.57
Corr (Vacancies, Output)	0.80	0.48	-0.18	-0.18	0.44	0.44	-0.39
Corr (JD Rate, Output)	-0.68	-0.71	-0.44	-0.44	-0.44	-0.44	-0.50
Corr (JC Rate, Output)	0.21	-0.56	-0.46	-0.46	-0.52	-0.52	-0.47
Corr (Labor Share, Output)	-0.39	-0.38	-0.08	0.31	-0.12	-0.23	0.02
Corr (Inflation Rate, Output)	0.22	0.35	0.13	0.13	-0.19	-0.19	0.29
Corr (Interest Rate, Output)	0.15	0.51	-0.14	-0.14	-0.30	-0.30	-0.06
Corr (Investment Share, Output)	0.73	0.75	0.67	0.66	0.79	0.79	0.74
Corr (Vacancies, Employment)	0.87	0.64	-0.67	-0.67	0.88	0.88	-0.88
Corr (Output, Inflation)	0.22	0.35	0.13	0.13	-0.19	-0.19	0.29
Corr (Employment, Inflation)	0.41	0.54	0.64	0.64	-0.38	-0.38	0.77
Corr (Vacancies, Inflation)	0.37	-0.11	-0.87	-0.87	-0.36	-0.36	-0.86
Corr (JD Rate, Inflation)	-0.27	-0.63	-0.68	-0.68	0.37	0.37	-0.85
Corr (JC Rate, Inflation)	0.09	-0.78	-0.73	-0.73	0.37	0.37	-0.85
Corr (Labor Share, Inflation)	0.07	0.53	0.53	0.90	-0.49	0.31	0.46
Corr (Interest Rate, Inflation)	0.34	0.63	0.71	0.71	0.67	0.67	0.71
Corr (Investment Share, Inflation)	0.29	0.64	0.64	0.64	-0.36	-0.36	0.69
Reg. Coeff. of LS on Output	-0.29	-0.35	-0.13	0.34	-0.14	0.00	-0.08
Reg. Coeff. of LS on Inflation	0.53	1.81	1.25	4.15	-0.96	0.01	1.00
Corr (Output, Data)		0.74	0.88	0.88	0.79	0.79	0.88
Corr (Employment, Data)		0.46	0.55	0.55	-0.06	-0.06	0.57
Corr (Vacancies, Data)		-0.04	-0.40	-0.40	0.06	0.06	-0.43
Corr (JD Rate, Data)		0.53	0.31	0.31	-0.07	-0.07	0.30
Corr (JC Rate, Data)		-0.04	0.04	0.04	0.10	0.10	-0.03
Corr (Labor Share, Data)		0.43	0.41	0.04	0.30	0.18	0.43
Corr (Investment Share, Data)		0.31	0.17	0.17	0.27	0.27	0.15
<b>Log Likelihood</b>		<b>11,170</b>	<b>11,628</b>	<b>11,356</b>	<b>11,886</b>	<b>11,879</b>	<b>11,072</b>

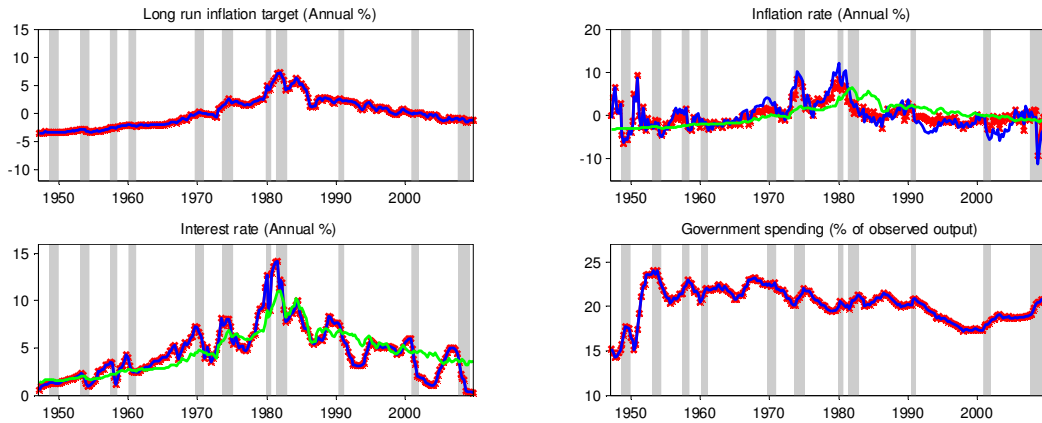
Data are taken in logarithms, HP-filtered with a smoothing parameter of 10,000, and then moments are calculated. Source: Author's calculations from model and data.

**Figure 1a – Real variables (observed vs model-generated, allocative model)**



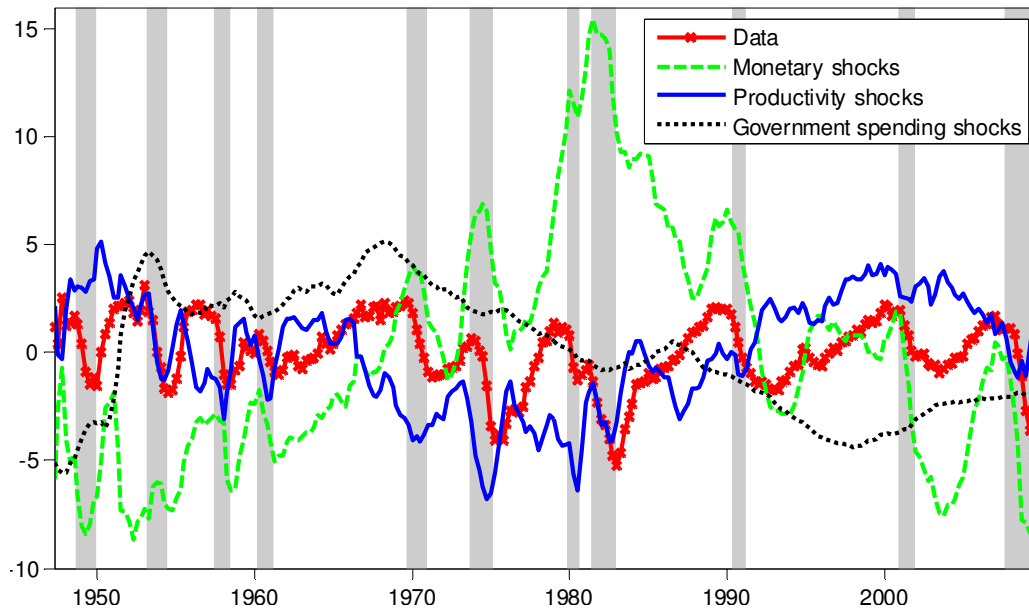
Red 'x' lines denote observed data; blue solid lines denote model-generated data as described in the text. For details on data sources and calculations, see text.

**Figure 1b – Policy variables (observed vs model-generated, allocative model)**



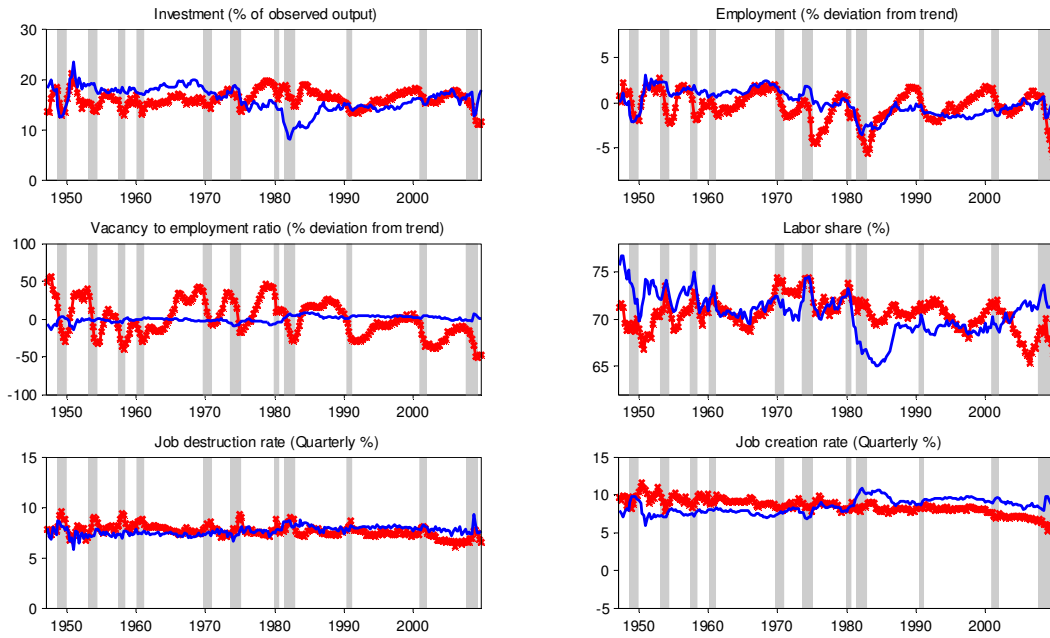
Red 'x' lines denote observed data; blue solid lines denote model-generated data as described in the text; and the light green line denotes trend inflation as given by long-term interest rates. For details on data sources and calculations, see text.

**Figure 2 – Effects of classes of shocks on employment, allocative model.**



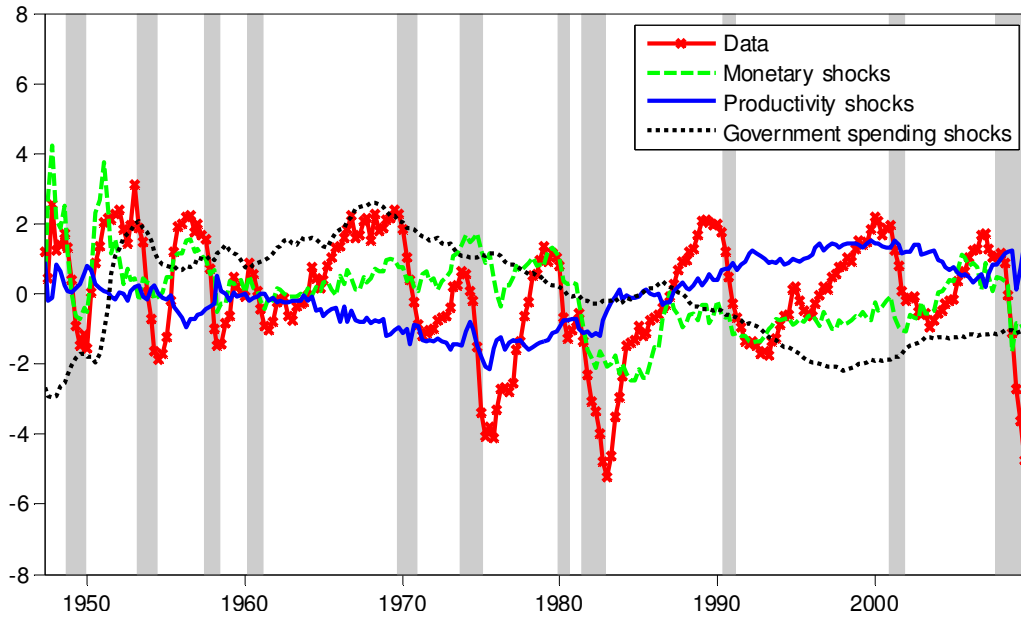
This figure shows the effects of the estimated shocks from 1947.III onward, when fed through the model. Gray lines indicate recessions.

**Figure 3 – Real variables (observed vs model-generated, nonallocative model)**



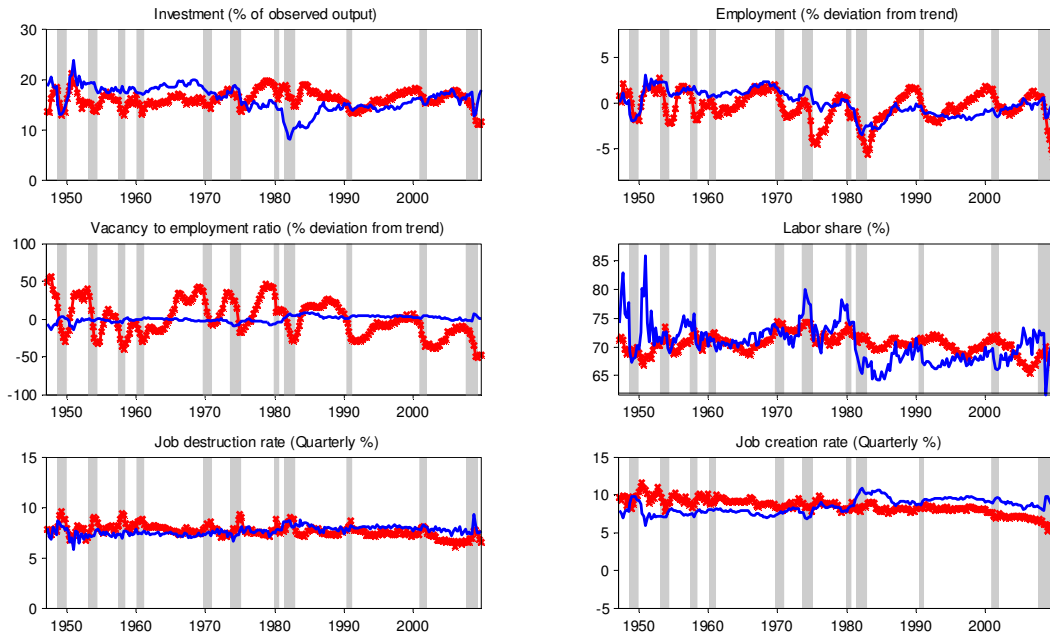
See Figures 1a and 1b for explanation.

**Figure 4 – Effects of classes of shocks on employment, nonallocative model.**



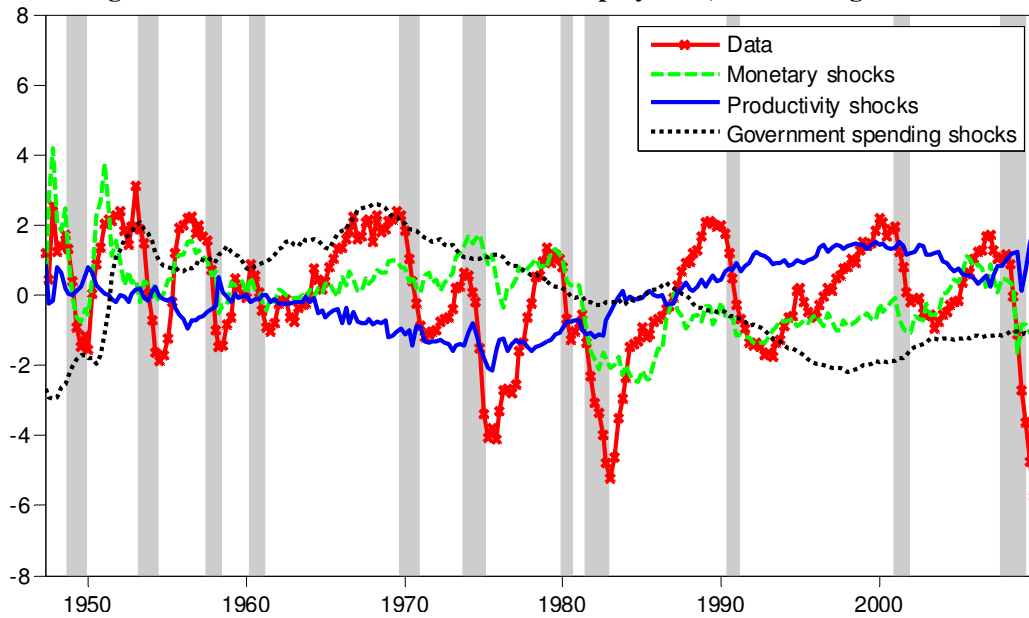
See Figure 2 for explanation.

**Figure 5 – Real variables (observed vs model-generated, flexible wage model)**



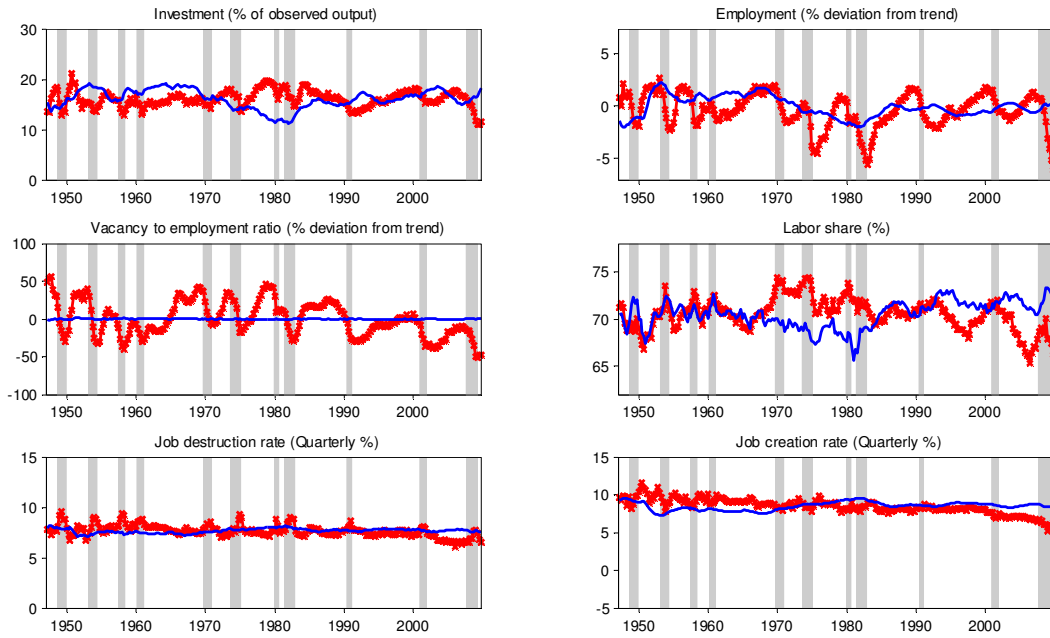
See Figures 1a and 1b for explanation.

**Figure 6 – Effects of classes of shocks on employment, flexible wage model.**



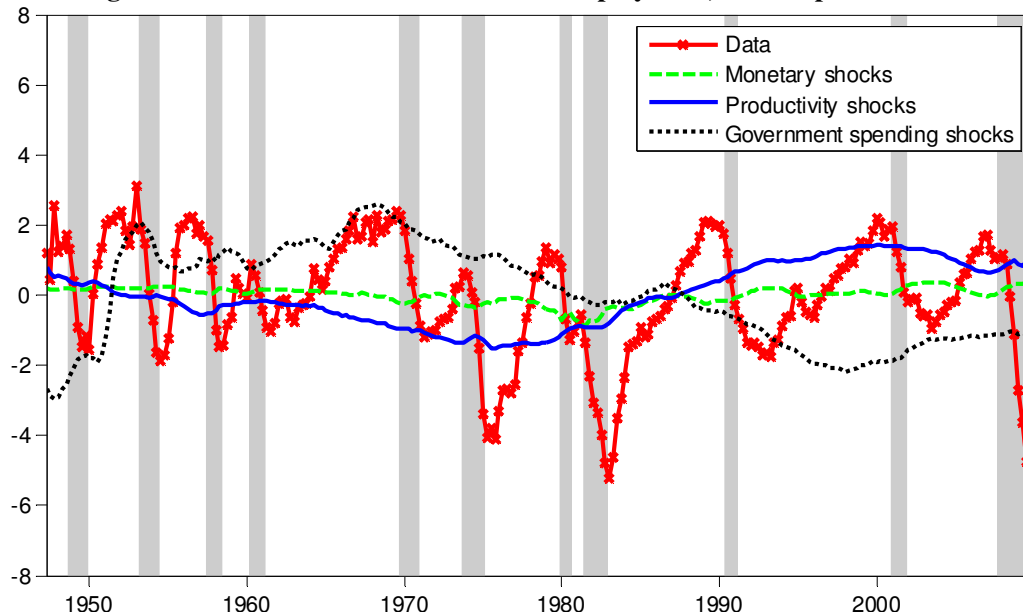
See Figure 2 for explanation.

**Figure 7 – Real variables (observed vs model-generated, flexible price model)**



See Figures 1a and 1b for explanation.

**Figure 8 – Effects of classes of shocks on employment, flexible price model.**



See Figure 2 for explanation.