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UNEMPLOYMENT AND BUSINESS CYCLES

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We develop and estimate a general equilibrium search and matching model that accounts for key business cycle properties of macroeconomic aggregates, including labor market variables. In sharp contrast to leading New Keynesian models, we do not impose wage inertia. Instead we derive wage inertia from our specification of how firms and workers negotiate wages. Our model outperforms a variant of the standard New Keynesian Calvo sticky wage model. According to our estimated model, there is a critical interaction between the degree of price stickiness, monetary policy, and the duration of an increase in unemployment benefits.

KEYWORDS: Search and matching, unemployment, business cycles, wage inertia, Nash bargaining, alternating offer bargaining, wage rules, unemployment benefits, Bayesian estimation.

1. INTRODUCTION

MACROECONOMIC MODELS have difficulty accounting for the magnitude of business cycle fluctuations in employment and unemployment. A classic example is provided by the class of real business cycle models pioneered by Kydland and Prescott (1982).[1] Models that build on the search and matching framework of Diamond (1982), Mortensen (1982), and Pissarides (1985) also have difficulty accounting for the volatility of labor markets. For example, Shimer (2005) argues that these models can only do so by resorting to implausible parameter values.

Empirical New Keynesian models have been relatively successful in accounting for the cyclical properties of employment by assuming that wage setting is subject to nominal rigidities.[2] The implied wage inertia prevents sharp, counterfactual cyclical swings in wages and inflation that would otherwise occur in these models. Empirical New Keynesian models have been criticized on at least four grounds. First, these models do not explain wage inertia; they simply assume it. Second, agents in the model would not choose to subject themselves to the nominal wage frictions imposed on them by the modeler.[3] Third, empirical New Keynesian models assume that wages are indexed to inflation, but there is little evidence that this type of indexation is widely used.[4] Fourth, these

[1] See, for example, the discussion in Chetty, Guren, Manoli, and Weber (2012).

[2] For example, Christiano, Eichenbaum, and Evans (2005), Smets and Wouters (2007), and Galí, Smets, and Wouters (2012) assume that nominal wages are subject to Calvo-style rigidities.

[3] This criticism does not necessarily apply to a class of models initially developed by Hall (2005). We discuss these models in the conclusion.

[4] Most of the relevant evidence on cost of living allowances (COLAs) is based on studies of major collective bargaining agreements (those covering 1000 or more workers). Those studies

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[Correction added on 4 March 2021, after first online publication: The copyright line was updated.]

models cannot be used to examine some key policy issues such as the effects of changes in unemployment benefits.[5]

We integrate search and matching models into an otherwise standard New Keynesian framework. Our models can account for the response of key macroeconomic aggregates to monetary and technology shocks. These aggregates include labor market variables like wages, employment, job vacancies, and unemployment. In contrast to leading empirical New Keynesian models, we do not assume that wages are subject to exogenous nominal rigidities. Instead, we derive wage inertia as an equilibrium outcome.

As in standard New Keynesian models, we assume that price setting is subject to Calvo-style rigidities. But, guided by the microevidence on prices, we assume that firms that do not reoptimize their price must keep it unchanged, that is, no price indexation.

One version of our model pursues a variant of Hall and Milgrom's (2008) (henceforth HM) approach to labor markets, in which real wages are determined by alternating offer bargaining (henceforth AOB).[6] We also consider a version of the model in which real wages are determined by Nash bargaining. In both versions of the model we assume, as in Pissarides (2009), that there is a fixed cost component in hiring.

We estimate the different versions of our model using a Bayesian variant of the strategy in Christiano, Eichenbaum, and Evans (2005) (henceforth CEE).[7] That strategy involves minimizing the distance between the dynamic response to monetary policy shocks, neutral technology shocks, and investment-specific technology shocks in the model and the analog objects in the data. The latter are obtained using an identified vector autoregression (VAR) for 12 postwar, quarterly U.S. times series that include key labor market variables.

Both the AOB and Nash bargaining models succeed in accounting for the key features of our estimated impulse response functions. In both models, real

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indicate that in 1976, 61 percent of workers covered by those agreements received contracts that included COLAs and that this proportion declined to only 22 percent of workers by 1995 (see Devine (1996)). There is virtually no evidence that there is indexation in the nonunion sector. According to Card (1986), "It is generally believed that escalation provisions are rare in the nonunion sector." Significantly, the fraction of workers covered by unions is small and shrinking. The percent of U.S. wage and salary workers (excluding incorporated self-employed) in all industries represented by unions declined from 23 percent in 1983 to 12 percent in 2014 (see Bureau of Labor statistics series LUU0204899700).

[5] Galí (2011) and Galí, Smets, and Wouters (2012) provide an interpretation of the sticky wage model that has implications for unemployment and unemployment benefits. However, that interpretation relies on the presence of pervasive union power in labor markets, an assumption that seems questionable in the United States (see Christiano (2012)).

[6] For a paper that uses a wage contract motivated by alternating offer bargaining in a calibrated real business cycle model, see Hertweck (2006). In independent work, Clerc (2015) introduces alternating offer bargaining into a calibrated New Keynesian model without capital.

[7] We implement the Bayesian version of the CEE procedure that was developed in Christiano, Trabandt, and Walentin (2011a).

wages have two key properties that define what we refer to as *wage inertia*. First, the real wage responds relatively little to shocks. Second, the response that does occur is very persistent. These properties are essential ingredients in the AOB and Nash bargaining model's ability to account for the estimated response of the economy to shocks. Wage inertia plays a particularly important role in the dynamics of inflation.[8] According to our VAR analysis, inflation responds very little to a monetary policy shock. The only way for the model to account for this small response is for a monetary policy shock to generate a small change in firms' marginal costs. That requires that real wages be inertial. According to our VAR analysis, there is a relatively large drop in inflation after a positive neutral technology shock. Other things being equal, a rise in technology drives down marginal cost and inflation in our model. Wage inertia prevents a substantial rise in real wages that would otherwise undo this downward pressure on inflation.

At the posterior mode of the parameters, the estimated AOB and Nash models both generate impulse response functions that are virtually identical to each other. So the likelihood of the two models is roughly the same. But, for the Nash bargaining model to match the empirical impulse response functions requires a very high replacement ratio that is extremely implausible from the perspective of our prior.[9] In contrast, the AOB model does not require implausible parameter values to account for the data. The marginal likelihood of a model is the weighted average of the likelihood evaluated at the various possible values of the parameters. For a given set of parameter values, the weight corresponds to the associated prior probability. These observations explain why the marginal likelihood of the AOB model is substantially higher than that of the Nash bargaining model and why we take the former to be our benchmark search and matching model.

Wage inertia is central to the success of our AOB and Nash bargaining models. But is it a central property of a broader class of empirically successful models? To address this question, we begin by noting that in our AOB and Nash bargaining models, the real wage is the solution to a bargaining problem. The surplus sharing rules implied by these models can also be interpreted as restricted rules for setting the real wage as a function of the models' date t state variables. So we estimate a model in which the sharing rule is replaced by a general real wage rule. The latter makes the date t real wage an unrestricted function of the model's date t state variables. Our key result is that the estimated general real wage rule does in fact satisfy wage inertia in the sense defined above. These results provide evidence in favor of the view that wage

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[8] The importance of acyclicality in wages in accounting for inertia in inflation is an important theme in the New Keynesian literature. See, for example, CEE.

[9] For a discussion of microdata that suggests that a high replacement ratio is implausible, see, for example, the discussion in Hornstein, Krusell, and Violante (2010).

inertia is an important component of a broad class of empirically successful macromodels.[10]

How does the performance of the AOB model compare with that of the standard empirical New Keynesian model? That model incorporates Calvo wage-setting frictions along the lines developed in Erceg, Henderson, and Levin (2000). We show that the AOB model substantially outperforms the Calvo sticky wage New Keynesian model with no wage indexation in terms of statistical fit. We also show that the impulse response functions of the estimated AOB model are very similar to those of the Calvo sticky wage model with indexation. So, given the limitations of Calvo sticky wage models, there is simply no need to work with them. The dynamics of the AOB and Calvo sticky wage models are roughly the same. But the AOB model can be used to analyze a broader set of labor market variables and policy questions.

To illustrate the latter point, we study the macroeconomic effects of changes in unemployment benefits. Using the AOB model we argue that the effects of unemployment benefits depend critically on the nature of monetary policy. The more aggressive the central bank is in fighting inflation, the more contractionary is the effect of an increase in unemployment benefits. We argue that a rise in unemployment benefits is more contractionary than is implied by flexible price models.[11] The basic intuition is straightforward. By increasing workers' outside option, an increase in unemployment benefits leads to an increase in wages. As in any standard search model, this rise in wages leads to a fall in the number of vacancies posted by firms. In our model, additional contractionary forces come into play. Specifically, the rise in real wages leads to an increase in inflation. If the monetary authority responds to that increase by raising the real interest rate, then consumption and investment spending fall. As a result, the contraction in economic activity will be larger than is implied by standard search models.

To see how critical the nature of monetary policy is for the analysis of unemployment benefits, consider a situation in which the zero lower bound (ZLB) on the nominal interest rate is binding. An increase in unemployment benefits will still be inflationary. But if the nominal rate of interest does not change, then inflation reduces the real interest rate. Other things being equal, this effect leads to a rise in consumption and investment spending. Depending on parameter values, for example, the amount of time that agents expect the ZLB to bind, an increase in unemployment benefits can actually be expansionary. That said, for the empirically plausible case, the estimated AOB model implies

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[10] The role of wage inertia in labor market dynamics is the subject of some controversy in the literature. For example, Hall (2005), Shimer (2005), and Hall and Milgrom (2008) argue that wage inertia is important. In contrast, Hagedorn and Manovskii (2008) and Ljungqvist and Sargent (2015) challenge that view. In the Appendix (Christiano, Eichenbaum, and Trabandt (2016)) we clarify the relationship between our findings and the literature.

[11] For an analysis in flexible price models, see, for example, Hagedorn, Karahan, Manovskii, and Mitman (2013).

that the effects of an increase in unemployment benefits in the ZLB are likely to be quite small.

It is worth emphasizing that in standard sticky wage New Keynesian models an increase in unemployment benefits has no effects, regardless of the stance of monetary policy. So our analysis of unemployment benefits provides a concrete example of the advantages of moving to a search-theoretic framework. More generally, any development that shifts bargaining power between firms and workers (e.g., free trade agreements or technological developments that increase the feasibility of outsourcing) will have important general equilibrium effects that can be analyzed in extensions of our model.

Our paper is organized as follows. Section 2 presents our search and matching model economy. Section 3 presents the standard sticky wage model. Section 4 describes our econometric methodology. Sections 5 and 6 present the empirical results for our search and matching models, and our alternative models, respectively. Section 7 reports the results of our experiments with unemployment benefits. Concluding remarks appear in Section 8.

2. THE MODEL ECONOMY

In this section we discuss our benchmark model economy. We embed search and matching labor market frictions into an otherwise standard New Keynesian model. We do so in a way that preserves the analytic tractability of the Calvo-style price-setting model.[12]

2.1. *Households*

The economy is populated by a large number of identical households. The representative household has a unit measure of workers that it supplies inelastically to the labor market. We denote the fraction of employed workers in the representative household in period t by l_t. An employed worker earns the nominal wage rate, W_t. An unemployed worker receives D_t goods in government-provided unemployment compensation. We assume that each worker has the same concave preferences over consumption and that households provide perfect consumption insurance, so that each worker receives the same level of consumption, C_t. The preferences of the representative household are the equally weighted average of the preferences of its workers:

$$E_0 \sum_{t=0}^{\infty} \beta^t \ln(C_t - bC_{t-1}), \quad 0 \le b < 1. \tag{1}$$

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[12] For an early application of this strategy, see Walsh (2003).

Here b controls the degree of habit formation in preferences. The representative household's budget constraint is

$$P_tC_t + P_{I,t}I_t + B_{t+1} \leq \left(R_{K,t}u_t^K - a\left(u_t^K\right)P_{I,t}\right)K_t + (1-l_t)P_tD_t + W_tl_t + R_{t-1}B_t - T_t. \tag{2}$$

Here T_t denotes lump sum taxes net of profits, P_t denotes the price of consumption goods, $P_{I,t}$ denotes the price of investment goods, B_{t+1} denotes one period risk-free bonds purchased in period t with gross return, R_t, and I_t denotes the quantity of investment goods. The object $R_{K,t}$, denotes the rental rate of capital services, K_t denotes the household's beginning of period t stock of capital, $a(u_t^K)$ denotes the cost, in units of investment goods, of the capital utilization rate, u_t^K, and $u_t^K K_t$ denotes the household's period t supply of capital services. The functional form for the increasing and convex function, $a(\cdot)$, is described below. All prices, taxes, and profits in (2) are in nominal terms.[13]

The representative household's stock of capital evolves as

$$K_{t+1} = (1-\delta_K)K_t + \left[1 - S(I_t/I_{t-1})\right]I_t.$$

The functional form for the increasing and convex adjustment cost function, $S(\cdot)$, is described below.[14]

2.2. *Final Good Producers*

A final homogeneous good, Y_t, is produced by competitive and identical firms using the technology

$$Y_t = \left[\int_0^1 (Y_{j,t})^{1/\lambda}\,dj\right]^{\lambda}, \tag{3}$$

where $\lambda > 1$. The representative firm chooses specialized inputs, $Y_{j,t}$, to maximize profits,

$$P_tY_t - \int_0^1 P_{j,t}Y_{j,t}\,dj,$$

subject to the production function (3). The firm's first order condition for the jth input is

$$Y_{j,t} = (P_t/P_{j,t})^{\lambda/(\lambda-1)}Y_t. \tag{4}$$

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[13] In Christiano, Eichenbaum, and Trabandt (2015) we argue that our model is not subject to the Chodorow-Reich and Karabarbounis (2014) critique of the setup of Hall and Milgrom (2008), which implies a highly procyclical opportunity cost of employment.

[14] Eberly, Rebelo, and Vincent (2012) review the literature that provides microfoundations for this form of investment adjustment costs. In addition, they provide empirical evidence in favor of this form of adjustment costs using detailed firm-level data from COMPUSTAT.

The homogeneous output, Y_t, can be used to produce either consumption goods or investment goods. The production of the latter uses a linear technology in which one unit of Y_t is transformed into Ψ_t units of I_t.

2.3. *Retailers*

The jth input good in (3) is produced by a *retailer*, with production function

$$Y_{j,t} = k_{j,t}^{\alpha}(z_t h_{j,t})^{1-\alpha} - \phi_t. \tag{5}$$

The retailer is a monopolist in the product market and is competitive in factor markets. Here $k_{j,t}$ denotes the total amount of capital services purchased by firm j and ϕ_t represents a fixed cost of production. Also, z_t is a neutral technology shock. Finally, $h_{j,t}$ is the quantity of an intermediate good purchased by the jth retailer. This good is purchased in competitive markets at the price P_t^h from a *wholesaler*. As in CEE, we assume that to produce in period t, the retailer must borrow $P_t^h h_{j,t}$ at the gross nominal interest rate, R_t. The retailer repays the loan at the end of period t after receiving sales revenues. The jth retailer sets its price, $P_{j,t}$, subject to the demand curve, (4), and the following Calvo sticky price friction (6):

$$P_{j,t} = \begin{cases} P_{j,t-1} & \text{with probability } \xi, \\ \tilde{P}_t & \text{with probability } 1-\xi. \end{cases} \tag{6}$$

Here, $\tilde{P}_t$ denotes the price set by the fraction $1-\xi$ of producers who can reoptimize at time t. We assume these producers make their price decision before observing the current period realization of the monetary policy shock, but after the other time t shocks. This assumption is necessary to ensure that our model satisfies the identifying assumptions that we make in our empirical work. We do not allow the nonoptimizing firms to index their prices to some measure of inflation. In this way, the model is consistent with the observation that many prices remain unchanged for extended periods of time (see Eichenbaum, Jaimovich, and Rebelo (2011) and Klenow and Malin (2011)).

2.4. *Wholesalers, Workers, and the Labor Market*

The law of motion for aggregate employment, l_t, is given by

$$l_t = (\rho + x_t)l_{t-1}. \tag{7}$$

Here ρ is the probability that a given firm–worker match continues from one period to the next. So ρl_{t-1} denotes the number workers that were attached to firms in period $t-1$ and remain attached at the start of period t. Also, $x_t l_{t-1}$ denotes the number of new firm–worker meetings at the start of period t. We refer to x_t as the hiring rate because, in the equilibria that we study, meetings always result in employment. According to (7) workers are engaged in production as soon as they are hired. Our timing convention differs from the standard one in the literature, in which workers begin employment in the period after they meet a firm. We do not adopt this assumption because the time period in our model is one quarter and it would not be plausible to posit such a long delay between a worker–firm meeting and the start of employment.[15]

The number of workers searching for work at the start of period t is the sum of the number of unemployed workers in period $t-1$, $1-l_{t-1}$, and the number of workers who separate from firms at the end of $t-1$, $(1-\rho)l_{t-1}$. The probability, f_t, that a searching worker meets a firm is given by

$$f_t = \frac{x_t l_{t-1}}{1-\rho l_{t-1}}.$$

Wholesaler firms produce the intermediate good using labor that has a fixed marginal productivity of unity. As in Pissarides (2009), a wholesaler firm that wishes to meet a worker in period t must post a vacancy at cost s_t, expressed in units of the consumption good. The vacancy is filled with probability Q_t. In case the vacancy is filled, the firm must pay a fixed real cost, κ_t, before bargaining with the newly matched worker. Let J_t denote the value to the firm of a worker, expressed in units of the final good:

$$J_t = \vartheta_t^p - w_t^p. \tag{8}$$

Here ϑ_t^p denotes the expected present value, over the duration of the worker–firm match, of the real intermediate good price, $\vartheta_t \equiv P_t^h/P_t$. Also, w_t^p denotes a similar present value of the real wage, $w_t \equiv W_t/P_t$. The real wage is determined by worker–firm bargaining and is discussed below. In recursive form,

$$\vartheta_t^p = \vartheta_t + \rho E_t m_{t+1} \vartheta_{t+1}^p, \quad w_t^p = w_t + \rho E_t m_{t+1} w_{t+1}^p. \tag{9}$$

Here m_{t+1} is the time t household discount factor that firms and workers view as an exogenous stochastic process and is discussed below. Free entry by wholesalers implies that, in equilibrium, the expected benefit of a vacancy equals the cost:

$$Q_t(J_t - \kappa_t) = s_t. \tag{10}$$

Let V_t denote the value to a worker of being matched with a firm. We express V_t as the sum of the expected present value of wages earned while the match endures and the continuation value, A_t, when the match terminates:

$$V_t = w_t^p + A_t. \tag{11}$$

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[15] Our empirical analysis compares model- and VAR-based responses to shocks. This comparison only makes sense in our context if the time period of the model coincides with the quarterly time period of the VAR.

Here

$$A_t = (1-\rho)E_t m_{t+1}\big[f_{t+1}V_{t+1} + (1-f_{t+1})U_{t+1}\big] + \rho E_t m_{t+1} A_{t+1}. \tag{12}$$

The variable U_t denotes the value of being an unemployed worker,

$$U_t = D_t + \tilde{U}_t, \tag{13}$$

where $\tilde{U}_t$ denotes the continuation value of unemployment:

$$\tilde{U}_t \equiv E_t m_{t+1}\big[f_{t+1}V_{t+1} + (1-f_{t+1})U_{t+1}\big]. \tag{14}$$

The vacancy filling rate, Q_t, and the job finding rate for workers, f_t, are assumed to be related to labor market tightness, Γ_t, as

$$f_t = \sigma_m \Gamma_t^{1-\sigma}, \quad Q_t = \sigma_m \Gamma_t^{-\sigma}, \quad \sigma_m > 0, 0 < \sigma < 1,$$

where

$$\Gamma_t = \frac{v_t l_{t-1}}{1-\rho l_{t-1}}. \tag{15}$$

Here $v_t l_{t-1}$ denotes the number of vacancies posted by firms at the start of period t.

2.5. *Alternating Offer Bargaining Model*

This section describes the details of bargaining arrangements between firms and workers.[16] At the start of period t, l_t matches are determined. At this point, each worker in l_t engages in bilateral bargaining over the current wage rate, w_t, with a wholesaler firm. Each worker–firm bargaining pair takes the outcome of all other period t bargains as given. In addition, agents have beliefs about the outcome of future wage bargains, conditional on remaining matched. Under their beliefs those future wages are not a function of current actions. Because bargaining in period t applies only to the current wage rate, we refer to it as *period-by-period bargaining*.

The periods $t = 1, 2, \ldots$ in our model represent quarters. We suppose that bargaining proceeds across M subperiods within the period, where M is even. The firm makes a wage offer at the start of the first subperiod. It also makes an offer at the start of a subsequent odd subperiod in the event that all previous offers have been rejected. Similarly, the worker makes a wage offer at

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[16] A well known feature of bargaining models is that equilibrium outcomes depend on the specification of what happens out of equilibrium. This dependence is a feature of many models. Examples include models of debt and strategic models of monetary policy, as well as models of strategic interactions between firms.

the start of an even subperiod in case all previous offers have been rejected. The worker makes the last offer, which is take-it-or-leave-it.[17] In subperiods $j = 1, \ldots, M - 1$, the recipient of an offer has the option to accept or reject it. If the offer is rejected, the recipient may declare an end to the negotiations or he may plan to make a counteroffer at the start of the next subperiod. In the latter case there is a probability, δ, that bargaining breaks down. We now explain the bargaining in detail.

Consider a firm that makes a wage offer, $w_{j,t}$, in subperiod $j < M$, j odd. The firm sets $w_{j,t}$ as low as possible subject to the worker not rejecting it. The resulting wage offer, $w_{j,t}$, satisfies the indifference condition

$$V_{j,t} = \max\{U_{j,t}, \delta U_{j,t} + (1 - \delta)[D_t/M + V_{j+1,t}]\}. \tag{16}$$

We assume that when an agent is indifferent between accepting and rejecting an offer, he accepts it. The left hand side of (16), $V_{j,t}$, denotes the value to a worker of accepting the wage offer $w_{j,t}$:

$$V_{j,t} = w_{j,t} + \tilde{w}_t^p + A_t. \tag{17}$$

Here, $\tilde{w}_t^p$ denotes the present discounted value of the future wages that workers and firms believe will prevail while their match endures:

$$\tilde{w}_t^p = \rho E_t m_{t+1} w_{t+1}^p. \tag{18}$$

In (17) and (18), $\tilde{w}_t^p$ and A_t are taken as given by the period t worker–firm bargaining pair.

The right hand side of (16) is the maximum, over the worker's outside option, $U_{j,t}$, and the worker's *disagreement payoff*. The latter is the value of a worker who rejects a wage offer with the intention of making a counteroffer in the next subperiod. We assume the disagreement payoff exceeds the outside option, though in practice this must be verified. The first term in the disagreement payoff reflects that the negotiations break down with probability δ, in which case the worker reverts to his outside option, with value $U_{j,t}$:

$$U_{j,t} = \frac{M - j + 1}{M} D_t + \tilde{U}_t.$$

Here $\tilde{U}_t$ is defined in (14). Also, the term multiplying D_t reflects our assumption that the worker receives unemployment benefits in period t in proportion to the number of subperiods spent in nonemployment. The second term in the disagreement payoff reflects the fact that with probability $1 - \delta$ the worker receives unemployment benefits, D_t/M, and then makes a counteroffer $w_{j+1,t}$ to the firm that he (correctly) expects will be accepted.

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[17] Here our bargaining environment differs from that of HM. The latter assume that bargaining can in principle go on forever, so that there is no last offer.

Next consider the problem of a worker who makes an offer in subperiod, j, where $j < M$ and j is even. The worker offers the highest possible wage, $w_{t,j}$, subject to the firm not rejecting it. The resulting wage offer, $w_{j,t}$, satisfies the indifference condition

$$J_{j,t} = \max\{0, \delta \times 0 + (1-\delta)[-\gamma_t + J_{j+1,t}]\}. \tag{19}$$

The left hand side of (19) denotes the value to a firm of accepting the wage offer $w_{j,t}$,

$$J_{j,t} = \frac{M-j+1}{M}\vartheta_t + \tilde{\vartheta}_t^p - (w_{j,t} + \tilde{w}_t^p), \tag{20}$$

where

$$\tilde{\vartheta}_t^p = \rho E_t m_{t+1} \vartheta_{t+1}^p. \tag{21}$$

The term multiplying ϑ_t in (20) reflects our assumption that a worker produces $1/M$ intermediate goods in each subperiod during which production occurs.

The expression on the right of the equality in (19) is the maximum over the firm's outside option (i.e., zero) and its disagreement payoff. We assume the firm's disagreement payoff exceeds its outside option, though in practice this must be verified. If the firm rejects the worker's offer with the intention of making a counteroffer, there is a probability, δ, that negotiations break down and both the worker and firm are sent to their outside options. With probability $1-\delta$ the firm makes a counteroffer, $w_{j+1,t}$, in the next subperiod that it (correctly) expects will be accepted. To make a counteroffer, the firm incurs a real cost, γ_t. The second expression in the square bracketed term in (19) is the value associated with a successful firm counteroffer, $w_{j+1,t}$.

Finally, consider subperiod M in which the worker makes the final, take-it-or-leave-it offer. The worker chooses the highest possible wage subject to the firm not rejecting it, which leads to the indifference condition

$$J_{M,t} = 0. \tag{22}$$

Here $J_{M,t}$ is (20) with $j = M$.

We now discuss the solution to the bargaining game. To this end, it is useful to note that $w_{j,t}$ and $\tilde{w}_t^p$ always appear as a sum in the indifference conditions, (16) and (19) (see (17) and (20)). Define

$$w_{j,t}^p \equiv w_{j,t} + \tilde{w}_t^p \tag{23}$$

for $j = 1, \dots, M$. We obtain $w_{M,t}^p$ by solving (22):

$$w_{M,t}^p = \vartheta_t / M + \tilde{\vartheta}_t^p.$$

Then (16) for $j = M - 1$ can be solved for w^p_{M-1} and (19) can be solved for w^p_{M-2}.[18] In this way, the indifference conditions can be solved uniquely to obtain

$$w^p_{1,t}, w^p_{2,t}, w^p_{3,t}, \dots, w^p_{M,t}, \tag{24}$$

conditional on variables that are exogenous to the worker–firm bargaining pair. The solution to the bargaining problem, w^p_t, is just $w^p_{1,t}$. The linearity of the indifference conditions gives rise to a simple closed-form expression for the solution,[19]

$$w^p_t = \frac{1}{\alpha_1 + \alpha_2}\left[\alpha_1 \vartheta^p_t + \alpha_2(U_t - A_t) + \alpha_3 \gamma_t - \alpha_4(\vartheta_t - D_t)\right], \tag{25}$$

where

$$\alpha_1 = 1 - \delta + (1 - \delta)^M, \quad \alpha_2 = 1 - (1 - \delta)^M,$$
$$\alpha_3 = \alpha_2 \frac{1 - \delta}{\delta} - \alpha_1, \quad \alpha_4 = \frac{1 - \delta}{2 - \delta}\frac{\alpha_2}{M} + 1 - \alpha_2.$$

It can be shown that α_1, α_2, α_3, and α_4, are strictly positive.

It is useful to observe that after rearranging the terms in (25) and making use of (8) and (11), (25) can be written as

$$J_t = \beta_1(V_t - U_t) - \beta_2 \gamma_t + \beta_3(\vartheta_t - D_t), \tag{26}$$

with $\beta_i = \alpha_{i+1}/\alpha_1$ for $i = 1, 2, 3$. We refer to (26) as the *alternating offer bargaining sharing rule*.

It is a standard result that the solution to the finite horizon AOB game is unique. Consistent with this observation, we see that for given $\tilde{w}^p_t$, ϑ_t, ϑ^p_t, U_t, A_t, and D_t, the real wage is uniquely determined by

$$w_t = w^p_t - \tilde{w}^p_t, \tag{27}$$

where w^p_t is defined in (25). In effect, we have defined a mapping from beliefs about future wages, summarized in $\tilde{w}^p_t$, to the present actual wage, w_t. We only consider equilibria in which the current actual wage and the believed future wages are the same time invariant functions of the contemporaneous state of the economy.

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[18] Recall our assumption that disagreement payoffs are no less than outside options.

[19] See the Appendix for a detailed derivation.

2.6. *Nash Bargaining Model*

It will be useful to contrast the quantitative implications of our model with one in which wages are determined according to a Nash sharing rule. Specifically, we define the *Nash bargaining model* as the version of our model in which we replace the AOB sharing rule (26) with the *Nash sharing rule*

$$J_t = \frac{1-\eta}{\eta}(V_t - U_t). \tag{28}$$

Here, η is the share of total surplus, $J_t + V_t - U_t$, received by the worker. The bargaining solution in both the Nash and AOB models takes the form of a static sharing rule. However, the two sharing rules are not nested. The Nash sharing rule obviously does not nest the AOB sharing rule. More subtly, the AOB sharing rule does not nest the Nash sharing rule. The reason is that, in general, for a given η in (28), one cannot find M, δ, and γ such that $\beta_1 = (1-\eta)/\eta$ and $\beta_2 = \beta_3 = 0$.[20] The nonnested nature of the sharing rules is the reason that we treat the two models as distinct.

2.7. *Present Value Bargaining*

The equilibrium allocations associated with period-by-period bargaining can also be supported by an alternative bargaining arrangement, which we call *present value bargaining*. Under this arrangement, a given firm–worker pair bargains only once, over w_t^p, when they first meet. It is straightforward to verify that if they pursue AOB, then the w_t^p that they agree on satisfies (25) or, equivalently, (26). Under Nash bargaining, w_t^p satisfies (28). Under these respective bargaining arrangements it is immaterial to the firms and workers how exactly the period-by-period wage rate is paid out, as long as it is consistent with the agreed-upon w_t^p. For example, in one scenario workers and firms simply agree to the constant flow nominal wage rate that is consistent with w_t^p.[21] In this scenario, the only workers who experience a wage change is the subset who start new jobs.

A potential problem with present value bargaining is that not all the state contingent wage payments that are consistent with an agreed-upon w_t^p are time consistent. For example, consider a scenario in which $w_t = w_t^p$ and the wage rate is zero thereafter. If bargaining were reopened at a later date, the

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[20] Binmore, Rubinstein, and Wolinsky (1986) describe a class of environments in which the Nash bargaining solution is the solution to AOB bargaining. Our bargaining environment is different and the Nash solution is nested in the AOB solution only in the special case $\eta = 1/2$. In this case, as $M \to \infty$, $\gamma, \delta \to 0$, $\gamma/\delta \to 0$, and $(1-\delta)^M \to 0$, then $\beta_1 \to 1$ and $\beta_2, \beta_3 \to 0$. For $\eta \neq 1/2$ we have not been able to find M, γ, and δ such that $\beta_1 = (1-\eta)/\eta$ and $\beta_2 = \beta_3 = 0$.

[21] See Pissarides (2009) and Shimer (2004) for a closely related discussion in simple search and matching models with no nominal frictions.

worker would no longer have an incentive to accept the previously agreed-upon zero wage rate. That is, in general, present value bargaining requires strong assumptions about agents' ability to commit. Under period-by-period bargaining we are able to avoid these assumptions. Moreover, w_t is uniquely determined so it is straightforward to incorporate wage data into our analysis.

2.8. *Market Clearing, Monetary Policy, and Functional Forms*

Market clearing in intermediate goods and in the services of capital requires

$$\int_0^1 h_{j,t}\,dj = l_t, \qquad u_t^K K_t = \int_0^1 k_{j,t}\,dj,$$

respectively. Market clearing for final goods requires

$$C_t + \big(I_t + a\big(u_t^K\big)K_t\big)/\Psi_t + (s_t/Q_t + \kappa_t)x_t l_{t-1} + G_t = Y_t, \tag{29}$$

where G_t denotes government consumption.

Perfect competition in the production of investment goods implies that the nominal price of investment goods equals the corresponding marginal cost:

$$P_{I,t} = P_t/\Psi_t.$$

Equality between the demand for loans by retailers, $h_t P_t^h$, and the supply by households, B_{t+1}/R_t, requires

$$h_t P_t^h = B_{t+1}/R_t.$$

The asset pricing kernel, m_{t+1}, is constructed using the marginal contribution of consumption to discounted utility, which we denote by λ_t:

$$m_{t+1} = \beta\lambda_{t+1}/\lambda_t.$$

We adopt the specification of monetary policy

$$\begin{aligned}\ln(R_t/R) = {} & \rho_R \ln(R_{t-1}/R) + (1-\rho_R)\big[r_\pi \ln(\pi_t/\bar{\pi}) + r_y \ln\big(\mathcal{Y}_t/\mathcal{Y}_t^*\big)\big] \\ & + \sigma_R \varepsilon_{R,t}.\end{aligned}$$

Here $\bar{\pi}$ denotes the monetary authority's inflation target. The monetary policy shock, $\varepsilon_{R,t}$, has unit variance and zero mean. Also, R is the steady state value of R_t. The variable, $\mathcal{Y}_t$, denotes gross domestic product (GDP),

$$\mathcal{Y}_t = C_t + I_t/\Psi_t + G_t,$$

and $\mathcal{Y}_t^*$ denotes the value of $\mathcal{Y}_t$ along the nonstochastic steady state growth path.

Working with the data from Fernald (2012) we find that the growth rate of total factor productivity is well described by an independent and identically distributed (i.i.d.) process. Accordingly, we assume that $\ln \mu_{z,t} \equiv \ln(z_t/z_{t-1})$ is i.i.d. We also assume that $\ln \mu_{\Psi,t} \equiv \ln(\Psi_t/\Psi_{t-1})$ follows a first order autoregressive process. The parameters that control the standard deviations of the innovations in both processes are denoted by σ_z and σ_Ψ, respectively. The autocorrelation of $\ln \mu_{\Psi,t}$ is denoted by ρ_Ψ.

The sources of growth in our model are neutral and investment-specific technological progress. Let

$$\Phi_t = \Psi_t^{\alpha/(1-\alpha)} z_t. \tag{30}$$

To guarantee balanced growth in the nonstochastic steady state, we require that each element in $[\phi_t, s_t, \kappa_t, \gamma_t, G_t, D_t]$ grows at the same rate as Φ_t in steady state. To this end, we adopt the specification[22]

$$[\phi_t, s_t, \kappa_t, \gamma_t, G_t, D_t]' = [\phi, s, \kappa, \gamma, G, D]' \Omega_t. \tag{31}$$

Here Ω_t is defined as

$$\Omega_t = \Phi_{t-1}^{\theta} (\Omega_{t-1})^{1-\theta}, \tag{32}$$

where $0 < \theta \leq 1$ is a parameter to be estimated. With this specification, Ω_t/Φ_{t-1} converges to a constant in nonstochastic steady state. When θ is close to zero, Ω_t is virtually unresponsive in the short run to an innovation in either of the two technology shocks, a feature that we find attractive on a priori grounds. Given the specification of the exogenous processes in the model, Y_t/Φ_t, C_t/Φ_t, w_t/Φ_t, and $I_t/(\Psi_t \Phi_t)$ converge to constants in nonstochastic steady state.

We assume that the cost of adjusting investment takes the form

$$\begin{aligned} S(I_t/I_{t-1}) = \frac{1}{2}\big(&\exp\big[\sqrt{S''}(I_t/I_{t-1} - \mu \times \mu_\Psi)\big] \\ &+ \exp\big[-\sqrt{S''}(I_t/I_{t-1} - \mu \times \mu_\Psi)\big]\big) - 1. \end{aligned}$$

Here μ and μ_Ψ denote the unconditional growth rates of Φ_t and Ψ_t. The value of I_t/I_{t-1} in nonstochastic steady state is $(\mu \times \mu_\Psi)$. In addition, S'' denotes the second derivative of $S(\cdot)$, evaluated at steady state. The object, S'', is a parameter to be estimated. It is straightforward to verify that $S(\mu \times \mu_\Psi) = S'(\mu \times \mu_\Psi) = 0$.

We assume that the cost associated with setting capacity utilization is given by

$$a(u_t^K) = \sigma_a \sigma_b (u_t^K)^2/2 + \sigma_b(1-\sigma_a) u_t^K + \sigma_b(\sigma_a/2 - 1),$$

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[22] Our specification follows Christiano, Trabandt, and Walentin (2012).

where σ_a and σ_b are positive scalars. For a given value of σ_a, we select σ_b so that the steady state value of u_t^K is unity. The object, σ_a, is a parameter to be estimated.

3. THE CALVO STICKY WAGE MODEL

We now describe a medium-sized DSGE model that incorporates the Calvo sticky wage framework of Erceg, Henderson, and Levin (2000). The final homogeneous good, Y_t, is produced by competitive and identical firms using the technology (3). The representative final good producer buys the jth specialized input, $Y_{j,t}$, from a monopolist who produces the input using the technology (5). Capital services are purchased in competitive rental markets. In (5), $h_{j,t}$ now refers to the quantity of a homogeneous labor input that the monopolist purchases from a representative labor contractor. The representative contractor produces the homogeneous labor input by combining differentiated labor inputs, $l_{i,t}$, $i \in (0, 1)$, using the technology

$$h_t = \left[\int_0^1 (l_{i,t})^{1/\lambda_w} \, di \right]^{\lambda_w}, \quad \lambda_w > 1. \tag{33}$$

Labor contractors are perfectly competitive and take the nominal wage rate, W_t, of h_t as given. They also take the wage rate, $W_{i,t}$, of the ith labor type as given. Profit maximization on the part of contractors implies

$$l_{i,t} = (W_t / W_{i,t})^{\lambda_w/(\lambda_w - 1)} h_t. \tag{34}$$

There is a continuum of households, each indexed by $i \in (0, 1)$. The ith household is the monopoly supplier of $l_{i,t}$ and chooses $W_{i,t}$ subject to (34) and Calvo wage-setting frictions. That is, the household optimizes the wage, $W_{i,t}$, with probability $1 - \xi_w$. With probability ξ_w, the wage rate is given by

$$W_{i,t} = W_{i,t-1}. \tag{35}$$

Note that we do not allow for indexation when households do not reoptimize.

With one exception, the ith household's budget constraint is given by (2). We replace $l_t W_t$ by $l_{i,t} W_{i,t} + A_{i,t}$. Here $A_{i,t}$ represents the net proceeds of an asset that provides insurance against the idiosyncratic uncertainty associated with the Calvo wage-setting friction. Apart from employment and $A_{i,t}$, the other choice variables in (2) need not be indexed by i because of household access to insurance and our specification of preferences:

$$\ln(C_t - bC_{t-1}) - \varkappa \frac{l_{i,t}^{1+\psi}}{1+\psi}, \quad \varkappa > 0, \psi \geq 0. \tag{36}$$

Interestingly, unemployment benefits have no effect in this model because they are financed by lump sum transfers and Ricardian equivalence holds in the model.

4. ECONOMETRIC METHODOLOGY

We estimate our model using a Bayesian variant of the strategy in CEE that minimizes the distance between the dynamic response to three shocks in the model and the analog objects in the data. The latter are obtained using an identified VAR for postwar quarterly U.S. time series that include key labor market variables. The particular Bayesian strategy that we use is the one developed in Christiano, Trabandt, and Walentin (2011a) (henceforth CTW).

To facilitate comparisons, our analysis is based on the same VAR as used in CTW who estimate a 14 variable VAR using quarterly data that are seasonally adjusted and cover the period 1951Q1–2008Q4. As in CTW, we identify the dynamic responses to a monetary policy shock by assuming that the monetary authority sees the contemporaneous values of all the variables in the VAR and a monetary policy shock affects only the Federal Funds Rate contemporaneously. As in Altig, Christiano, Eichenbaum, and Linde (2011), Fisher (2006), and CTW, we make two assumptions to identify the dynamic responses to the technology shocks: (i) the only shocks that affect labor productivity in the long run are the innovations to the neutral technology shock, z_t, and the innovation to the investment-specific technology shock, Ψ_t, and (ii) the only shock that affects the price of investment relative to consumption in the long run is the innovation to Ψ_t. These identification assumptions are satisfied in our model. Standard lag-length selection criteria lead CTW to work with a VAR with two lags.[23]

We include the following variables in the VAR:[24] $\Delta \ln$(relative price of investment), $\Delta \ln$(real GDP/hours), $\Delta \ln$(GDP deflator), unemployment rate, ln(capacity utilization), ln(hours), ln(real GDP/hours) − ln(real wage), ln(nominal C/nominal GDP), ln(nominal I/nominal GDP), ln(vacancies), job separation rate, job finding rate, ln(hours/labor force), Federal Funds rate.

Given an estimate of the VAR we can compute the implied impulse response functions to the three structural shocks. We stack the contemporaneous and 14 lagged values of each of these impulse response functions for 12 of the VAR variables in the $N \times 1$ vector, $\hat{\psi}$. We do not include the job separation rate and the size of the labor force because our model assumes those variables are constant. We include these variables in the VAR to ensure the VAR results are not driven by an omitted variable bias.

The logic underlying our model estimation procedure is as follows. Suppose that our structural model is true. Denote the true values of the model parameters by θ_0. Let $\psi(\theta)$ denote the model-implied mapping from a set of values for the model parameters to the analog impulse responses in $\hat{\psi}$. Thus, $\psi(\theta_0)$ denotes the true value of the impulse responses whose estimates appear in $\hat{\psi}$.

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[23] See CTW for a sensitivity analysis with respect to the lag length of the VAR.

[24] See the technical appendix in CTW for details about the data.

According to standard classical asymptotic sampling theory, when the number of observations, T, is large, we have

$$\sqrt{T}\big(\hat{\psi} - \psi(\theta_0)\big) \overset{a}{\sim} N\big(0, W(\theta_0, \zeta_0)\big).$$

Here ζ_0 denotes the true values of the parameters of the shocks in the model that we do not formally include in the analysis. Because we solve the model using a log-linearization procedure, $\psi(\theta_0)$ is not a function of ζ_0. However, the sampling distribution of $\hat{\psi}$ is a function of ζ_0. We find it convenient to express the asymptotic distribution of $\hat{\psi}$ in the form

$$\hat{\psi} \overset{a}{\sim} N\big(\psi(\theta_0), V\big), \tag{37}$$

where

$$V \equiv W(\theta_0, \zeta_0)/T.$$

For simplicity our notation does not make the dependence of V on θ_0, ζ_0, and T explicit. We use a consistent estimator of V. Motivated by small sample considerations, this estimator has only diagonal elements (see CTW). The elements in $\hat{\psi}$ are graphed in Figures 1–3 (see the solid lines). The gray areas are centered, 95 percent probability intervals computed using our estimate of V.

In our analysis, we treat $\hat{\psi}$ as the observed data. We specify priors for θ and then compute the posterior distribution for θ given $\hat{\psi}$ using Bayes' rule. This computation requires the likelihood of $\hat{\psi}$ given θ. Our asymptotically valid approximation of this likelihood is motivated by (37):

$$f(\hat{\psi}|\theta, V) = (2\pi)^{-N/2}|V|^{-1/2}\exp\big[-0.5\big(\hat{\psi} - \psi(\theta)\big)'V^{-1}\big(\hat{\psi} - \psi(\theta)\big)\big]. \tag{38}$$

The value of θ that maximizes the above function represents an approximate maximum likelihood estimator of θ. It is approximate for three reasons: (i) the central limit theorem underlying (37) only holds exactly as $T \to \infty$, (ii) our proxy for V is guaranteed to be correct only for $T \to \infty$, and (iii) $\psi(\theta)$ is calculated using a linear approximation.

Treating the function, f, as the likelihood of $\hat{\psi}$, it follows that the Bayesian posterior of θ conditional on $\hat{\psi}$ and V is

$$f(\theta|\hat{\psi}, V) = \frac{f(\hat{\psi}|\theta, V)p(\theta)}{f(\hat{\psi}|V)}. \tag{39}$$

Here, $p(\theta)$ denotes the prior distribution of θ and $f(\hat{\psi}|V)$ denotes the marginal density of $\hat{\psi}$:

$$f(\hat{\psi}|V) = \int f(\hat{\psi}|\theta, V)p(\theta)\,d\theta.$$

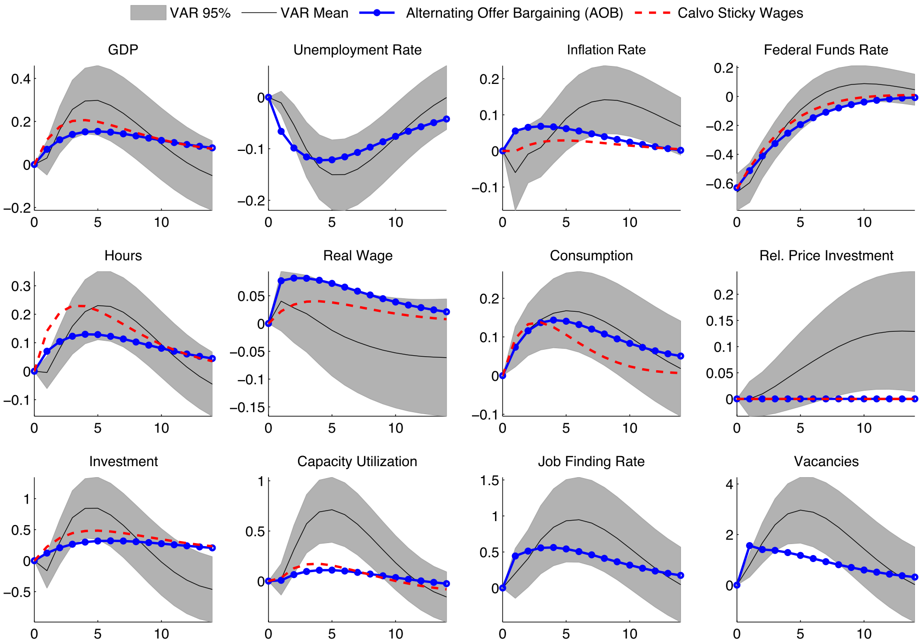

FIGURE 1.—Responses to a monetary policy shock: AOB vs. Calvo. x-axis in quarters; y-axis for inflation and federal funds rate in annual percentage points, for unemployment rate and job finding rate in percentage points, and for all other variables in percent.

The mode of the posterior distribution of θ can be computed by maximizing the value of the numerator in (39), since the denominator is not a function of θ. We compute the posterior distribution of the parameters using a standard Monte Carlo Markov chain (MCMC) algorithm.

We evaluate the relative empirical performance of different models by comparing their implication for the marginal likelihood of $\hat{\psi}$. To compute a marginal likelihood, we use Geweke's modified harmonic mean procedure. For an analysis of the validity of this approach to comparing models, see Inoue and Shintani (2015).

5. EMPIRICAL RESULTS FOR SEARCH AND MATCHING MODELS

In this section we present the empirical results for our search and matching models. The first subsection discusses the a priori restrictions that we impose on the models. The next two subsections report estimation results for the AOB and Nash bargaining models, respectively.

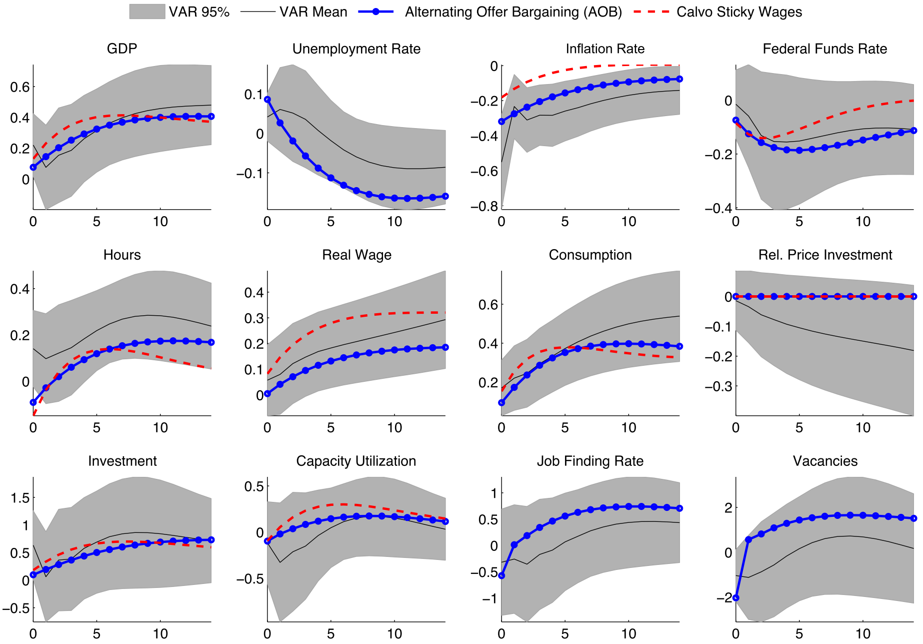

FIGURE 2.—Responses to a neutral technology shock: AOB vs. Calvo. x-axis in quarters; y-axis for inflation and federal funds rate in annual percentage points, for unemployment rate and job finding rate in percentage points, and for all other variables in percent.

5.1. *Parameter and Steady State Restrictions*

Some model parameter values were set a priori. See Panel A of Table I. We specify β so that the steady state annual real rate of interest is 3 percent. The depreciation rate on capital, δ_K, is set to imply an annual depreciation rate of 10 percent. The values of μ and μ_Ψ are determined by the sample average of real per capita GDP and real investment growth. We set the parameter M to 60, which roughly corresponds to the number of business days in a quarter. This assumption is consistent with HM, who assume that it takes 1 day to counter an offer. We set $\rho = 0.9$, which implies a match survival rate that is consistent with the values used in HM, Shimer (2012), and Walsh (2003). We discuss the parameters ξ_w and λ_w, which pertain to the sticky wage model, below.

We choose values for five model parameters, σ_m, γ, ϕ, G, and $\bar{\pi}$, so that, conditional on the other parameters, the model satisfies the five steady state targets listed in Panel B in Table I. Following den Haan, Ramey, and Watson (2000) and Ravenna and Walsh (2008), the target for the steady state vacancy filling rate, Q, is 0.7. The steady state unemployment rate is 5.5 percent, which corresponds to the average unemployment rate in our sample. The profits of wholesalers are zero in steady state, the steady state ratio of government consumption to gross output is 0.2, and steady state inflation, π, is 2.5 percent.

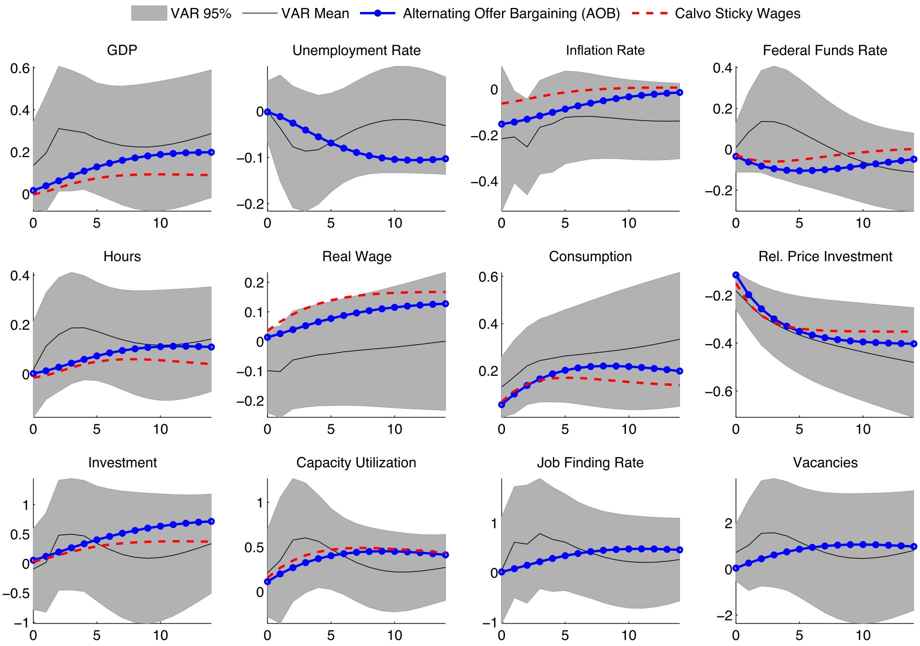

FIGURE 3.—Responses to an investment-specific technology shock: AOB vs. Calvo. x-axis in quarters; y-axis for inflation and federal funds rate in annual percentage points, for unemployment rate and job finding rate in percentage points, and for all other variables in percent.

TABLE I

NON-ESTIMATED PARAMETERS AND CALIBRATED VARIABLES

Parameter	Value	Description
		Panel A: Parameters
δ_K	0.025	Depreciation rate of physical capital
β	0.9968	Discount factor
ρ	0.9	Job survival probability
M	60	Max. bargaining rounds per quarter (alternating offer model)
λ_w	1.2	Wage markup parameter (Calvo sticky wage model)
ξ_w	0.75	Wage stickiness (Calvo sticky wage model)
$400\ln(\mu)$	1.7	Annual output per capita growth rate
$400\ln(\mu \cdot \mu_\Psi)$	2.9	Annual investment per capita growth rate
		Panel B: Steady State Values
$400(\pi - 1)$	2.5	Annual net inflation rate
Profits	0	Intermediate goods producers profits
Q	0.7	Vacancy filling rate
u	0.055	Unemployment rate
G/Y	0.2	Government consumption to gross output ratio

5.2. *AOB Model Results*

Table III reports the mean and 95 percent probability intervals for the priors and posteriors of the parameters in the AOB model. Several features are worth noting. First, the posterior mode of ξ implies a reasonable degree of price stickiness, with prices changing on average once every four quarters.

Second, the posterior mode of δ implies that there is a roughly 0.2 percent chance of an exogenous breakup in negotiations when a wage offer is rejected. Our estimate of δ is somewhat lower than HM's calibrated value for δ of 0.55 percent.

Third, the posterior mode of our model parameters imply that it costs roughly 0.6 of one day's revenue for a firm to prepare a counteroffer to a worker (see the bottom of Table II).

Fourth, the fixed cost component of hiring accounts for the lion's share of the total cost of meeting a worker. Table III reports the posterior mode values of

$$\eta_s = \frac{svl}{Y}, \quad \eta_h = \frac{\kappa x l}{Y}.$$

TABLE II

STEADY STATES AND IMPLIED PARAMETERS AT ESTIMATED POSTERIOR MODE IN STRUCTURAL ALTERNATING OFFER BARGAINING AND NASH BARGAINING MODELS

Variable	Alternating Offer Bargaining	Nash Bargaining	Description
K/Y	7.35	6.64	Capital to gross output ratio (quarterly)
C/Y	0.56	0.58	Consumption to gross output ratio
I/Y	0.24	0.21	Investment to gross output ratio
l	0.945	0.945	Steady state labor input
R	1.014	1.014	Gross nominal interest rate (quarterly)
R^{real}	1.0075	1.0075	Gross real interest rate (quarterly)
mc	0.70	0.70	Marginal cost (inverse markup)
σ_b	0.036	0.036	Capacity utilization cost parameter
Y	1.18	1.06	Gross output
f	0.63	0.63	Job finding rate
ϑ	0.91	0.84	Marginal revenue of wholesaler
x	0.1	0.1	Hiring rate
J	0.06	0.07	Value of firm
V	271.2	258.4	Value of work
U	270.4	258.2	Value of unemployment
v	0.14	0.14	Vacancy rate
w	0.90	0.84	Real wage
$\bar{\pi}$	2.5	2.5	Inflation target (annual percent)
ϕ/Y	0.42	0.43	Fixed cost to gross output ratio
σ_m	0.66	0.66	Level parameter in matching function
η	–	0.67	Total surplus share received by workers
$\gamma/(\vartheta/M)$	0.59	–	Counteroffer costs as share of daily revenue

TABLE III

PRIORS AND POSTERIORS OF PARAMETERS: STRUCTURAL WAGE SETTING MODELS[a]

		Posterior Distribution **Mode**, [2.5–97.5%]		
	Prior Distribution $\mathcal{D}$, **Mode**, [2.5–97.5%]	Alternating Offer Bargaining	Nash Bargaining	Calvo Sticky Wages[b]
	Price Setting Parameters			
Price stickiness, ξ	$\mathcal{B}$, **0.68**, [0.45–0.84]	**0.75**, [0.69–0.78]	**0.74**, [0.69–0.79]	**0.74**, [0.67–0.77]
Price markup parameter, λ	$\mathcal{G}$, **1.19**, [1.11–1.31]	**1.42**, [1.33–1.51]	**1.43**, [1.35–1.52]	**1.24**, [1.14–1.31]
	Monetary Authority Parameters			
Taylor rule: smoothing, ρ_R	$\mathcal{B}$, **0.76**, [0.37–0.94]	**0.84**, [0.81–0.87]	**0.84**, [0.82–0.87]	**0.77**, [0.75–0.81]
Taylor rule: inflation, r_π	$\mathcal{G}$, **1.69**, [1.42–2.00]	**1.38**, [1.21–1.65]	**1.38**, [1.23–1.69]	**2.02**, [1.82–2.39]
Taylor rule: GDP, r_y	$\mathcal{G}$, **0.08**, [0.03–0.22]	**0.03**, [0.01–0.07]	**0.04**, [0.02–0.08]	**0.01**, [0.00–0.02]
	Preferences and Technology Parameters			
Consumption habit, b	$\mathcal{B}$, **0.50**, [0.21–0.79]	**0.80**, [0.78–0.84]	**0.81**, [0.78–0.84]	**0.68**, [0.65–0.74]
Capacity utilization adjustment cost, σ_a	$\mathcal{G}$, **0.32**, [0.09–1.23]	**0.11**, [0.04–0.30]	**0.18**, [0.05–0.32]	**0.03**, [0.01–0.16]
Investment adjustment cost, S''	$\mathcal{G}$, **7.50**, [4.57–12.4]	**15.7**, [11.0–19.6]	**15.2**, [10.7–19.0]	**5.03**, [4.15–7.95]
Capital share, α	$\mathcal{B}$, **0.33**, [0.28–0.38]	**0.26**, [0.20–0.27]	**0.23**, [0.21–0.27]	**0.33**, [0.27–0.34]
Technology diffusion, θ	$\mathcal{B}$, **0.50**, [0.13–0.87]	**0.05**, [0.02–0.07]	**0.03**, [0.01–0.05]	**0.04**, [0.02–0.86]
	Labor Market Parameters			
Prob. bargaining breakup, 100δ	$\mathcal{G}$, **0.18**, [0.04–1.53]	**0.19**, [0.09–0.37]		
Replacement ratio, D/w	$\mathcal{B}$, **0.39**, [0.21–0.60]	**0.37**, [0.22–0.63]	**0.88**, [0.85–0.90]	
Hiring fixed cost/output, $100\eta_h$	$\mathcal{G}$, **0.91**, [0.50–1.67]	**0.46**, [0.24–0.84]	**0.64**, [0.34–1.07]	
Vacancy cost/output, $100\eta_s$	$\mathcal{G}$, **0.05**, [0.01–0.28]	**0.03**, [0.00–0.12]	**0.02**, [0.00–0.09]	
Matching function parameter, σ	$\mathcal{B}$, **0.50**, [0.31–0.69]	**0.55**, [0.47–0.61]	**0.54**, [0.47–0.61]	
Inverse labor supply elasticity, ψ	$\mathcal{G}$, **0.94**, [0.57–1.55]			**0.92**, [0.33–1.01]

(*Continues*)

TABLE III—*Continued*

		Posterior Distribution **Mode**, [2.5–97.5%]		
	Prior Distribution $\mathcal{D}$, **Mode**, [2.5–97.5%]	Alternating Offer Bargaining	Nash Bargaining	Calvo Sticky Wages[b]
	Exogenous Processes Parameters			
Standard deviation monetary policy, $400\sigma_R$	$\mathcal{G}$, **0.65**, [0.56–0.75]	**0.63**, [0.57–0.70]	**0.63**, [0.58–0.70]	**0.64**, [0.57–0.71]
Standard deviation neutral technology, $100\sigma_{\mu_z}$	$\mathcal{G}$, **0.08**, [0.03–0.22]	**0.16**, [0.11–0.19]	**0.14**, [0.11–0.18]	**0.32**, [0.28–0.35]
Standard deviation investment technology, $100\sigma_\Psi$	$\mathcal{G}$, **0.08**, [0.03–0.22]	**0.12**, [0.08–0.15]	**0.11**, [0.08–0.16]	**0.15**, [0.12–0.19]
AR(1) investment technology, ρ_Ψ	$\mathcal{B}$, **0.75**, [0.53–0.92]	**0.72**, [0.60–0.85]	**0.74**, [0.59–0.83]	**0.57**, [0.44–0.66]
	Memo Items			
Log marginal likelihood (MCMC, 12 observables)		286.7	272.9	
Log marginal likelihood (MCMC, 9 observables[c])				262.6

[a] For model specifications where particular parameter values are not relevant, the entries in this table are blank. Posterior mode and parameter distributions are based on a standard MCMC algorithm with a total of 10 million draws (11 chains; 50 percent of draws used for burn-in; draw acceptance rates about 0.24). The $\mathcal{B}$ and $\mathcal{G}$ denote beta and gamma distributions, respectively.

[b] Calvo sticky wage model as in Erceg, Henderson, and Levin (2000).

[c] Data set excludes unemployment, vacancies and job finding rates.

Here, η_s and η_h denote the share of vacancy posting costs and hiring fixed costs to gross output in steady state, respectively. The fixed cost component of meeting a worker, expressed as a percent of the total cost, is[25]

$$\frac{\eta_h}{\eta_h + \eta_s} = 0.94.$$

The importance of hiring fixed costs is consistent with microevidence reported in Yashiv (2000), Cheremukhin and Restrepo-Echavarria (2010), and Carlsson, Eriksson, and Gottfries (2013).[26]

Krause and Lubik (2007) argue, in a calibrated model with $\kappa = 0$, that inertial real wages do not help make marginal costs acyclical. The reason is that, in their model, the cost of hiring goes up dramatically in a boom as the labor market tightens. So even with inertial real wages, the marginal cost of hiring and of production are strongly procyclical when $\kappa = 0$. This logic does not apply in our model where most of the costs of hiring reflect κ.

Fifth, in steady state the total cost associated with hiring a new worker is roughly 7 percent of the wage rate. That is,

$$\frac{\frac{s}{Q} + \kappa}{w} = \frac{\eta_s + \eta_h}{1 - \rho} \frac{Y}{wl} = 0.068.$$

Silva and Toledo (2009) report that, depending on the exact costs included, the value of this statistic is between 4 and 14 percent, a range that encompasses our estimate.

Sixth, the prior mode of the replacement ratio, D/w, is roughly 0.4. Based on studies of unemployment insurance, HM report a range of estimates for the replacement ratio between 0.1 and 0.4. Based on their summary of the literature, Gertler, Sala, and Trigari (2008) argue that a plausible upper bound for the replacement ratio is 0.7 when one takes informal sources of insurance into account. Our prior mode for D/w is roughly in the middle of all these estimates. According to Table III the prior and posterior distributions of D/w are quite similar. We interpret this result as indicating that the replacement ratio does not play a critical role in the AOB model's ability to account for the data. A corollary of this result is that identification of D/w must come from microeconomic data.

Seventh, the posterior mode of θ, which governs the responsiveness of $[\phi_t, \kappa_t, \gamma_t, G_t, s_t, D_t]$ to technology shocks, is small (0.05) and the associated

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[25] Here we have used the facts $v = x/Q$ and that the cost of meeting a worker is, by (10), equal to $s/Q + \kappa$.

[26] Using different models estimated on macrodata of various countries, Christiano, Trabandt, and Walentin (2011b), Furlanetto and Groshenny (2012), and Justiniano and Michelacci (2012) also conclude that hiring fixed costs are important relative to the vacancy posting cost.

probability interval is quite tight. So these variables are quite unresponsive in the short run to technology shocks. A large value of θ would make γ_t and D_t rise by more after a positive technology shock. But this would imply a larger rise in the real wage rate and induce counterfactual implications for hours worked and inflation.

Eighth, the posterior mode of the parameters governing monetary policy are similar to those reported in the literature (see for example Christiano, Trabandt, and Walentin (2011a)).

Ninth, the posterior mode of the markup is roughly 42 percent, which is higher than the 20 percent estimate in the benchmark model reported in CEE, which assumes dynamic price indexation. By that we mean firms that do not reoptimize their current period price, adjust that price by the aggregate inflation rate realized in the previous period. In contrast, the point estimate of the markup is roughly 40 percent when CEE estimate a version of their model with static price indexation. By that we mean firms that do not reoptimize their current period price, adjust that price by the steady state inflation rate. This version of the model seems most comparable to ours, in which there is no indexation at all.

Tenth, the posterior mode of the investment adjustment cost parameter, S'', is 15.5. To interpret this parameter, CEE work with a log-linear approximation of the Euler equation associated with the household investment decision. They show that the elasticity of investment to a temporary, 1 percent, shock in the price of installed capital, $P_{k'}$, is $1/S''$. In our context, this elasticity is equal to 0.06 percent. The analog elasticity to a permanent 1 percent jump in $P_{k'}$ is $1/[(1-\beta)S'']$ or 9 percent.

Eleventh, the posterior model of the habit parameter, b, is 0.80. High values of this parameter emerge generically in estimated New Keynesian (NK) dynamic stochastic general equilibrium (DSGE) models (see, e.g., CEE and Smets and Wouters (2007)). A high value of b allows the model to accommodate the two features of the estimated responses to a time t expansionary monetary policy shock. First, such a shock leads to a hump-shaped rise in consumption. Second, while consumption is rising, the interest rate is falling. If $b = 0$, our model cannot generate the hump shape, nor can it accommodate the negative comovement between the real interest rate and consumption. Indeed, a fall in the real interest rate would be associated with a *fall* in the expected growth rate of consumption.

Twelfth, the posterior mode of the utilization cost parameter, σ_a, is 0.11. CEE show that $1/\sigma_a$ can be interpreted as the elasticity of capital utilization with respect to the rental rate of capital.

The solid black lines in Figures 1–3 display VAR-based estimates of impulse responses to a monetary policy shock, a neutral technology shock, and an investment-specific technology shock, respectively. The grey areas represent 95 percent probability intervals. The solid lines with the circles correspond to the impulse response functions of the AOB model evaluated at the posterior mode of the estimated parameters.

Figure 1 shows that the AOB model does reasonably well at reproducing the estimated effects of an expansionary monetary policy shock, including the hump-shaped rise of real GDP and hours worked as well as the muted response of inflation. Notice that real wages respond by less than hours to the monetary policy shock. Even though the maximal rise in hours worked is roughly 0.13 percent, the maximal rise in real wages is only 0.08 percent. Significantly, the model accounts for the hump-shaped fall in the unemployment rate as well as the rise in the job finding rate and vacancies that follow in the wake of an expansionary monetary policy shock. The model does understate the rise in the capacity utilization rate. The sharp rise of capacity utilization in the estimated VAR may reflect that our capacity utilization rate data pertain to the manufacturing sector, which may overstate the average response across all sectors in the economy.

The basic intuition for how a monetary policy shock affects the economy in the AOB model is as follows. As in standard New Keynesian models, an expansionary monetary policy shock drives the real interest rate down, inducing an increase in the demand for final goods. This rise induces an increase in the demand for the output of sticky price retailers. Since they must satisfy demand, the retailers purchase more of the wholesale good. Therefore, the relative price of the wholesale good increases and the marginal revenue product, ϑ_t, associated with a worker rises. Other things equal, this rise motivates wholesalers to hire more workers and thus increases the probability that an unemployed worker finds a job. The latter effect induces a rise in workers' disagreement payoffs. The resulting increase in workers' bargaining power generates a rise in the real wage. Given our estimated parameter values, alternating offer bargaining generates a moderate increase in real wages, a large rise in employment, a substantial decline in unemployment, and a small rise in inflation. If there was a large, persistent rise in the real wage, the model would generate a counterfactually large rise in inflation. The reason is that real wages are a key component of firms' real marginal costs. Firms that have a chance to reset prices set those prices as an increasing function of current and expected future real marginal cost. So to account for the observed cyclical behavior of inflation, it is critical for the model to generate small cyclical movements in marginal cost.

From Figure 2 we see that the model also does a good job of accounting for the estimated effects of a neutral technology shock. Of particular note is that the model reproduces the estimated sharp fall in the inflation rate that occurs after a positive neutral technology shock.[27] For inflation to fall sharply, there must be a sharp drop in marginal cost. This in turn requires that the rise in the real wage that occurs after a technology shock is small. As Fig-

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[27] For additional evidence that inflation responds more strongly to technology shocks than to monetary policy shocks, see Paciello (2011).

ure 2 shows, the AOB model has this property. Below, we argue that the ability to account for the sharp fall in inflation after a technology shock is useful for discriminating between different models. Also, the model generates a sharp fall in the unemployment rate along with a large rise in job vacancies and the job finding rate. So the estimated AOB model is not subject to Shimer's (2005) critique of search and matching models with low replacement rates.

Figure 3 shows that the model also does a good job of accounting for the estimated response of the economy to an investment-specific technology shock.

Finally, to get a sense of which features of the data help to identify the bargaining parameters, (δ, γ), and the parameters governing the matching technology, (σ, s, κ), we proceeded as follows. We recomputed the impulse response functions for the estimated AOB model, perturbing each parameter one at a time. The results are displayed in the Appendix. We found that the impulse responses to the monetary policy shock are the most sensitive to the perturbations. This result suggests that most of the information about these parameters comes from the monetary policy impulse responses. The response of inflation, real wages, the job finding rate, and, to a lesser extent, the unemployment rate and GDP, are particularly sensitive to perturbations in δ, γ, s, and κ. The response of vacancies to a monetary policy shock is very sensitive to a perturbation in σ.

5.3. *Nash Bargaining Model Results*

When we estimated the Nash bargaining model, the resulting impulse response functions are virtually identical to the ones implied by the estimated AOB model. For this reason, we do not report the Nash bargaining model's impulse response functions in Figures 1–3. Priors and posteriors for the model parameters are reported in Table III. With one important exception, the posterior mode values of the parameters that the Nash bargaining and AOB models share in common are basically the same. The important exception is the replacement ratio, D/w. The posterior mode for D/w is 0.88 in the Nash bargaining model versus 0.37 in the AOB model. In both cases, the posterior probability intervals are very tight, with no overlap. Two other parameter estimates come out slightly different: the curvature on the capacity utilization adjustment cost function, σ_a, and the share of hiring fixed cost, η_h.

There is a substantial 14 log point difference in the marginal likelihood between the two models because the Nash bargaining model must reach far into the right tail of the prior distribution for D/w to match the impulse response functions. This is easily seen using the Laplace approximation, $\mathcal{L}$, of the log marginal likelihood,[28]

$$\mathcal{L} = \ln f\big(\hat{\psi}|\theta^{*}, V\big) - \ln\big[(2\pi)^{-N}\big|G_{\theta\theta}\big(\theta^{*}\big)\big|^{1/2}\big] + \ln p\big(\theta^{*}\big), \tag{40}$$

where θ^{*} denotes the mode of the posterior distribution of θ and $G_{\theta\theta}$ denotes the Hessian of the log posterior distribution.[29] The other variables in (40) are defined in Section 4.

We compute (40) for both the AOB model and the Nash bargaining model. It turns out that the log likelihoods, $\ln f(\hat{\psi}|\theta^{*}, V)$, of the two models are essentially the same: 344.6 and 343.9 in the case of the AOB and Nash bargaining model, respectively. The object in square brackets in (40) is also roughly the same for the two models. Thus, the 14 log point gap between the AOB and Nash bargaining models is due to the difference in the prior term, $\ln p$, evaluated at posterior modes, θ^{*}, of the two models. Most of that difference is due to the implausibly high value of D/w (0.88) that the Nash bargaining model needs so as to account for the data.

The high value of D/w is critical to the performance of the Nash bargaining model. To make this observation precise we begin by recalculating the impulse response functions implied by the Nash bargaining model making only one change: we reparameterize the replacement ratio, D/w, from 0.88 to 0.37, where the latter value is the posterior mode of D/w in the estimated AOB model. The dashed lines in Figures 4–6 are the impulse response functions corresponding to this reparameterized Nash bargaining model, while the solid lines with circles depict the impulse responses of the Nash bargaining model evaluated at the estimated posterior mode with D/w equal 0.88.

Figure 4 shows that this one change leads to a dramatic deterioration in the performance of the Nash bargaining model. All of the quantity variables like hours worked and real GDP as well as unemployment are now much less responsive to a monetary policy shock. In contrast, the real wage and inflation respond by too much relative to the VAR-based impulse response functions. Figures 5 and 6 reveal a similar pattern with respect to the technology shocks. Consistent with the results in Shimer (2005), the Nash bargaining model with the lower replacement ratio generates very small changes in the unemployment rate after a neutral technology shock. Significantly, this version of the model also generates counterfactually large movements in inflation. However these shortcomings are remedied by a higher value of D/w. With respect to unemployment, this finding is reminiscent of Hagedorn and Manovskii's (2008)

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[28] This approximation appears to be an excellent one in our application. When we use the MCMC algorithm to compute the log likelihood for the AOB, Nash bargaining, and the Calvo sticky wage model discussed in Section 6.3 below, we obtain the values 286.7, 272.9, and 262.6, respectively (see Table III). The corresponding values computed using the Laplace approximation are 286.5, 272.6, and 262.3, respectively.

[29] See, for example, Christiano, Trabandt, and Walentin (2011a).

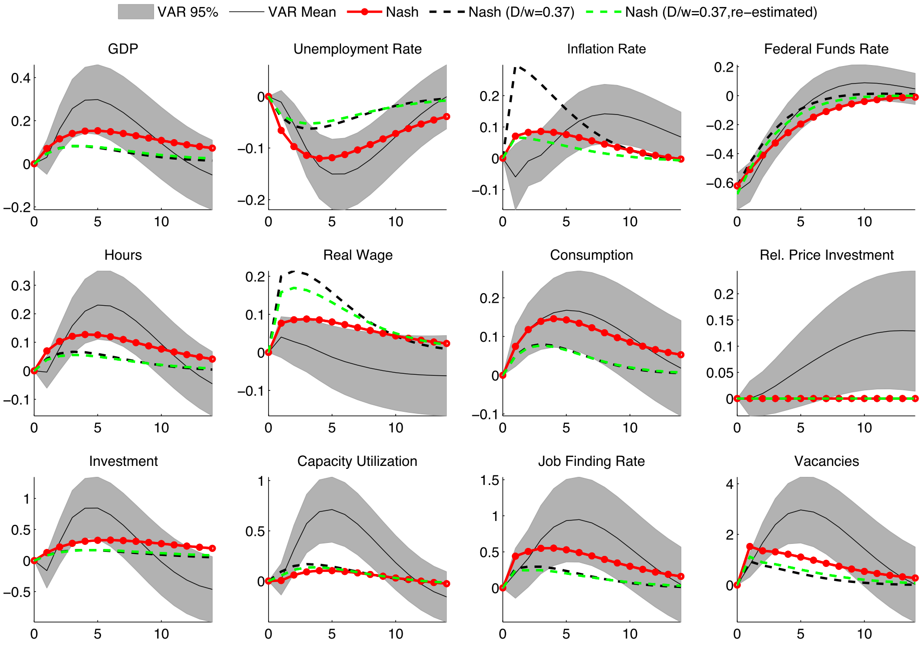

FIGURE 4.—Responses to a monetary policy shock: Nash bargaining. x-axis in quarters; y-axis for inflation and federal funds rate in annual percentage points, for unemployment rate and job finding rate in percentage points, and for all other variables in percent.

argument that a high replacement ratio has the potential to boost the volatility of unemployment and vacancies in search and matching models with Nash bargaining.

To further assess the role played by D/w, we reestimated the Nash bargaining model holding the value of D/w fixed at 0.37. The marginal likelihood of the Nash bargaining model with $D/w = 0.37$ is a dramatic 126 log points lower than the marginal likelihood in the estimated AOB model.[30] The dashed–dotted lines in Figures 4–6 correspond to the impulse response functions associated with this version of the Nash bargaining model. Figure 4 indicates that this model cannot account for the rise in output, hours worked, consumption, investment, vacancies, and the job finding rate that occur after an expansionary monetary policy shock. Just as importantly, the model implies that real wages rise in a counterfactual manner after such a shock. While less dramatic, Figures 5 and 6 show that the model's performance with respect to the technology shocks also deteriorates. Taken together, our results indicate that empirically plausible versions of the Nash bargaining model must assume a very high value of D/w.

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[30] The full set of parameter estimates is available upon request from the authors.

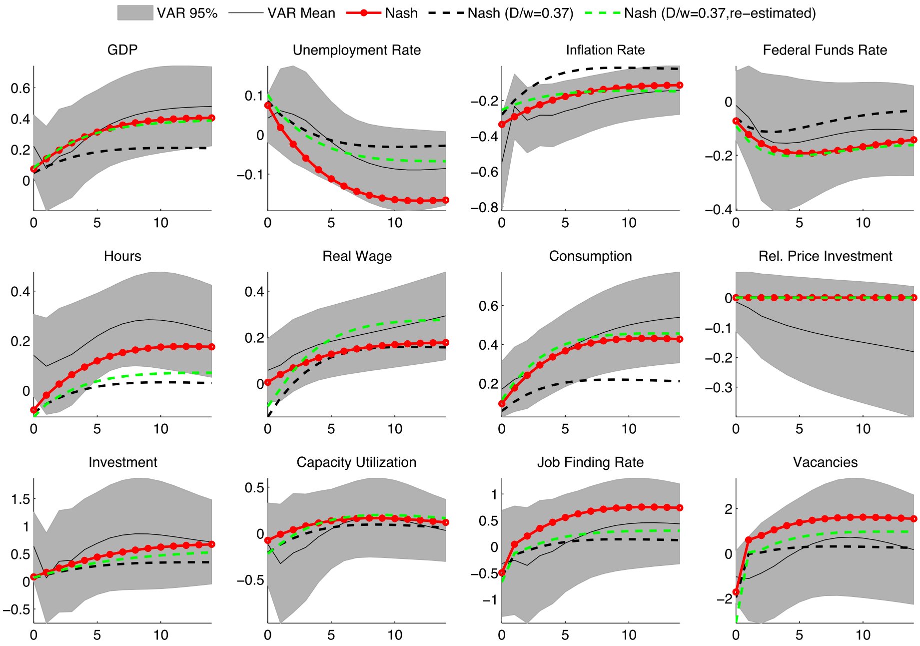

FIGURE 5.—Responses to a neutral technology shock: Nash bargaining. x-axis in quarters; y-axis for inflation and federal funds rate in annual percentage points, for unemployment rate and job finding rate in percentage points, and for all other variables in percent.

6. ASSESSING THE SEARCH AND MATCHING MODELS AGAINST ALTERNATIVES

In our search and matching model, the real wage is the solution to a bargaining problem, the implications of which are fully summarized in the sharing rule. The next subsection reports the results of estimating our model with a reduced form sharing rule that nests the AOB and Nash sharing rules as special cases. The second subsection below reports the results of replacing the sharing rule with two alternative wage rules: (i) a general wage rule that makes the date t real wage a log-linear function of all of the model's date t state variables, and (ii) motivated by the results in (i) we consider an easy-to-interpret simple wage rule that summarizes the key characteristics of the general wage rule. In the final subsection, we consider how the performance of our model compares with that of the standard empirical New Keynesian model with Calvo sticky wages.

6.1. *The Reduced Form Sharing Rule Model*

Consider the reduced form sharing rule

$$(41)\qquad J_t = \epsilon_1(V_t - U_t) - \epsilon_2\Omega_t + \epsilon_3(\vartheta_t - D_t),$$

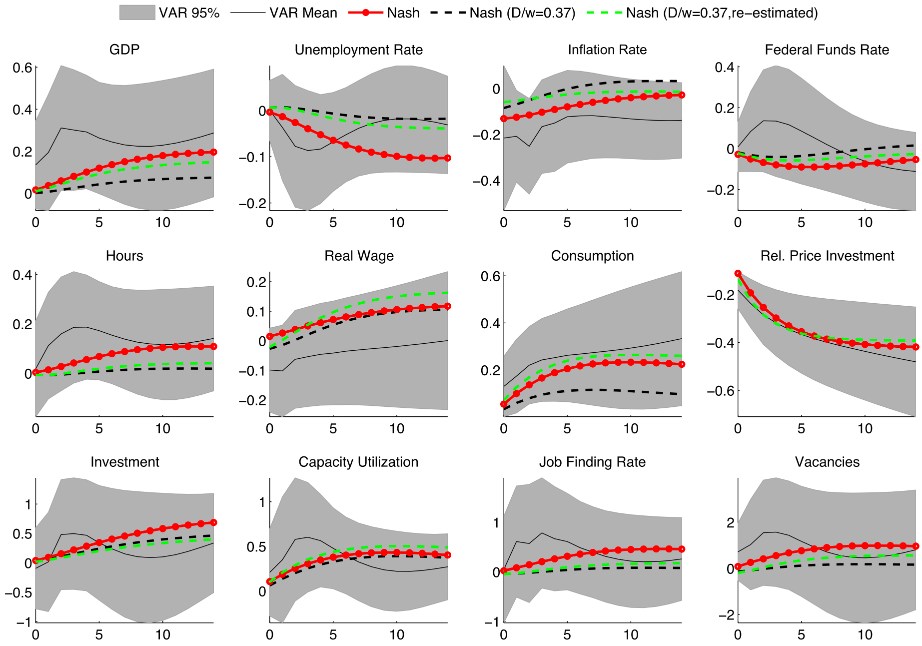

FIGURE 6.—Responses to an investment-specific technology shock: Nash bargaining. x-axis in quarters; y-axis for inflation and federal funds rate in annual percentage points, for unemployment rate and job finding rate in percentage points, and for all other variables in percent.

where Ω_t is defined in (32). We define the *reduced form sharing rule model* as the version of our model in which the sharing rule is given by (41) and the ϵ_i's are unrestricted. The reduced form sharing rule model nests, as special cases, the AOB and Nash models. In the AOB model, $\epsilon_1 = \beta_1$, $\epsilon_2 = \beta_2\gamma$, and $\epsilon_3 = \beta_3$. Here β_1, β_2, and β_3 are the functions of δ and M defined after (26). In the Nash model, $\epsilon_1 = (1-\eta)/\eta$ and $\epsilon_2 = \epsilon_3 = 0$. By comparing the estimated values of the sharing rule coefficients of the three models, we can assess the plausibility of the Nash and AOB models.

To maximize the impact of the data on inference about the ϵ_i's, we adopt uniform priors on these parameters. The upper (lower) bound of the uniform distribution is 3 times (−1 times) the mode of the posterior distribution on ϵ_i, $i = 1, 2, 3$, when we estimate the AOB model. We estimate the model with the reduced form sharing rule using the same priors for the other parameters as in the estimated AOB model (see Table III). Our results are reported in Table IV.[31]

Panels A and B report the mode and a 95 percent probability interval implied by the posterior distribution of ϵ_1, ϵ_2, and ϵ_3 in the AOB and Nash models, re-

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[31] A full set of parameter estimates is available upon request from the authors.

TABLE IV

AOB, NASH VERSUS REDUCED FORM SHARING RULE AT POSTERIOR MODES

Sharing Rule: $J_t = \epsilon_1(V_t - U_t) - \epsilon_2 \Omega_t + \epsilon_3(\vartheta_t - D_t)$

Panel A: Alternating Offer Bargaining (AOB) Sharing Rule[a]			
	ϵ_1	ϵ_2	ϵ_3
Posterior mode	**0.06**	**0.28**	**0.47**
95% probability interval	[0.03–0.12]	[0.13–0.35]	[0.44–0.49]
Panel B: Nash Bargaining Sharing Rule[b]			
	ϵ_1	ϵ_2	ϵ_3
Posterior mode	**0.48**	**0**	**0**
95% probability interval	[0.28–0.88]	–	–
Panel C: Reduced Form Sharing Rule[c]			
Reduced form sharing rule vs. AOB	$p(\epsilon_1 > 0.06)$[d] **0.23**	$p(\epsilon_2 > 0.28)$ **0.21**	$p(\epsilon_3 > 0.47)$ **0.24**
Reduced form sharing rule vs. Nash bargaining	$p(\epsilon_1 > 0.48)$[e] **8e−5**	$p(\epsilon_2 > 0)$ **0.25**	$p(\epsilon_3 > 0)$ **0.26**

[a] AOB model with $\epsilon_1 = \beta_1$, $\epsilon_2 = \beta_2\gamma$, and $\epsilon_3 = \beta_3$, where β_1, β_2, and β_3 are functions of δ and M; see Section 2.5 in the text. Values of ϵ_1, ϵ_2, and ϵ_3 as implied by estimated parameters listed in Table II.

[b] Nash bargaining model where ϵ_1 is a function of η; see Section 2.6 in the text. Parameter value of ϵ_1 as implied by estimated parameters listed in Table II.

[c] Reduced form sharing rule model in which ϵ_1 and ϵ_3 are estimated as unrestricted parameters and ϵ_2 is set to obtain a steady state unemployment rate of 5.5 percent.

[d] The term $p(\epsilon_1 > 0.06)$ denotes the probability that ϵ_1 in the estimated reduced form sharing rule model is larger than the mode value for ϵ_1 in the estimated AOB model.

[e] The term $p(\epsilon_1 > 0.48)$ denotes the probability that ϵ_1 in the estimated reduced form sharing rule model is larger than the mode value for ϵ_1 in the estimated Nash model.

spectively. Denote the mode of these distributions by ϵ_i^x for $x = \text{AOB}, \text{Nash}$, $i = 1, 2, 3$. Panel C reports a measure of closeness of the ϵ_i^x's to the corresponding posterior distribution implied by the reduced form sharing rule model. We use the p-value as our measure of closeness. Thus, according to panel C in Table IV, $\text{prob}[\epsilon_i > \epsilon_i^{\text{AOB}}]$ is between 0.21 and 0.24 for $i = 1, 2, 3$. So the sharing rule parameters implied by the AOB model are quite plausible relative to the posterior distribution implied by the reduced form sharing rule model.

In contrast, the Nash model does very poorly by this metric. Specifically, $\text{prob}[\epsilon_1 > \epsilon_1^{\text{Nash}}]$ is essentially zero. Thus, the sharing parameters implied by the Nash model are extremely implausible under the posterior distribution implied by the generalized sharing rule model. This last result corroborates our findings, based on the marginal likelihood, that the AOB model provides a better statistical fit of the data than the Nash model.

6.2. *General Wage Rule Model*

While more general than the Nash and AOB sharing rules, equation (41) might still be quite restrictive. Accordingly, we also consider a reduced form model in which the date t real wage is assumed to be a log-linear function of all date t state variables of the AOB model. We treat the coefficients on the state variables as free parameters to be estimated.

Let $\bar{w}_t$ denote the real wage scaled by Φ_t:

$$\bar{w}_t \equiv w_t / \Phi_t. \tag{42}$$

Here Φ_t denotes the combination of neutral and investment-specific technology shocks defined in (30). The state variables of the model include R_{t-1}, $k_{t-1} = K_{t-1}/(\Psi_{t-1}\Phi_{t-1})$, l_{t-1}, Ω_{t-1}, $c_{t-1} = C_{t-1}/\Phi_{t-1}$, $i_{t-1} = I_{t-1}/(\Psi_{t-1}\Phi_{t-1})$, $\mu_{z,t}$, $\mu_{\Psi,t}$, and p^*_{t-1}.[32] Let

$$\begin{aligned}\ln(\bar{w}_t/\bar{w}) = {} & \varkappa_1 \ln(R_{t-1}/R) + \varkappa_2 \ln(k_{t-1}/k) \\ & + \varkappa_3 \ln(l_{t-1}/l) + \varkappa_4 \ln\big(p^*_{t-1}/p^*\big) \\ & + \varkappa_5 \ln(\Omega_{t-1}/\Omega) + \varkappa_6 \ln(c_{t-1}/c) \\ & + \varkappa_7 \ln(i_{t-1}/i) + \varkappa_8 \ln(\mu_{z,t}/\mu_z) \\ & + \varkappa_9 \ln(\mu_{\Psi,t}/\mu_\Psi),\end{aligned} \tag{43}$$

where variables without a time subscript indicate nonstochastic steady state.

We define the *general wage rule model* as the version of our model in which the wage is determined by (43). Table V reports the prior probability interval as well as the posterior mode and probability interval of the coefficients $\varkappa_i$, $i = 1, \dots, 9$, in (43). We arrived at the priors as follows. The solution to the estimated AOB model implies a representation for $\bar{w}_t$ of the form displayed in (43). Our priors correspond to the values of $\varkappa_i$, $i = 1, \dots, 9$, implied by the AOB model, evaluated at the posterior mode of its parameters. One way to evaluate how restrictive is the wage rule implicit in the AOB sharing rule, (41), is to compare the priors and posteriors of the $\varkappa_i$'s. With two exceptions, the priors and posteriors are qualitatively similar. In the case of $\varkappa_2$ and $\varkappa_3$ there is a sign switch in the mean of the prior and the mode of the posterior. To evaluate the significance of the differences between the priors and posteriors, we examine how the models respond to shocks. Figure 7 displays the impulse response functions of unemployment, inflation, and the real wage to our three shocks.[33] Notice that wages and inflation respond somewhat more to a monetary policy shock in the AOB model than in the general wage rule model. This difference helps to explain the lower marginal likelihood associated with the AOB model. It also illustrates the crucial role that real wages play in determining the response of inflation to a monetary policy shock. Specifically, the reason that the

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[32] Here, p^*_t denotes the measure of price dispersion across retailers, which captures the effects of resource misallocation due to price-setting frictions (see Yun (1996)). In particular, $p^*_t = (P^*_t/P_t)^{\lambda/(\lambda-1)}$, where $P^*_t = [\int_0^1 P_{i,t}^{\lambda/(1-\lambda)}\,di]^{(1-\lambda)/\lambda}$ and $P_t = [\int_0^1 P_{i,t}^{1/(1-\lambda)}\,di]^{1-\lambda}$.

[33] A complete set of impulse response functions is available upon request from the authors.

TABLE V

PRIORS AND POSTERIORS OF PARAMETERS: SIMPLE AND GENERAL WAGE RULES[a]

	Prior Distribution $\mathcal{D}$, **Mode**, [2.5–97.5%]	Posterior Distribution **Mode**, [2.5–97.5%] Simple Wage Rule	Posterior Distribution **Mode**, [2.5–97.5%] General Wage Rule
	Price Setting Parameters		
Price stickiness, ξ	$\mathcal{B}$, **0.68**, [0.45–0.84]	**0.75**, [0.70–0.85]	**0.60**, [0.58–0.70]
Price markup parameter, λ	$\mathcal{G}$, **1.19**, [1.11–1.31]	**1.36**, [1.26–1.47]	**1.39**, [1.31–1.48]
	Monetary Authority Parameters		
Taylor rule: smoothing, ρ_R	$\mathcal{B}$, **0.76**, [0.37–0.94]	**0.87**, [0.84–0.89]	**0.87**, [0.85–0.89]
Taylor rule: inflation, r_π	$\mathcal{G}$, **1.69**, [1.42–2.00]	**1.33**, [1.23–1.68]	**1.35**, [1.20–1.64]
Taylor rule: GDP, r_y	$\mathcal{G}$, **0.08**, [0.03–0.22]	**0.06**, [0.03–0.12]	**0.05**, [0.02–0.10]
	Preferences and Technology Parameters		
Consumption habit, b	$\mathcal{B}$, **0.50**, [0.21–0.79]	**0.82**, [0.80–0.85]	**0.83**, [0.81–0.85]
Capacity utilization adjustment cost, σ_a	$\mathcal{G}$, **0.32**, [0.09–1.23]	**0.25**, [0.02–0.43]	**0.28**, [0.13–0.40]
Investment adjustment cost, S''	$\mathcal{G}$, **7.50**, [4.57–12.4]	**13.4**, [10.7–18.3]	**14.8**, [10.7–17.8]
Capital share, α	$\mathcal{B}$, **0.33**, [0.28–0.38]	**0.23**, [0.20–0.27]	**0.23**, [0.20–0.26]
Technology diffusion, θ	$\mathcal{B}$, **0.50**, [0.13–0.87]	**0.01**, [0.00–0.02]	**0.01**, [0.00–0.02]
	Labor Market Parameters		
Hiring fixed cost/output, $100\eta_h$	$\mathcal{G}$, **0.91**, [0.50–1.67]	**0.52**, [0.23–0.78]	**0.47**, [0.25–0.86]
Vacancy cost/output, $100\eta_s$	$\mathcal{G}$, **0.05**, [0.01–0.28]	**0.05**, [0.00–0.13]	**0.03**, [0.00–0.14]
Matching function parameter, σ	$\mathcal{B}$, **0.50**, [0.31–0.69]	**0.52**, [0.45–0.59]	**0.55**, [0.47–0.60]
	Simple Wage Rule Parameters		
Scaled real wage$_{t-1}$, ι_1	$\mathcal{B}$, **0.75**, [0.53–0.92]	**0.96**, [0.92–0.97]	
Employment$_{t-1}$, ι_2	$\mathcal{N}$, **0.00**, [−1.96–1.96]	**0.03**, [0.02–0.06]	
Neutral technology growth$_t$, ι_3	$\mathcal{N}$, **0.00**, [−1.96–1.96]	**−0.15**, [−0.55–0.00]	
Investment technology growth$_t$, ι_4	$\mathcal{N}$, **0.00**, [−1.96–1.96]	**−0.26**, [−0.53–−0.18]	

(*Continues*)

TABLE V—*Continued*

	Prior Distribution $\mathcal{D}$, **Mode**, [2.5–97.5%]	Posterior Distribution **Mode**, [2.5–97.5%] Simple Wage Rule	 General Wage Rule
	General Wage Rule Parameters		
Nominal interest rate$_{t-1}$, $\varkappa_1$	$\mathcal{U}$, **−0.47**, [−1.42–0.47]		**−0.27**, [−0.39–0.07]
Scaled capital$_{t-1}$, $\varkappa_2$	$\mathcal{U}$, **−0.06**, [−0.18–0.06]		**0.06**, [0.02–0.06]
Employment$_{t-1}$, $\varkappa_3$	$\mathcal{U}$, **−0.01**, [−0.03–0.01]		**−0.03**, [−0.03–0.01]
Price dispersion$_{t-1}$, $\varkappa_4$	$\mathcal{U}$, **−0.75**, [−2.25–0.75]		**−1.00**, [−2.04–0.77]
Composite technology diffusion$_{t-1}$, $\varkappa_5$	$\mathcal{U}$, **0.76**, [−0.76–2.27]		**0.01**, [0.01–0.24]
Scaled consumption$_{t-1}$, $\varkappa_6$	$\mathcal{U}$, **0.13**, [−0.13–0.40]		**0.05**, [0.03–0.19]
Scaled investment$_{t-1}$, $\varkappa_7$	$\mathcal{U}$, **0.08**, [−0.08–0.24]		**0.04**, [0.02–0.08]
Neutral technology growth$_t$, $\varkappa_8$	$\mathcal{U}$, **−0.95**, [−2.84–0.95]		**−1.01**, [−1.75–−0.23]
Investment technology growth$_t$, $\varkappa_9$	$\mathcal{U}$, **−0.22**, [−0.67–0.22]		**−0.29**, [−0.69–−0.04]
	Exogenous Processes Parameters		
Standard deviation monetary policy shock, $400\sigma_R$	$\mathcal{G}$, **0.65**, [0.56–0.75]	**0.58**, [0.51–0.64]	**0.56**, [0.51–0.64]
Standard deviation neutral technology shock, $100\sigma_{\mu_z}$	$\mathcal{G}$, **0.08**, [0.03–0.22]	**0.17**, [0.14–0.20]	**0.17**, [0.14–0.20]
Standard deviation investment technology shock, $100\sigma_\Psi$	$\mathcal{G}$, **0.08**, [0.03–0.22]	**0.12**, [0.08–0.16]	**0.12**, [0.09–0.16]
AR(1) investment technology, ρ_Ψ	$\mathcal{B}$, **0.75**, [0.53–0.92]	**0.70**, [0.60–0.83]	**0.70**, [0.57–0.80]
	Memo Item		
Log marginal likelihood (MCMC, 12 observables):		306.5	308.9

[a] For model specifications where particular parameter values are not relevant, the entries in this table are blank. Posterior mode and parameter distributions are based on a standard MCMC algorithm with a total of 10 million draws (11 chains; 50 percent of draws used for burn-in; draw acceptance rates about 0.24). The $\mathcal{B}$, $\mathcal{G}$, $\mathcal{N}$, and $\mathcal{U}$ denote beta, gamma, normal, and uniform distributions, respectively. For the uniform distribution, the mean is reported instead of the mode.

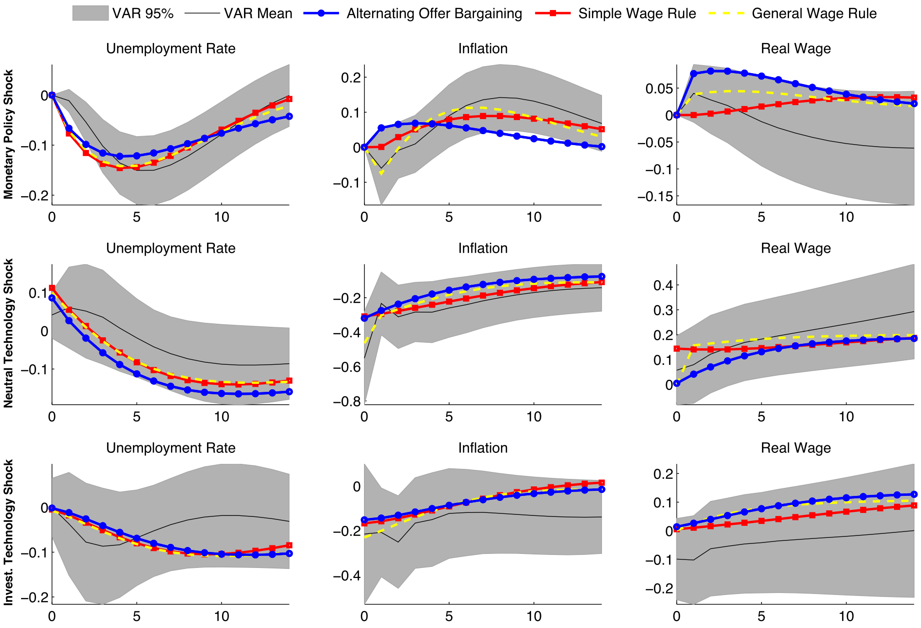

FIGURE 7.—Impulse responses to shocks: simple and general wage rules. x-axis: quarters; y-axis: percent.

response of inflation is stronger in the AOB model than in the general wage rule model is that the real wage response is stronger. Figure 7 also shows that the dynamic responses of the AOB and general wage rule models to technology shocks are very similar.

We infer from the previous discussion that the wage rule in the general wage rule model and the one implicit in the AOB model are reasonably similar. The key property that they share is that real wages are inertial. We believe that any successful account of the data will have to somehow account for that feature.

6.3. *Simple Wage Rule Model*

Next, we work with the following simple—easy-to-interpret—rule for the real wage, which in principle has the ability to capture the two key features of the general wage rule discussed in the previous section:

$$\begin{aligned}(44)\qquad \ln(\bar{w}_t/\bar{w}) &= \iota_1 \ln(\bar{w}_{t-1}/\bar{w}) + \iota_2 \ln(l_{t-1}/l) \\ &\quad + \iota_3 \ln(\mu_{z,t}/\mu_z) + \iota_4 \ln(\mu_{\Psi,t}/\mu_\Psi).\end{aligned}$$

We define the *simple wage rule model* as the version of our model in which the wage is determined by (44). The definition of $\bar{w}_t$ in (42) implies that the impact on $\ln w_t$ of an innovation in $\ln z_t$ and in $\ln \Psi_t$ is $1 + \iota_3$ and $\iota_4 + \alpha/(1-\alpha)$, respectively. So negative values of ι_3 and ι_4 imply less than complete pass-through from technology shocks to the real wage in the period of the shock. High values of ι_1 ensure that the incomplete pass-through persists over time. Finally, note that we exclude the time t shock to monetary policy in (44) so as to be consistent with the identifying assumptions in our VAR analysis. Monetary policy does affect w_t dynamically through $\ln l_{t-1}$. Other things equal, we anticipate a low value of ι_2 because the estimated response of w_t to a monetary policy shock is persistently small.

Table V reports the posterior mode and probability interval of the coefficients ι_i, $i = 1, \dots, 4$, in the simple wage rule. Four things are worth noting. First, the data are quite informative about the coefficients, ι_i, $i = 1, \dots, 4$, in the sense that, in each case, the posterior probability interval is much smaller than the prior probability interval. Second, as anticipated, the posterior mode for ι_1 is quite large. Third, the posterior mode for ι_2 is small. Finally, the posterior modes for ι_3 and ι_4 are negative.

According to Table V, the marginal likelihoods for the simple wage rule model and the general wage rule model are very similar. It is evident that the impulse response functions of the general wage rule model and the simple wage rule model are very similar. We interpret these two observations as supporting the notion that the simple wage rule succinctly captures the key features of the general wage rule.

We conclude this section by addressing the question, "If the simple wage rule is a good description of the data, why bother with structural models like the AOB model?" First, it is important to recall that the AOB model does capture the key features of both wage rule models. Second, it is important to be clear about the limitations of the wage rule models. For example, these models cannot be used to study the effects of policy interventions such as a change in unemployment benefits. From the perspective of the AOB and the Nash models, the coefficients in the wage rule models depend on objects like the level of unemployment benefits, D. The wage rule models are silent on how these coefficients vary in response to changes in policy.

Finally, one could in principle reinterpret our wage rules as wage norms in the sense of Hall (2005). Even with this interpretation it would be difficult to use the model to analyze the effects of policy changes. For example, one would have to verify that the wage produced by the general wage rule does not induce the worker or the firm to walk away from the match. If the implied wage did not satisfy this condition the model would be silent about the resulting implications.

6.4. *Calvo Sticky Wage Model*

In this subsection we discuss the empirical properties of the Calvo sticky wage model and compare its performance to the AOB model. Recall that our

Calvo sticky wage model rules out indexation of wages to technology and inflation. We comment on a version of the model that allows for such indexation at the end of this subsection.

Table I reports parameter values of the sticky nominal wage model that we set a priori. Motivated by the findings in Barattieri, Basu, and Gottschalk (2014), we fix ξ_w to 0.75, so that nominal wages change on average once a year.[34] Table III reports the posterior mode of the estimated sticky wage model parameters. Figures 1–3 show that with two important exceptions, the Calvo sticky wage model does reasonably well at accounting for the estimated impulse response functions. These exceptions are that the model substantially understates the response of inflation to a neutral technology shock and, to a somewhat lesser extent, to a monetary policy shock.

We now compare the marginal likelihood of the AOB model with that of the Calvo sticky wage model. According to Table III, the log marginal likelihood of the AOB and Calvo sticky wage models is 286.7 and 262.6, respectively. However, these numbers cannot be compared directly, because the AOB model is based on a larger data set than the Calvo sticky wage model is. To compare the two models requires that we integrate out unemployment, vacancies, and the job finding rate in the AOB marginal likelihood of the data. But the nonnegativity property of densities implies that this integration cannot produce a log marginal likelihood smaller than 286.7. Thus, the log marginal likelihood of the AOB model is at least 24.1 log points higher than the log marginal likelihood of the sticky wage model. We conclude that there is substantial statistical evidence in favor of the AOB model relative to the Calvo sticky wage model.

We also estimated a version of the Calvo sticky wage model where we allow for wage indexation. In particular, we assume that if a labor supplier cannot reoptimize his wage, then it changes by the steady state growth rate of output times the lagged inflation rate. The Calvo sticky wage model with indexation and the AOB model fit the data about as well, in that their impulse response functions are very similar.[35] But the performance of the Calvo sticky wage model depends very much on the troubling wage indexation assumption.

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[34] We encountered numerical problems in calculating the posterior mode of model parameters when we did not place a dogmatic prior on ξ_w.

[35] The log marginal likelihood of the Calvo sticky wage model with indexation is 324.0. That number is higher than 286.7, the log marginal likelihood of the data implied by the AOB model. To compare these two log marginal likelihoods requires adjusting the 286.7 number by integrating out unemployment, vacancies, and the job finding rate in the marginal likelihood for the AOB model. It is not clear what the relative magnitudes of the two log marginal likelihood would be after this adjustment.

7. THE DYNAMIC EFFECTS OF A CHANGE IN UNEMPLOYMENT BENEFITS

In this section we investigate the implications of our estimated AOB model for changes in unemployment benefits.[36] We look at these implications when the zero lower bound (ZLB) on nominal interest is binding and when it is not (i.e., in "normal times"). According to our estimated model, price-setting frictions and monetary policy play a key role in determining the response of the economy to a change in unemployment benefits, D. Our key findings are as follows. First, in normal times, a rise in D increases the value of being unemployed, so that the real wage rises, aggregate economic activity falls, and the unemployment rate rises. Second, other things being equal, when the ZLB is binding, a rise in D gives rise to countervailing expansionary forces. If those forces are sufficiently strong, a rise in D can in principle lead to an economic expansion. Third, whether we are in the ZLB or in normal times, the effects of a rise in D depend very much on how sticky prices are. Fourth, our estimated AOB model implies that a 1 percent increase in D that lasts roughly 2 years has a contractionary effect when the economy is not in the ZLB. The same increase has essentially no effect when the economy is in the ZLB.

7.1. *A Rise in Unemployment Benefits in Normal Times*

We investigate the effects of an unanticipated, transitory increase in unemployment benefits using the estimated version of our AOB model. The specific experiment that we perform is as follows. We suppose that the economy is in nonstochastic steady state and is expected to remain there indefinitely. In period $t = 0$ there is an unanticipated jump in unemployment benefits. Thereafter, there are no further shocks. Agents correctly understand that unemployment benefits will revert back to steady state. We replace D in (31) by d_t in time $t = 0$, where

$$\ln d_{t+1} = (1 - \rho_D) \ln D + \rho_D \ln d_t$$

for $t = 0, 1, 2, \ldots$. We set $d_0 > D$ so that the ratio of D_0 to the unshocked steady state value of w_0 jumps from its initial steady state value of 0.37 to 0.38. We consider two values of ρ_D: 0.75 and 0.90. The time needed to close 90 percent of the gap between d_t and D in these two cases is roughly 2 and 5 years, respectively. The first row of Figure 8 reports the dynamic impact of the shock to d_0 on unemployment for the estimated AOB model. Recall that the mode of the posterior distribution for the price stickiness parameter, ξ, is 0.75. Since

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[36] In independent work, Albertini and Poirier (2015) investigate the impact of unemployment benefits in a calibrated New Keynesian model with quadratic costs of adjustment in prices and no capital. They consider the effects in normal times and in times when the zero lower bound on the nominal interest rate binds.

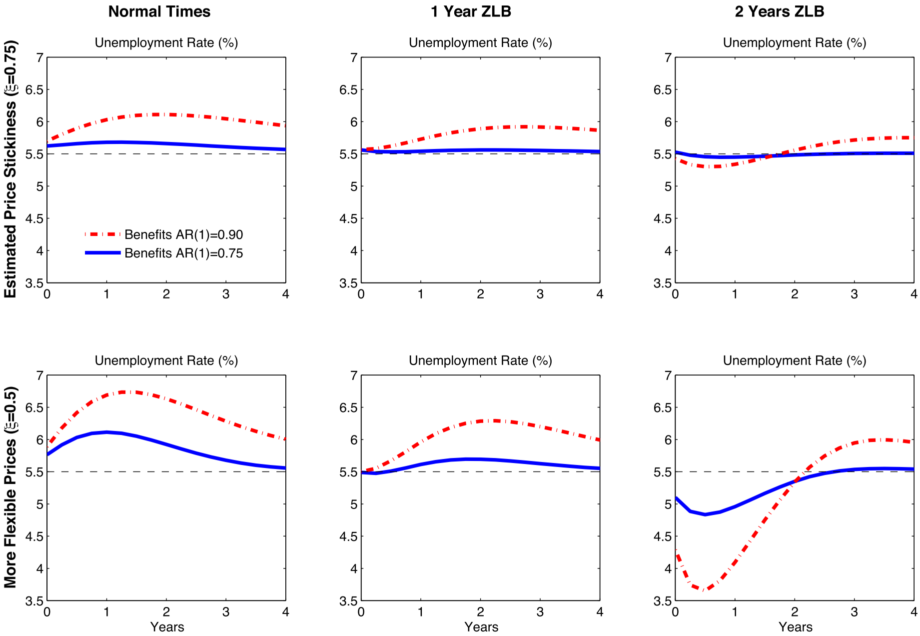

FIGURE 8.—Dynamic effects of a rise in unemployment benefits. 1pp rise in unemployment benefits relative to steady state wage. Normal Times: Taylor rule. 1 or 2 Years ZLB: 1 or 2 years constant nominal interest rate.

the effects of a change in unemployment benefits depend in an interesting way on the parameter ξ, we also report results for a version of the model where $\xi = 0.5$, so that prices are less sticky (see row 2).

Row 1 in Figure 8 shows that, in normal times, the increase in unemployment benefits leads to a relatively small, but persistent, increase in the unemployment rate. The intuition for this result is straightforward. In normal times, a rise in unemployment benefits increases the value of unemployment so that real wages rise. That rise has two effects. First, it reduces the incentive of firms to post vacancies. This standard contractionary effect is the one that is stressed in the literature (see, for example, Hagedorn et al. (2013)). The second effect reflects the presence of price-setting frictions in our model. These frictions have the consequence that the rise in the real wage leads to an increase in inflation. These frictions also imply that the response of monetary policy to inflation has an impact on economic activity. Specifically, our estimated monetary policy rule has the property that the nominal interest rate rises by more than inflation. The resulting rise in the real interest rate drives spending on goods and services down, thus magnifying the decline in aggregate economic activity induced by the rise in unemployment benefits.

Figure 8 shows that the magnitude of the rise in unemployment after the increase is increasing in ρ_D and decreasing in ξ. The larger is ρ_D, the more the value of unemployment rises with an increase in d_0, so the standard contractionary effect stressed in the literature is larger. The smaller is ξ, that is, the more flexible prices are, the larger is the immediate effect on inflation of a given rise in the real wage. Since it is the one-period inflation rate that enters the monetary policy rule, the more flexible prices are, the larger is the increase in the nominal interest rate associated with an increase in d_0. So the magnitude of the second effect (i.e., the real interest rate effect) discussed above is larger.

7.2. *A Rise in Unemployment Benefits When the ZLB Binds*

We now consider the effects of the same rise in d_0 studied in the previous section, with one modification. The ZLB is binding in period $t = 0$ when the shock occurs. We do not explicitly model why the ZLB is binding. Instead we simply assume that the nominal interest rate is fixed at its steady state value for x quarters after $t = 0$. We consider two cases: $x = 4, 8$.[37] This choice is motivated by results in Swanson and Williams (2014), who argue that, during the period 2009Q1–2012Q4, professional forecasters expected the ZLB to be binding between 1 and 2 years. In our experiments we assume that after the ZLB ceases to bind, policy reverts to our estimated interest rate rule.

We use the same two mechanisms discussed above to describe the dynamic effects of the increase in unemployment benefits. The standard contractionary effect—which raises the real wage and reduces firms' incentive to post vacancies—is still present. However, the second effect—which is based on the interaction of price-setting frictions and monetary policy—operates very differently when the ZLB is binding. As before, the increase in real wages leads to a rise in inflation. But with a fixed nominal interest rate, the rise in inflation leads to a fall in the real interest rate. That fall drives spending on goods and services up. So when the ZLB is binding the model embodies forces that, other things being equal, lead to an expansion in economic activity after an increase in unemployment benefits. These expansionary forces are stronger the longer the ZLB is expected to bind relative to the duration of the increase in unemployment benefits. To understand this point, suppose that the bulk of the increased benefits occurs after $t = x$, that is, after the ZLB ceases to bind. The logic of the previous section applies and the economy experiences a recession after $t = x$. Internalizing this fact, forward looking agents spend less in the

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[37] We obtain an exact solution to the nonlinear equilibrium conditions of the model using the extended path method (see, for example, Christiano, Eichenbaum, and Trabandt (2015)).

ZLB than they would have otherwise.[38] Finally, these expansionary forces are also stronger the more flexible prices are, conditional on the ZLB binding.[39]

Columns 2 and 3 in Figure 8 report our results for $x = 4$ and 8, respectively. Recall that row 1 corresponds to the estimated AOB model. Note that when $\rho_D = 0.75$, the standard contractionary effect and the effects stemming from the price-setting frictions in the ZLB roughly cancel. So the net effect of an increase in unemployment benefits in the ZLB is roughly zero. Consistent with our discussion above, when $\rho_D = 0.9$ and $x = 4$, the contractionary effect of an increase in unemployment benefits dominates and there is a positive, albeit small, rise in unemployment. Also consistent with the discussion above, when $\rho_D = 0.9$ and $x = 8$, the responses are shifted down. So there is a small fall in unemployment for the first year after the increase in benefits, followed by a small rise in unemployment. Finally, row 2 shows that the more flexible prices are, the larger are the effects stemming from price-setting frictions. We conclude that, from the perspective of our model, there is a critical interaction between the degree of price stickiness, monetary policy, and the duration of an increase in unemployment benefits.

We are keenly aware that our model does not capture some potentially important effects of unemployment compensation. Specifically, our model abstracts from heterogeneity among agents so that we cannot address the impact of an increase in the amount of time that agents are eligible for unemployment benefits. Pursuing this would expand the number of labor market states in the model and it would substantially complicate the worker–firm bargaining problem.[40] Finally, we have also abstracted from liquidity constraints, and we have assumed complete insurance against labor market outcomes. We leave these important extensions to future research.

8. CONCLUSION

This paper constructs and estimates an equilibrium business cycle model that can account for the response of the U.S. economy to neutral and investment-specific technology shocks as well as monetary policy shocks. The focus of our analysis is on how labor markets respond to these shocks. Significantly, our model does not assume that wages are sticky. Instead, we derive inertial wages from our specification of how firms and workers interact when negotiating wages.

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[38] The reasoning here is similar to the logic in Christiano, Eichenbaum, and Rebelo's (2011) discussion of the dependence of the government spending multiplier on the duration of the ZLB and the duration of an increase in government spending.

[39] This phenomenon is also discussed in Christiano, Eichenbaum, and Rebelo (2011) and Werning (2012).

[40] For interesting work on this issue in a flexible price setting, see Costain and Reiter (2008) and Hagedorn et al. (2013).

We have been critical of standard sticky wage models in this paper. Still, Hall (2005) describes one interesting line of defense for sticky wages. He introduces sticky wages into the search and matching framework in a way that satisfies the condition that no worker–employer pair has an unexploited opportunity for mutual improvement (Hall (2005, p. 50)). A sketch of Hall's logic is as follows: In a model with labor market frictions, there is a gap between the reservation wage required by a worker to accept employment and the highest wage a firm is willing to pay an employee. This gap, or bargaining set, fluctuates with the shocks that affect the surplus enjoyed by the worker and the employer. When calibrated based on aggregate data, the fluctuations in the bargaining set are sufficiently small and the width of the set is sufficiently wide that an exogenously sticky wage rate can remain inside the set for an extended period of time. Krause and Lubik (2007) and Trigari (2009), among others, pursue this idea in calibrated models. Gertler, Sala, and Trigari (2008) do so in an estimated, medium-sized DSGE model. A concern about this strategy for justifying sticky wages is that the microeconomic shocks that move actual firms' bargaining sets are far more volatile than what the aggregate data suggest. As a result, it may be harder to use the preceding approach to rationalize sticky wages than it had initially been recognized.

We wish to emphasize that our approach follows HM in assuming that the cost of disagreement in wage negotiations is relatively insensitive to the state of the business cycle. This assumption played a key role in the empirical success of our model. Assessing the empirical plausibility of this assumption using microeconomic data is a task that we leave to future research.

An interesting feature of the microdata is that there appear to be substantial movements in the wages of different types or groups of workers (e.g., geography, skill, education) in response to group-level shocks. In our preferred AOB model, wages display some sensitivity to broader economic conditions. On this basis we expect that a heterogeneous agent version of our model with localized labor markets could in principle account for the group-level patterns. Exploring the properties of this type of model represents another interesting avenue for future research.

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