How Sticky Wages In Existing Jobs Can Affect Hiring*

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Abstract

We consider a matching model of employment with flexible wages for new hires, but sticky wages within matches. Unlike most models of sticky wages, we allow effort to respond if wages are too high or too low. In the Mortensen-Pissarides model, employment is not affected by wage stickiness in existing matches. But it is in our model. If wages of matched workers are stuck too high, firms require more effort, lowering the value of additional labor and reducing hiring. We find that effort's response can greatly increase wage inertia.

Keywords: Effort, Employment, Sticky Wages, Wage Inertia

JEL Classification: E32, E24, J22

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1 Introduction

There is much evidence that wages are sticky within employment matches.[1] On the other hand, wages earned by new hires show greater flexibility. Pissarides (2009), for example, surveys eleven studies that distinguish between wage cyclicality for workers in continuing jobs versus those in new matches, seven based on U.S. data and four on European.[2] All find that wages for new matches are more procyclical than for those in continuing jobs. Reflecting such evidence, we consider a Mortensen-Pissarides model of employment with wages that are flexible for new hires while sticky within matches. But we depart from the sticky-wage literature by allowing that firms and workers bargain over worker effort more frequently than wage rates. Effort could reflect pace of work or breadth of tasks assigned. For salaried workers it could simply reflect hours spent at work or whether work is taken home. Employers make decisions on how much to produce and hiring/firing much more frequently that wages are typically determined. Since these choices influence effort required, an effort level must be at least implicitly settled upon more frequently that wages. To some extent, allowing effort to respond renders wages flexible within matches despite nominal rigidities. For instance, if the wage is ex post too high, our model predicts that the firm will require the worker to produce more, yielding some decline in the *effective* wage.

Relaxing constant effort has three important implications. For one, while Shimer (2004) and others illustrate that wage stickiness in existing matches does not matter for employment in the Mortensen-Pissarides model, it does matter if effort responds. Consider a shock that would lower a flexibly-chosen wage rate, such as a decline in productivity. Under sticky wages, if firms ask more of their existing workers, this lowers the marginal value of adding labor, lowering vacancies and hiring. By moving the economy along a downward sloping aggregate labor demand schedule, higher effort by current workers reduces demand for new hires.

Second, wage setting places much less weight on future desired wage rates if effort can

[1] Barattieri, Basu, and Gottschalk (2014), based on the Survey of Income and Program Participation, estimate an expected duration of nominal wages within matches of greater than a year. See also LeBow, Sachs, and Wilson (2003).

[2] Earlier papers stressing greater wage cyclicality for new hires include Bils (1985) and Beaudry and DiNardo (1991). Studies since Pissarides' survey, including Kudlyak (2014) and Basu and House (2016) on NLSY data and Haefke, et al. (2013) on CPS data, similarly find greater wage cyclicality for new hires. Topel and Ward (1992), among others, show that life-cycle wage changes also project heavily on job changes.

respond. The intuition is as follows. Suppose that the bargained wage is above anticipated future desired wage rates. Under fixed effort this creates pressure to lower the bargained wage to maintain the bargained division of match rents. But, if effort responds, then the too-high future wage will be partly offset by higher effort. So it exerts less sway for lowering the bargained wage today. In this sense, bargaining discounts the future as though wages are more flexible. It is often argued that New-Keynesian models generate too little price inertia because of forward-looking wage and price setting. This motivates adding ingredients such as sticky information or dropping rational expectations in favor of a "hybrid" Phillips curve.[3] Our model weakens the forward-looking element of wage setting and generates much more inertia in aggregate wages, even though we maintain fully rational expectations.

Third, effort's response under sticky wages significantly alters the behavior of productivity across recessions. We subject the model to shocks to labor demand (productivity shocks), as well as labor supply (preference shocks). Effort's response raises productivity during a recession driven by a drop in labor demand, while lowering it during a recession characterized by a fall in labor supply. In fact, predicted responses for wages and measured productivity are remarkably similar across these differing shocks if effort responds. This is consistent with the relatively acyclical movements in wages and productivity, compared to employment and output, that is typical of recent U.S. recessions.

We consider two versions of our model. We first allow firms to require different effort levels across workers of all vintages, as dictated by Nash bargaining. This may require very different effort levels across workers. During a recession the efficient contract for new hires dictates low effort at low wage while matched workers, whose wages do not adjust, work at an elevated pace. Alternatively, we impose a technological constraint that workers of differing vintages must operate at a similar pace.

The latter model—where efforts are coordinated across workers—generates especially strong wage inertia and greater employment volatility. Again consider a negative shock to productivity. Firms can require higher effort from past hires with stuck high wages. But, if

[3]Fuhrer (2006) and Mankiw and Reis (2002), among others, argue that data show more price inertia than predicted by New-Keynesian models, including that inflation lags measures of the output gap or monetary shocks. To add inertia Mankiw and Reis introduce sticky information; Gali and Gertler (1999) introduce the hybrid information Phillips curve; Christiano, Eichenbaum, and Evans (2005) introduce backward-looking indexing.

new hires must work the same pace, this implies high effort for them as well. For reasonable parameters firms distort the contract for new hires rather than give rents—i.e., high wages without high effort—to its current workers. This produces a great deal of aggregate wage inertia. The sticky wage for past hires drives up effort for all workers. Reflecting this, the bargained wages for new hires, though flexible, will be higher as well. This dynamic continues in subsequent periods. High wages for new hires drives up their subsequent effort, driving up effort and wages for the next cohort of hires, and so forth, thus producing a great deal of wage inertia. Gertler and Trigari (2009), among others, assume that new hires receive the existing sticky-bargained wage. Although this adds inertia, we show its effect on aggregate wages is much more limited than in our model because the new hires are few relative to the flow of workers bargaining over wages. Furthermore, wage setters do not down-weight future target wage rates, as we show is the case if effort can respond.[4]

Direct evidence on cyclicality of worker effort is sparse. Lazear, Shaw, and Stanton (2013) examine data on productivity of individual workers at a large (20,000 workers) service company for the period June 2006 to May 2010, bracketing the Great Recession. At this company a computer keeps track of worker productivity. They find that an increase in the local unemployment rate of 5 percentage points is associated with an increase in effort of 3.75 percent. There is also evidence that in the wake of the Great Recession firms required more of workers in the form of added tasks. For instance, among a random sample of 600 U.S. workers surveyed during July 2011, 55 percent stated that their responsibilities had increased as a result of the recession–27 percent said that their duties had doubled. Similarly, from a survey of 571 professional bankers, lawyers and accountants, conducted in London in early 2010, 70 percent of respondents stated they had "stepped up" to the more demanding responsibilities because colleagues had been displaced.[5,6] Our model predicts such a response

[4]More specifically, our model differs from Gertler and Trigari (2009, G-T for short) in three ways: (i) wages of newly hired workers are completely flexible in our model, whereas there is no distinction of wages between newly hired and existing workers in G-T; (ii) there is an endogenous effort choice; and (iii) we assume a constant vacancy posting cost as in the standard Mortensen-Pissarides model, whereas in G-T firms face a quadratic adjustment cost when posting vacancies.

[5]The U.S. survey was conducted for the publication Workforce Management. It covered workers from a variety of industries, including retail, financial services, manufacturing and health care. The London survey was conducted for the financial services recruiting firm Joslin Rowe.

[6]Looking at earlier episodes, Anger (2011) studies paid and unpaid overtime hours in Germany for 1984 to 2004. She finds that unpaid overtime (extra) hours are highly countercyclical, in sharp contrast to cyclicality

in effort during a recession, assuming it is driven by shocks that reduce labor demand.

Our paper proceeds as follows. In section 2 we present our model of employment under sticky wages and endogenous effort, which we calibrate in Section 3. In Section 4 we characterize wage dynamics, especially how effort's response reduces forward looking and adds inertia to wage setting. In section 5 we examine how the model economies respond to aggregate shocks that affect labor demand (i.e., productivity) or labor supply (preferences) and compare moments from those models to those for U.S. data. The model with a common effort response does much better than the competing models in matching the acyclicality in wages and productivity relative to that in employment or output. Before concluding, in section 6 we examine whether productivity is in fact less procyclical in industries that we measure to have stickier wages. While the evidence is somewhat mixed, for goods industries the answer is clearly yes.

2 Model

Transitions between employment and unemployment are modeled with matching between workers and firms in a Diamond-Mortensen-Pissarides (DMP) framework, but allowing for a choice of labor effort at work.

2.1 Environment

- **Workers:** There is a continuum of identical workers whose mass is normalized to one. Each worker has preferences defined by:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Big\{ c_t + \psi \frac{(1-e_t)^{1-1/\gamma} - 1}{1 - 1/\gamma} \Big\},$$

  where c_t denotes consumption in period t and e_t the effort level at work. The time discount factor is denoted by β. The market equates $(\frac{1}{1+r})$, where r is the rate of return on consumption loans, to this discount factor; so consumers are indifferent to consuming or saving their wage earnings. Each period, an individual worker is either

in paid overtime hours. Schor (1987) reports cyclicality of physical activity (effort) for piece-rate workers in U.K. manufacturing for 1970 to 1986. These data show effort to be procyclical. But for piece-rate workers higher effort does not reduce the effective wage rate; so these data do not address how effort of hourly or salaried paid workers will respond under wage stickiness.

employed or unemployed. When employed (or matched with a firm), a worker is paid wage w_t and exerts effort e_t. The parameter γ reflects the worker's willingness to substitute effort levels over time. When unemployed, a worker engages in job search and is entitled to collect unemployment insurance benefits b. An unemployed worker's labor effort is set equal to zero.

- **Firms:** There is a continuum of identical firms. A matched firm produces output according to a constant-returns-to-scale Cobb-Douglas production technology:

  $$y_t = z_t e_t^{\alpha}(k_t e_t)^{1-\alpha},$$

  where z_t denotes the aggregate productivity, k_t capital per effort so that $k_t e_t$ is the total amount of capital employed by a matched firm.

  The capital market is perfectly competitive, with the aggregate capital stock, K, owned by workers. We treat capital as mobile across firms, with no adjustment costs. At the optimum, given the constant-returns-to-scale production technology, capital-labor ratio k_t is common across all matches and satisfies:

  $$r_t + d = (1-\alpha) z_t k_t^{-\alpha},$$

  where d denotes the maintenance cost per unit of capital; hence $r_t + d$ is the rental rate of capital.

- **Staggered Wage Contracts:** Wages for a match are determined through Nash bargaining between the worker and firm at the first period employed. Wage stickiness is introduced through wage contracts *à la* Calvo (1983). Each period, provided a match survives the exogenous match separation shocks, the wage is renegotiated with probability $1-\lambda$. Since the match wage remains unchanged with probability λ, λ is a measure of wage stickiness; average wage duration is $1/(1-\lambda)$. We denote the probability distribution function of wages by $G(w)$.

- **Choice of Labor Effort:** In addition to wages, effort level is also determined through Nash bargaining given the contracted wage. Unlike wage bargaining, a match determines the effort level each period. We see it as reasonable that the pace of work, or hours of work for those salaried, can change without accompanying wage bargaining. Above we cited evidence that workers were assigned a wider range of tasks during the Great Recession as separated workers were not replaced. Those occurrences do not seem tied to explicit wage bargains. Two versions of the model are considered: (i) each worker-firm pair chooses effort individually and (ii) choice of common effort across workers (say, due to required coordinating of workers in production). These cases are discussed at length below.

We assume that the firm and worker cannot commit future effort choices. This parallels the treatment of employment choices in sticky-wage models, which typically disallow that firms or workers can commit to separation decisions over the duration of the sticky wage.[7]

- **Aggregate Output:** Aggregate output (Y_t) also exhibits constant returns to scale in aggregate capital K_t, and labor L_t:

$$Y_t = n_t \int z_t k_t^{1-\alpha} e_t(w)\, dG_t(w) = z_t k_t^{1-\alpha} L_t = z_t \bar{K}^{1-\alpha} L_t^{\alpha}.$$

Here n_t denotes the total number of employed workers (or matches) and $L_t = n_t \bar{e}_t$ sums efforts of all workers to give total efficiency units of labor input, where $\bar{e}_t = \int e_t\, dG(w)$ is the average effort level. It is important to distinguish between effective labor input in the model, L_t, and employment as measured in the data, which corresponds to n_t.[8]

For simplicity, we treat investment adjustment costs as prohibitive at the aggregate level, with the aggregate capital stock fixed with respect to cyclical fluctuations at $\bar{K}$. Capital's role here is to provide a convenient channel so that labor's marginal product

[7]The endogenous response of effort in our model eliminates scenarios where workers or firms dissolve a match that has positive joint value. If bargaining committed future effort levels to mimic choices under flexible wages, the present value of the match could go negative to either the worker or firm, even though the joint value stays positive. For instance, in response to a negative productivity shock, the flexible-wage effort choice declines, reinforcing the impact of wage stickiness to reduce rents to the firm.

[8]In our model variations in n_t reflect only employment, as there is no intensive margin corresponding to the paid workweek. By ignoring variations in paid hours we implicitly assume that pay for extra hours (including any overtime premium) just matches that required to compensate workers for their disutility. If, instead, it overcompensates then that would push the bargained effort, describe below, to increase when paid hours expand. If it under-compensates, then it would push bargained effort lower.

In presenting data results below, we distinguish whether measures are for employment or total hours (employment times average paid workweek). All productivity measures, e.g., TFP, are based on total hours.

is decreasing in aggregate effective units of labor–that is, so the aggregate demand for labor is downward sloping. From the firm's view, aggregate movements in the output to capital ratio are reflected via the competitive rental rate of capital.

- **Matching Technology:** Each period new matches are formed through a constant returns to scale aggregate matching technology:

$$M(u_t, v_t) = \chi u_t^{\eta} v_t^{1-\eta},$$

where u_t denotes the total number of unemployed workers and v_t the total number of vacancies. Thanks to the constant returns of the matching function, the matching probabilities for an unemployed worker, denoted by p, and for a vacancy, q, are functions of only labor market tightness θ $(= v/u)$: $p(\theta_t) = \chi\theta_t^{1-\eta}$ and $q(\theta_t) = \chi\theta_t^{-\eta}$. Finally, we assume that each period existing matches break at the exogenous rate δ and that firms posts vacancies at unit cost κ to recruit workers.

2.2 Value Functions and Choices for Wages and Labor Effort

For simplicity time subscripts are omitted: variables are understood to refer to time period t, unless marked with a prime ($'$) denoting period $t+1$ (or by $''$ for $t+2$). Let $\mathbf{s}$ conveniently denote the set of aggregate state variables, which includes the productivity shock, z, and the probability distribution of wages for workers, $G(w)$.

Let $W(w, \mathbf{s})$ denote the utility value for a worker who is employed (matched) at wage w under aggregate state $\mathbf{s}$:

$$\begin{aligned} W(w, \mathbf{s}) = {} & w + \psi \frac{(1-e)^{1-1/\gamma} - 1}{1 - 1/\gamma} \\ & + \beta \Big\{ (1-\delta)\mathbb{E}\Big[\big\{ \lambda W(w, \mathbf{s}') + (1-\lambda) W(w^{*\prime}, \mathbf{s}') \big\} \big| \mathbf{s} \Big] + \delta \mathbb{E}\big[U(\mathbf{s}') | \mathbf{s} \big] \Big\}. \end{aligned} \tag{1}$$

$w^{*\prime}$ denotes next period's wage, provided the match is given an opportunity to renegotiate. Effort level e is determined through Nash bargaining, which is described below in detail. Let $U(\mathbf{s})$ denote the value for an unemployed worker for state $\mathbf{s}$:

$$U(\mathbf{s}) = b + \beta \Big\{ p(\theta)\mathbb{E}\big[W(w^{*\prime}, \mathbf{s}') \big| \mathbf{s} \big] + \big(1 - p(\theta)\big)\mathbb{E}\big[U(\mathbf{s}') \big| \mathbf{s} \big] \Big\}, \tag{2}$$

where b denotes unemployment insurance benefits (or simply the value of leisure when not working). From the values for employed versus unemployed workers, a worker's match surplus

$H(w, \mathbf{s})$ is defined as follows:

$$\begin{aligned} H(w, \mathbf{s}) &= W(w, \mathbf{s}) - U(\mathbf{s}) \\ &= w - b + \psi \frac{(1-e)^{1-1/\gamma} - 1}{1 - 1/\gamma} + \beta(1-\delta)\lambda \mathbb{E}\big[H(w, \mathbf{s}') - H(w^{*\prime}, \mathbf{s}')|\mathbf{s}\big] \\ &+ \beta\big(1 - \delta - p(\theta)\big)\mathbb{E}\big[H(w^{*\prime}, \mathbf{s}')|\mathbf{s}\big]. \end{aligned} \tag{3}$$

Analogously, let $J(w, \mathbf{s})$ denote the value of a matched firm whose worker is contracted at wage w when the aggregate state is $\mathbf{s}$:

$$J(w, \mathbf{s}) = \alpha z k^{1-\alpha} e - w + \beta(1-\delta)\lambda \mathbb{E}\big[J(w, \mathbf{s}') - J(w^{*\prime}, \mathbf{s}')|\mathbf{s}\big] + \beta(1-\delta)\mathbb{E}\big[J(w^{*\prime}, \mathbf{s}')|\mathbf{s}\big]. \tag{4}$$

Note that a firm's output, net of rental cost of its capital, is $y - (r+d)ke = \alpha z k^{1-\alpha} e$.

Firms post vacancies, v, such that the expected value of hiring a worker equals the cost of vacancy (i.e., the value of vacancy $V(\mathbf{s}) = 0$):

$$\kappa = \beta q(\theta)\mathbb{E}\big[J(w^{*\prime}, \mathbf{s}')|\mathbf{s}\big]. \tag{5}$$

The wage is determined by Nash bargaining between a worker and firm when matches are newly formed, as well as for the fraction λ of ongoing matches that renegotiate a wage.

$$w^*(\mathbf{s}) = \underset{w}{\operatorname{argmax}}\, H(w, \mathbf{s})^{\eta} J(w, \mathbf{s})^{1-\eta}. \tag{6}$$

We have imposed that the firm's bargaining parameter coincides with the relative importance of vacancies in the matching function so that the Hosios condition holds.

The first order condition for the Nash-bargained wage $w^*(\mathbf{s})$ is:

$$\eta J(w^*, \mathbf{s})\partial H(w^*, \mathbf{s})/\partial w + (1-\eta)H(w^*, \mathbf{s})\partial J(w^*, \mathbf{s})/\partial w = 0. \tag{7}$$

An increase in wage under fixed effort is a pure transfer from firm to worker, so $\partial H(w^*, \mathbf{s})/\partial w = -\partial J(w^*, \mathbf{s})/\partial w$. In turn, we have $J(w^*, \mathbf{s})/H(w^*, \mathbf{s}) = (1-\eta)/\eta$. More generally, if effort is chosen to maximize joint surplus, as our model implies under flexible wages, then an envelope condition still implies that $J(w^*, \mathbf{s})/H(w^*, \mathbf{s}) = (1-\eta)/\eta$. Under sticky wages, our model does not necessarily deliver the joint wealth maximizing effort choice. A marginally higher bargained wage, by increasing subsequent effort choice, can marginally increase or decrease joint surplus. Nevertheless, we have, for the log-linearized decisions analyzed below, $\partial H(w^*, \mathbf{s})/\partial w \approx -\, \partial J(w^*, \mathbf{s})/\partial w$. Therefore, across the model variations we consider, we have:[9]

$$\frac{J(w,\mathbf{s})}{H(w,\mathbf{s})} \approx \frac{1-\eta}{\eta}. \tag{8}$$

Given the bargained wage, each period the firm and its matched workers must bargain over effort. We consider two alternatives. First, we treat effort as bargained by the firm separately for each individual worker. Second, we consider the firm as bargaining over a common effort level jointly with all its matched workers. We refer to the former as the "individual effort model," the latter as the "common effort model".

Effort level in the individual effort model, given the contracted wage w and the aggregate state $\mathbf{s}$, is determined through Nash bargaining between the firm and each worker:

$$e^*(w,\mathbf{s}) = \underset{e}{\operatorname{argmax}}\, H(w,\mathbf{s})^{\eta} J(w,\mathbf{s})^{1-\eta}$$

This yields the following first order condition for $e^*(w,\mathbf{s})$:

$$\frac{\alpha z k^{1-\alpha}}{\psi(1-e^*)^{-1/\gamma}} = \frac{\eta}{(1-\eta)} \frac{J(w,\mathbf{s})}{H(w,\mathbf{s})}, \tag{9}$$

where $e^*(w,\mathbf{s})$ is also reflected in the surpluses of worker and firm, $H(w,\mathbf{s})$ and $J(w,\mathbf{s})$. Under a flexibly-chosen wage, since $J(w^*,\mathbf{s})/H(w^*,\mathbf{s}) = (1-\eta)/\eta$, this reduces to $\alpha z k^{1-\alpha} = \psi(1-e^*)^{-1/\gamma}$. Intuitively, under flexible wages the marginal product of effort equals its marginal disutility, as needed to maximize joint surplus. But under a sticky wage that will not generally be true. For instance, if the wage is stuck above its flexible counterpart, so $J(w^*,\mathbf{s})/H(w^*,\mathbf{s}) < (1-\eta)/\eta$, then the marginal product of effort gets pushed below its marginal disutility.[10] This reflects that, under the sticky wage, effort choice must serve the purpose of dividing match surplus, not just maximizing match surplus.[11]

Of course, it may not be realistic for a firm to vary work rules so freely across its employees. For instance, it is presumably difficult for any employer engaging workers in team

[9] Please see Appendix A for additional detail.

[10] At the outset of a sticky wage contract we have from (8) that $H(w^*,\mathbf{s})/J(w^*,\mathbf{s}) \approx \eta/(1-\eta)$. So, at that point, $\psi(1-e^*)^{-1/\gamma} \approx \alpha z k^{1-\alpha}$, with effort "close" to its flexible wage counterpart.

[11] Our model predicts higher effort if relative rents for the worker, $H(w,\mathbf{s}) - J(w,\mathbf{s})$, deviates above its flexible-wage counterpart. This resembles efficiency-wage models with imperfect monitoring that relate effort to worker rents in the job (e.g, Uhlig and Xu, 1996). But there are important differences from those settings. We assume effort is observable. There are no a priori rents, or queuing, in our model, even with sticky wages. We have Nash bargaining, whereas the efficiency wage is typically defined to minimize the firm's labor cost. Put in the context of Nash bargaining, that corresponds to putting all weight on the firm's objective. To the extent this is generalized, the efficiency wage model predictions for effort are weakened (Strand, 2003).

production to assign expectations of effort and performance that differ so dramatically across coworkers, especially if relative performance is a basis for promotion. For this reason, we also consider the common effort model, which is our preferred benchmark.

We assume this common effort level is also determined through bargaining. But, unlike wage bargaining and the individual effort bargaining above, this common effort bargaining involves all workers at the firm. Moreover, because the contracted wages of these matched workers differ, the surpluses accruing to the parties are heterogeneous. To capture this environment we employ a multi-party bargaining protocol. Specifically, $e^*(\mathbf{s})$ is chosen according to the Nash bargain:

$$e^*(\mathbf{s}) = \underset{e}{\operatorname{argmax}} \left[\prod \left(H(w,\mathbf{s})\right)^{dG(w)}\right]^{\eta} \left[\int J(w,\mathbf{s})dG(w)\right]^{1-\eta}. \tag{10}$$

Workers are stratified by their bargained wage w. We assume all workers receive equal weight in bargaining; so for a wage group of share $dG(w)$, the bargaining share is $dG(w)$.[12] The first-order condition for choosing the common effort $e^*(\mathbf{s})$ is:

$$\frac{\alpha z k^{1-\alpha}}{\psi(1-e^*)^{-1/\gamma}} = \frac{\eta}{(1-\eta)} \left[\int J(w,\mathbf{s})dG(w)\right] \left[\int \frac{1}{H(w,\mathbf{s})} dG(w)\right]. \tag{11}$$

The bracketed terms on the right side are, respectively, the average firm surplus (arithmatic mean) across all matches and the harmonic mean of surplus across workers.[13]

In steady-state, or under flexible wages, the right-hand side reduces to 1, with effort's marginal product equated to its marginal disutility. But under sticky wages, predetermined according to (6), the marginal product of effort will be pushed below its marginal disutility if the wage is stuck too high.[14]

[12] Nash bargaining guarantees positive surplus for the firm and for each worker, provided total surplus is positive. Under the common effort choice, it is conceivable for the firm to experience negative surplus for some workers, with this cross-subsidized by more profitable (lower wage) matches. But this will not occur for sufficiently small shocks, given we calibrate realized matches to have surplus in steady state.

[13] This reflects the multi-party bargaining for the choice of common effort level between the firm and all workers where firm's surplus is the average profit across matched jobs. One could consider an alternative multi-party bargaining protocol where workers' surplus are also represented by the arithmatic mean as well. The resulting FOC is identical to that under our bargaining protocol, to a log-linear approximation.

[14] Under both individual and common effort choices we treat the wage as Nash bargained at the individual match level, dividing rents over that match. Under common effort we assume workers treat subsequent effort choices as independent of their bargained wage, as they are trivially small relative to the firm's workforce. For the firm there potentially exists an incentive to bargain upward the wages of new hires, in order to push up the effort of other workers. This represents a form of "cheating" on bargains previously negotiated. We exclude such cheating by assuming that the firm can commit to negotiate individual wages on the basis

In addition to the wage and effort levels, a key variable for the model dynamics is the vacancy-unemployment ratio (θ). Combining (4) and (5) yields the forward-looking difference equation for θ:

$$\frac{\kappa}{q(\theta)} \approx \beta \mathbb{E}\left[\alpha y' - \beta(1-\delta)\lambda\mu(\mathbf{s}'')(w^{*\prime} - w^{*\prime\prime}) + (1-\delta)\frac{\kappa}{q(\theta')}\middle|\mathbf{s}\right]. \tag{12}$$

where $-\mu(\mathbf{s}'')(w^{*\prime} - w^{*\prime\prime})$ is a first-order Taylor approximation to $J(w^{*\prime}, \mathbf{s}'') - J(w^{*\prime\prime}, \mathbf{s}'')$. This expression for the dynamics of θ holds for both the individual effort and the common effort models. However, due to the differences in the first-order condition for effort described above, cyclicality of the vacancy-unemployment ratio differs considerably across the two models.

3 Calibration

Imposed Parameters The period is a quarter. The discount factor β is set to 0.99, implying an annualized real interest rate of 4 percent. The real interest rate (1 percent), combined with the maintenance cost $d = 2.5$ percent per unit, yields a steady-state quarterly rental rate of capital (marginal product of capital), $r + d$, of 3.5 percent. The elasticities for u_t and v_t in the matching function, η and $1 - \eta$, are each set to one half, partly for convenience, but also to be roughly consistent with empirical estimates (e.g., Rogerson and Shimer, 2010).

Key parameters for the impact of wage stickiness on hiring are the duration of wage contracts, the Frisch elasticity of labor effort, and labor's share in production. We set the average duration of wage contracts to one year, which implies $\lambda = 3/4$. This is a typical choice for calibrating wage stickiness in the literature. It also coincides with our estimates from individual data reported in Section 6.

The Frisch elasticity of labor effort, $\gamma\frac{1-e}{e}$, reflects both parameter γ and the level of effort. We first normalize effort, by choice of ψ, so that $e = 0.5$ in steady state.[15] This implies the Frisch elasticity is γ. This elasticity is difficult to calibrate, given that effort is typically not

of dividing individual match surplus as in (6). Because negotiated wages anticipate future common effort levels, but do not attempt to influence these choices, wage choices under common effort reflect $\frac{J(w,\mathbf{s})}{H(w,\mathbf{s})} = \frac{1-\eta}{\eta}$ exactly, not just approximately.

[15]The steady state effort level reflects the utility parameter ψ, and other calibrated parameters, according to: $e = 1 - \left(\frac{\psi}{\alpha}\right)^{\gamma}\left(\frac{r+\delta}{1-\alpha}\right)^{\frac{\gamma(1-\alpha)}{\alpha}}$.

observed. We set $\gamma = 0.5$ so that the Frisch elasticity for effort is 0.5. Comparing this choice to estimates of the Frisch elasticity for the workweek margin, it is in the range surveyed by Hall (2009). For salaried workers we might anticipate a larger elasticity for effort than the workweek, as effort movements in our model would reflect movements in their workweek as well as intensity per hour. For hourly paid workers, we might anticipate a smaller elasticity for effort than for the workweek.[16]

Labor's share, under Cobb-Douglas production, dictates the elasticity of the labor demand schedule. In turn, this dictates the degree that higher effort from existing workers will crowd out hiring. We set the labor share parameter in production, α, to 0.64. This implies aggregate labor demand is very elastic, with elasticity of $\frac{1}{1-\alpha} = 2.78$, yielding only modest crowding out effects. But other factors could be introduced that limit the short-run elasticity of labor demand, further magnifying effort's impact on hiring.[17]

Targeted Parameters Other parameters are chosen to match the following steady-state targets. The labor-market tightness ($\theta = v/u$) is normalized to one. The match efficiency ($\chi = 0.6$) is chosen so that the job finding rate, $p(\theta) = \chi\theta^{1-\eta}$, is 60 percent in steady state given an elasticity of the matching function with respect to unemployment, η, of 1/2. The job separation rate ($\delta = 4$ percent) is chosen so that the steady-state unemployment rate is 6.25 percent. The vacancy posting cost (κ) is chosen to satisfy the free entry condition in (5). Given the steady-state wage ($\widetilde{w}$), the unemployment benefit (b) is chosen so that the replacement rate (in terms of utility), $b \Big/ \left(w_{ss} + \psi \frac{(1-e)^{1-1/\gamma} - 1}{1-1/\gamma} \right)$, equals 75 percent, which is the benchmark value in Costain and Reiter (2008).

Our parameter choices are summarized in Table 1.

[16] Schor (1987) reports a time-series for physical activity of 131,500 piece-rate workers in a standing panel of 171 British factories for years 1970 to 1986. The measure represents the ratio between actual effort and a standard level of intensity as defined by "time and motion" men. Schor regresses effort on hours per week in British manufacturing as well as additional variables. The estimated elasticity of effort with respect to the workweek varies from 0.52 to 0.60 across five specifications (with standard errors of about 0.14). Bils and Cho (1994) take this as an estimate of the relative Frisch elasticities for the effort versus workweek margins.

[17] In particular, if prices are sticky then increased effort might create sharper reductions in hiring, since price cuts cannot maintain output sold and produced. So price stickiness may complement wage stickiness as a force for employment volatility in our model, whereas in standard Keynesian models, with fixed effort, wage and pricing frictions act somewhat as substitutes.

4 Characterizing the Model's Wage Dynamics

Since analytical solutions are not available, we largely rely on numerical solutions that approximate the log-linearized equilibrium dynamics around steady state to describe business cycles in our model. Before performing the full quantitative analysis, we first focus on the model's wage dynamics in order to gain intuition for what drives the differences between our model and a standard fixed-effort, sticky-wage model. Implications for the model's other key variables such as effort and labor-market tightness follow from these dynamics in wages. (Detailed derivations of the steady state and the entire log-linearized dynamics around the steady state are provided in Appendix A.)

Let $\widetilde{x}$ denote the steady state of variable x, while $\widehat{x}$ denotes the percentage deviation of x from $\widetilde{x}$.[18] The first-order condition for the wage at steady state is $\eta \widetilde{J} = (1-\eta)\widetilde{H}$. This yields the well-known condition for the Nash-bargained wage:

$$\widetilde{w} = (1-\eta)\left(b - \psi \frac{(1-\widetilde{e})^{1-1/\gamma} - 1}{1-1/\gamma}\right) + \eta(\alpha \widetilde{y} + \kappa \widetilde{\theta}). \tag{13}$$

$\widetilde{y} = \widetilde{z}\widetilde{k}^{1-\alpha}\widetilde{e}$ is output in the steady state, where $\widetilde{k} = \bar{K}/(\widetilde{n} \cdot \widetilde{e})$ denotes steady-state capital per efficiency unit of labor. The wage is a weighted average of the loss from working (unemployment benefits and foregone utility from leisure) and the sum of the firm's output and the vacancy posting costs per unemployed worker.

The steady-state effort choice, $\widetilde{e}$, for both bargaining protocols, equates the marginal rate of substitution between effort and consumption to effort's marginal productivity: $\psi(1-\widetilde{e})^{-1/\gamma} = \alpha \widetilde{z}\widetilde{k}^{1-\alpha}$. The steady-state Frisch elasticity equals $\gamma \frac{1-\widetilde{e}}{\widetilde{e}}$, which we denote for convenience by $\widetilde{\gamma}$.

For a "standard" sticky-wage version of our model with effort fixed, the deviation in the Nash-bargained wage can be expressed as:

$$\widehat{w}_t^* = (1-\tau)\sum_{j=0}^{\infty} \tau^j E\widehat{w}_{F,t+j}^*, \tag{14}$$

where $\tau = \beta(1-\delta)\lambda$. $\widehat{w}_{F,t}^*$ is the wage that would occur under flexible wage setting, often

[18] The steady state values are derived assuming no aggregate uncertainty, i.e., $z_t = \widetilde{z}$ for all t. Hence all variables are constant and, especially, the distribution of wages is degenerate at $\widetilde{w}$.

called the target or spot wage.[19] Equation (14) is the familiar time-dependent wage setting rule, e.g. Calvo (1983). The bargained wage reflects anticipated target flexible wage rates, with weights declining geometrically into the future. For our calibration $\tau = 0.713$.

The aggregate wage reflects $\widehat{w}_t^*$; but it also reflects the previous aggregate wage for the share, $\lambda(1-\delta)$, of workers who continue at their previous wage. For comparison of wage dynamics across models, we express the aggregate wage $\widehat{\overline{w}}_t$ as a weighted average of its lagged value ($\widehat{\overline{w}}_{t-1}$), its expected value one period ahead ($E\widehat{\overline{w}}_{t+1}$), and the target flexible wage ($\widehat{w}_{F,t}^*$):

$$\widehat{\overline{w}}_t = \pi_1 \widehat{\overline{w}}_{t-1} + \pi_2 E\widehat{\overline{w}}_{t+1} + (1-\pi_1-\pi_2)\widehat{w}_{F,t}^*, \tag{15}$$

where $\pi_1 = \frac{\lambda(1-\delta)}{1+\beta\lambda^2(1-\delta)^2}$ and $\pi_2 = \frac{\beta\lambda(1-\delta)}{1+\beta\lambda^2(1-\delta)^2}$.

We can contrast these dynamics for $\widehat{w}_t^*$ and $\widehat{\overline{w}}_t$ with those under our model with variable effort. To streamline the exposition, we focus on our preferred specification with common effort. The choice for $\widehat{w}_t^*$ under common effort can be written to parallel (14) as:

$$\widehat{w}_t^* = (1-\varphi)\sum_{j=0}^{\infty}\varphi^j E\widehat{w}_{F,t+j}^* + \left(1-\frac{\varphi}{\tau}\right)\sum_{j=0}^{\infty}\varphi^j E\left(\widehat{\overline{w}}_{t+j} - \widehat{w}_{F,t+j}^*\right), \tag{16}$$

where $\varphi = \tau\frac{(1+\widetilde{\gamma}(1-\alpha))\eta\widetilde{J}}{(1-\eta(1-\alpha))\widetilde{\gamma}\alpha\widetilde{y}+(1+\widetilde{\gamma}(1-\alpha))\eta\widetilde{J}}$, and $\widetilde{\gamma} = \gamma\frac{1-\widetilde{e}}{\widetilde{e}}$ is the Frisch elasticity of effort. As $\widetilde{\gamma}$ goes to zero, φ converges to τ, and the model becomes identical to the fixed effort case. That is, our model nests the standard model of fixed effort as the Frisch elasticity goes to zero.

More generally, φ is less than τ. For instance, for the benchmark calibration $\frac{\varphi}{\tau}$ equals only 0.277. (φ equals 0.198.) This implies that the newly set wage reflects, not just the anticipated target flexible wages, but also any expected deviation of the aggregate wage from that target. In fact, for the calibrated model the coefficient, $1-\frac{\varphi}{\tau}$, is large, equaling 0.723. Any expected deviation in the aggregate wage from its flexible counterpart means

[19] $\widehat{w}_{F,t}^*$ is the Nash bargained wage under wage flexibility derived in Appendix A. For fixed effort

$$\widehat{w}_{F,t}^* = \eta\alpha\left(\frac{\widetilde{y}}{\widetilde{w}}\right)(\widehat{z}_t - (1-\alpha)\widehat{n}_t) + \eta\kappa\left(\frac{\widetilde{\theta}}{\widetilde{w}}\right)\widehat{\theta}_t,$$

which is a special case, with $\widetilde{\gamma} = 0$, of the flexible wage under variable effort, (A.29):

$$\widehat{w}_{F,t}^* = \alpha\left(\frac{\widetilde{y}}{\widetilde{w}}\right)\left(\frac{\eta+\widetilde{\gamma}}{1+\widetilde{\gamma}(1-\alpha)}\right)(\widehat{z}_t - (1-\alpha)\widehat{n}_t) + \eta\kappa\left(\frac{\widetilde{\theta}}{\widetilde{w}}\right)\widehat{\theta}_t.$$

that the worker's effort will be pushed in that same direction; for this reason, the Nash bargain also pushes $\widehat{w}_t^*$ upward—a high wage is associated with high effort.

But the choice for $\widehat{w}_t^*$ differs from that under fixed effort in (14), even if the aggregate wage is not expected to deviate from the target flexible wage. For $\widetilde{\gamma} > 0$, because φ is less than τ, wage setting puts more weight on target wages in the near term than implied by discounting at factor τ. This reflects that the wage choice here influences the path for effort, as well as dividing the rents. It is optimal to align the wage with the current spot wage to achieve a more efficient effort choice today. Of course, this implies, in expectation, a less efficient choice later in the contract. But, due to separations or the Calvo probability of re-contracting, that impact on future effort choice may never arise. The larger is the Frisch elasticity, $\widetilde{\gamma}$, the more sensitive is wage setting to that discounting of future effort choices, and so the more wages reflect current target wages over future values. Because effort can respond in the future, the wage setting acts "as if" wages will be much more flexible in the future than implied simply by the Calvo parameter. Thus, the current wage bargaining puts less weights on the future (flexible) wages.

The aggregate wage under common effort can be written to parallel (15) as:

$$\widehat{\overline{w}}_t = \pi_1^c \widehat{\overline{w}}_{t-1} + \pi_2^c E \widehat{\overline{w}}_{t+1} + (1 - \pi_1^c - \pi_2^c) \widehat{w}_{F,t}^*, \tag{17}$$

where $\pi_1^c = \frac{(1-\delta)\lambda}{1+\varphi(1-\delta)\lambda-(1-(1-\delta)\lambda)(1-\varphi/\tau)}$ and $\pi_2^c = \frac{\varphi}{1+\varphi(1-\delta)\lambda-(1-(1-\delta)\lambda)(1-\varphi/\tau)}$.

We show in Appendix A that $\pi_1^c > \pi_1$. For our benchmark calibration it is much higher, with $\pi_1^c = 0.871$ versus $\pi_1 = 0.475$ under fixed effort. Thus, the aggregate wage exhibits much more inertia if effort responds. We also show in the appendix that $\pi_2^c < \pi_2$. For our calibration $\pi_2^c = 0.115$, versus $\pi_2 = 0.471$ under fixed effort. This is anticipated from (16) by the severe down-weighting of future target wage rates when effort responds. Finally, we can show that the coefficient on the current target flexible wage, $(1 - \pi_1^c - \pi_2^c)$, is pushed very low under the common effort model. For our calibration it is only 0.013, compared to 0.053 under fixed effort.

The impact on effort of sticky wages largely reflect these dynamics for wages, as effort will deviate from its flexible-wage counterpart so as to mirror the deviations of the aggregate wage from the flexible, target wage. So factors, such as a larger Frisch elasticity or stickier wage rate (larger λ), that generate greater wage inertia will, in turn, generate greater effects on effort. The model implications for labor market tightness and employment are more difficult to analyze, except numerically. But, to the extent wages are pushed above the target wage, thereby driving up effort, this reduces labor's marginal product given $\alpha < 1$. Thus the importance of wage stickiness on cyclicality of new hires follows from the inertia in aggregate wages, in combination with the size of capital's share, $1 - \alpha$.

Results under individual effort choice for the Nash bargained wage, $\widehat{w}_t^*$, and aggregate wage, $\widehat{\overline{w}}_t$, are provided in Appendix A. While the equations for $\widehat{w}_t^*$ and $\widehat{\overline{w}}_t$ take the same forms as do (16) and (17) under common effort, the equations' parameters differ considerably. As with common effort, the bargained wage discounts future target wages much more severely given that effort will be able to respond. But under individual effort, anticipated *aggregate* wage rates, given the target flexible wages, have essentially no impact on current wage setting because effort can adjust individually across matches. We show in Appendix A that parameter π_1 governing aggregate wage inertia is intermediate in the individual effort model to that under fixed effort and common-effort choice. But the parameter π_2 is *much* less than its corresponding value under fixed effort. As a result, the coefficient on the current target wage, $1 - \pi_1 - \pi_2$, is actually much higher than under fixed effort. For our calibration it equals 0.20, compared to 0.053 with effort fixed, and only 0.013 under common-effort choice. As a result, wages show far less persistence under individual than under common effort. We highlight these differences in the full model results to follow.

5 Results

We illustrate how our model with endogenous effort responds to contractionary aggregate shocks. We first consider a recession driven by a negative productivity shock that reduces labor demand, and then that driven by a preference shock reducing labor supply.

5.1 Response to Negative Labor Demand (Productivity) Shocks

5.1.1 Impact of an Effort Response

We first present the results under both flexible and sticky wages when effort is fixed in Figure 1. We give the productivity shock an auto-correlation of 0.95 (in panel 1).[20]. We

[20]An auto-correlation of 0.95 for productivity is fairly standard in the literature. It is also close to the auto-correlation of 0.96 we see for U.S. TFP, if we remove a quadratic trend, for 1959:I to 2017:IV. (We

assume a Calvo parameter of 0.75; so wages have an expected duration of four quarters. The newly-bargained wages, panel 2, respond sharply, responding essentially one-for-one to the productivity. It responds slightly less under sticky wages, reflecting that the bargained wage is likely to remain unchanged for a while. Of course, the aggregate wage (in panel 3) responds much less on impact under sticky wages. But after six, or so, quarters most wages will reflect the shock to productivity–so the aggregate wage coincides under flexible or sticky wages. The last panel of Figure 1 illustrates employment responds much less than one-to-one to the productivity shock. Under fixed effort, sticky-wage employment and output responses are identical to those under perfectly flexible wages. This is anticipated by the literature (Shimer, 2004, among others), and reflects that the expected present value of wages for new hires is exactly the same under flexible and sticky wages.

Figure 2 compares the three scenarios of sticky wages: (1) fixed effort, (2) an individual effort choice, (3) a common effort choice across workers (our preferred specification). Consider sticky wages with effort chosen individually across workers. The first panel of Figure 2 shows that the newly-bargained wage drops nearly twice as much during the first year as under fixed effort. The reason is apparent from Figure 3, which depicts the varied responses in effort across workers. The initial response for workers under sticky wages (i.e., old contracts) is an effort increase of 0.8 percent. But that effort increase drives the marginal product of labor even lower (along the downward-sloping marginal product of labor schedule) than dictated by the productivity shock alone.[21] As a result, the wage decreases more for new bargains. Overall, as depicted in Figure 2's third panel, average effort initially increases. This mitigates the initial impact on output and TFP (panels 4 and 5).

Returning to Figure 3, we see that the model yields dramatically different effort responses across workers. While the workers under sticky bargains increase effort by nearly enough to keep their productivity constant, the newly negotiating workers adjust their effort sharply in the opposite direction. If we view these workers operating within an organization, it seems unreasonable to have such varying work rules across employees. It is presumably difficult for any employer engaging workers in team production to assign expectations of effort and performance that differ so dramatically across coworkers. For this reason, we now move to

correct TFP for modestly procyclical capital utilization, as discussed in Section 6.1)

[21] For this reason, workers under new bargains actually decrease effort more than if all wages are flexible, as depicted in the appendix.

our preferred model with bargaining over a common effort level (denoted by solid line "−").

Looking at the first panel of Figure 2, under common effort we see that the wage in new bargains, though flexible, decreases far less than the magnitude of the productivity shock. As a result, as anticipated by Section 4, the model generates a great deal of inertia in wages. Even after two years, at which point 90 percent of wages have adjusted, the average wage is decreased by about 0.25 percent, which is only half the size of the decline in output.

The intuition is as follows. In bargaining over effort, firms face a trade-off between what is efficient for new bargains and what is most profitable for workers under sticky wages. After a negative shock the efficient new bargain asks for lower effort, combined with deeper wage cuts. But, because workers with dated wage bargains are over-paid, the firm can demand more effort from these workers. The effort bargain trades off these objectives, but is heavily driven by the desire to obtain the possible effort level from the sticky-wage workers (which is the majority of the workforce). Why does wage inertia persist well after all wages are renegotiated? Consider wage bargains in the first period after the shock. Because effort is increased for these workers, their wage is cut less. But that wage is then stuck higher going forward, acting to generate higher effort choices. In turn, this pushes future bargains to adopt higher effort and higher wages. Thus the wage rigidity pushes up effort, which pushes up subsequent wages, pushing up subsequent effort, and so forth. Our mechanism generates results similar to having a "relative-wage concern" in bargaining, emphasized by Keynes (1936) and others, even though relative wages are not a concern to agents.

Turning to panel 3 of Figure 2, we see that common effort increases to offset much of the negative shock to productivity. Output (panel 4) and measured TFP (panel 5) decline by less than half as much as the underlying shock to productivity during the first few quarters, and by about one-third less even after two years. The overall impact is a humped shape response in average effort, output, and measured TFP, despite no such shape for the underlying shock to productivity.

The strong response in effort reduces new hires' marginal product, and the benefit of hiring, beyond the direct impact of the drop in productivity. As a result, employment (panel 6) drops by nearly 40 percent more than under fixed effort. In fact, there is complementarity between the cyclical responses in effort and employment. The increase in effort amplifies the shock's impact on employment. But, by lowering labor market tightness, this in turn drives up match surplus for workers, thereby further increasing the choice for effort. The upshot is that sticky wages in existing contracts magnifies cyclicality of new hires, even though wages are flexible for these new hires.[22]

In Table 2 we report cyclical elasticities of employment, new-hire wages, aggregate wages and TFP with respect to output across the alternative sticky-wage models. The model economies are subjected to persistent productivity shocks (auto-correlation of 0.95). All series, model simulated or data, are HP-filtered. Appendix B additionally reports results for the flexible-wage models as well as model results for the variables' standard deviations and correlations with real output.

The first column of the table reports the quarterly statistics for the same variables for the U.S. economy for 1959:I to 2017:IV. The series for real output, employment, and average earnings are for the U.S. business sector as reported by the BLS program on Labor Productivity and Costs (http://www.bls.gov/lpc/). TFP is constructed from real output, hours, from the same source, and business-sector capital stock from the U.S. Department of Commerce.[23] Although there is no data series for w^*, a number of studies estimate cyclicality of new-hire wages. New hires are one component of workers that newly bargain on wages. Basu and House (2016) estimate an annual series for new-hire wages based on the NLS Youth (NLSY) panel data for 1978 to 2013. They then create a quarterly time series that extends before the NLSY time frame from imputations based on patterns in the original annual series. We employ this empirical counterpart to w^* in Table 2. The elasticity of the Basu-House new-hire real wage (w^*) with respect to aggregate output is 0.48, while that of the average aggregate wage ($\overline{w}$) is essentially zero (estimate of -0.03, with standard error of 0.05). So the new-hire wage series is considerably more procyclical than the aggregate.

Table 2, top panel gives results for the sticky-wage models for fluctuations driven by productivity shocks. For comparison, the last column reports the cyclicality from the standard sticky-wage model (with constant effort), but where wages of newly-hired workers are

[22] We explored robustness of results to the frequency of wage change and the Frisch elasticity for effort. Predictably, a lower frequency of wage change magnifies the effects. For instance, if wage duration is increased from one to two years, the common-effort response magnifies the impact on employment by nearly 70 percent, compared to the 50 percent impact in our benchmark calibration. If we increase the Frisch elasticity from 0.5 to 1.0, effort's response magnifies the impact on employment by 80 percent, rather than by 50 percent.

[23] The capital series is annual; we interpolate to create a quarterly series. It also reflects a correction for procyclical capital utilization, as discussed in Section 6.1.

explicitly tied to the sticky contracted wages of existing workers as, for instance, in Gertler and Trigari (2009). Thus the label G-T.[24] By assumption, cyclicality of the newly-hired wage is identical to that of the aggregate in G-T. The other sticky-wage models all generate newly-hired wages that are more cyclical than the aggregate. Both the models with fixed effort or individual effort exhibit wages that are more cyclical than seen in the data, especially for the aggregate wage. By contrast, our sticky-wage model with common effort generates wage cyclicality that is reasonably similar to the data, with elasticities of 0.35 and 0.16 respectively for w^* and $\overline{w}$, compared to their data elasticities of 0.48 and -0.03. Notice that the G-T model generates an aggregate wage that is actually twice as cyclical as for our model, so further from the data, despite setting the wage for new hires at that of existing sticky contracts.

In the data, the cyclicality–elasticity with respect to real output–of employment is 0.59. All the models under-predict this moment (i.e., exhibit the Shimer puzzle). But our model with a common-effort response generates by far the most cyclical employment across the models, with an elasticity of 0.46. Compared to the G-T economy, it not only generates more inertia in the aggregate wage, but also generates employment that is twice as cyclical, even though newly-hired wages are flexible. All the models overstate the elasticity of TFP to output, which is only 0.39 for the data. But the extent of that overstatement for the model with common-effort response, 0.65, is considerably less than for the other models, which are all in the range of 0.9.

5.1.2 Volatility of Employment Versus Productivity

In this subsection, we illustrate how our model can alleviate the so-called Shimer puzzle. Shimer (2005) pointed out that the volatility of unemployment (or employment) relative to labor productivity is at odds with calibrated responses of the Mortensen-Pissarides model driven solely by productivity shocks. Sticky wages for existing workers, provided that of new hires is flexible, do not alter these calculations under fixed effort. We show here that our preferred model, with bargaining over common effort, has a relatively small Shimer (2005) puzzle, despite the replacement flow value of unemployment being calibrated to only 75

[24] We calibrate the parameters of this model to be comparable to our benchmark (the replacement ratio of 0.75, Calvo parameter $\lambda = 3/4$, etc.).

percent. There are two reasons for this: (1) The effort response in the model exacerbates employment's response to productivity, as outlined above. (2) Effort's response masks part of the cyclicality of the underlying shock, so that employment fluctuations look larger relative to those in productivity.

If worker effort responds to underlying shocks, then measured TFP will reflect both "exogenous productivity" and endogenous variation of effort. It is necessary, therefore, to identify a series of exogenous shocks to productivity such that these shocks and the response in effort combine to yield the series for TFP we see in the data. To illustrate, first consider feeding the model a time series of exogenous productivity shocks (z's) which mimics U.S. TFP for 1959:I to 2017:IV. The first panel of Figure 4 displays this series (HP-filtered). Under the fixed effort model, measured TFP exactly coincides with these shocks. The upper right panel displays the time series for employment predicted by the fixed effort model as well as the actual U.S. data (both HP-filtered). It clearly illustrates the standard volatility problem–employment exhibits a standard deviation only one-seventh that in the data.

For models with endogenous effort, measured TFP differs systematically from exogenous productivity (z). For example, in our preferred common-effort model, effort moves oppositely the exogenous productivity shocks. The middle row of Figure 4 shows that, *if* we feed the model productivity shocks exactly equal to measured TFP from the data, then it generates a model TFP series that is actually much less procyclical than in the data. In order to match the measured TFP in the data, the model requires that we sufficiently magnify the shocks to productivity. More exactly, we iterate on the shocks, period by period, until measured TFP for our model converges to actual TFP data. The resulting productivity shocks are given in the last row of Figure 4. These required shocks are nearly twice as volatile as measured TFP. The right panel of the last row shows predicted employment in our common effort model, for the adjusted shocks, together with U.S. data. The model now accounts for nearly two-thirds of employment volatility, with a standard deviation for employment of 1 percent versus 1.56 percent in the data.

Since effort partially masks the impact of productivity shocks on TFP, here we fed in productivity shocks nearly twice as volatile as measured TFP. Given the literature does not have especially compelling explanations for productivity shocks, this doubling in size could be viewed as a deficiency of our model. But in our model productivity shocks are not the only source of volatility in TFP. We next entertain shocks to preferences. These produce business cycles in our model that closely resemble those from productivity shocks–in particular, TFP is modestly procyclical.

5.2 Responses to a Labor Supply (Preference) Shock

The shocks to productivity generate procyclical labor demand. But employment fluctuations can reflect shocks that generate movements along a labor demand schedule. We entertain shocks to the preference parameter ψ. Antecedents for such shocks, but under fixed effort, include Sveen and Weinke (2008). An increase in ψ is a contractionary shock to labor supply and, thereby, to employment and output. In Figure 5 we illustrate responses to a one percent increase in ψ for sticky-wage models with fixed versus variable effort. (Results under flexible wages are presented in Appendix B.) We give the shock an auto-correlation of 0.95 to mimic that for productivity shocks.

First consider responses when effort is fixed. Newly-bargained wages increase reflecting the negative shock to labor supply. The aggregate wage (second panel) responds much less initially; but after four quarters its path response largely converges to that of the flexible newly-bargained wages. The last panel illustrates employment's negative response. This response is identical to that under flexible wages (see Appendix B) as wage stickiness for ongoing contracts is irrelevant for quantities under fixed effort.

Figure 5 also displays responses for the models that allow effort to respond, either reflecting an individual or common effort choice. Under both models, opposite to the fixed-effort case, wage rates decline in response to the negative labor supply shock because it drives down worker effort. But the magnitudes differ considerably across the models. Effort under individual effort declines sufficiently that after 4 quarters aggregate effort has fallen by one-third of a percent. The decline in the aggregate wage is only about half as large as that in effort because the negative labor supply shock increases the effective price of labor. Aggregate effort and wages also fall in response to the negative labor supply shock under our preferred model with common effort; but these effects are much more muted. As with the productivity shock, the model generates a great deal of inertia in wages rates, with the newly-bargained and aggregate wage both still declining 4 years after the shock. Reflecting effort's response, both output and TFP display hump-shaped declines. Employment initially drops by about two-thirds as much as output.

Comparing the model responses for the preference shock (Figure 5) to those for the productivity shock (Figure 2), they are remarkably similar, except with respect to effort. Effort declines in response to the contractionary preference shock, whereas it increases in response to the contractionary shock to productivity. But the relative patterns in wages, output, TFP, and employment are qualitatively similar for the two shocks for the models that allow effort to respond.

Table 2, bottom panel reports results for fluctuations driven by preference shocks. As with productivity shocks, the table gives the elasticity of employment, wage rates, and TFP with respect to real output. (Appendix B additionally reports results for the variables' standard deviations and correlations with real output. It also compares the moments of the sticky-wage models to those under flexible wages.) The model economies are subjected to persistent preference shocks, with auto-correlation 0.95.[25]

As with productivity shocks, the data are much closer to the model with a common effort response. The fixed effort model generates very different fluctuations under preference versus productivity shocks. The elasticity of employment with respect to output now exceeds one at 1.31; that is more than twice that in the data (0.59).[26] Wages are extremely countercyclical, exhibiting elasticities with respect to real output of -1.03 to -0.61, respectively, for the newly-hired and aggregate wage rates. These elasticities are estimated at 0.48 and -0.03 for the data.

Results for the models with variable effort closely resemble those generated by productivity shocks (top panel). In particular, our preferred model with common effort generates an elasticity of employment with respect to output of 0.50 in response to preference shocks. That closely resembles the 0.46 elasticity it generates under productivity shocks. These elasticities are both quite close to the corresponding value in the data of 0.59. Despite the shock being to preferences, the model creates procyclical measured TFP. The elasticity of TFP with respect to output under common effort response, 0.60, is only slightly less than

[25] We do not entertain the labor supply shock in the G-T model because there is no corresponding disutility from working (i.e., labor effort).

[26] This comparison is slightly unfair, since it ignores movements in hours per worker in the data. (All hours fluctuations in the models reflect employment.) For the data the elasticity of total hours (employment times workweek) with respect to output is 0.78, so still far short of 1.31.

for fluctuations driven by technology, 0.65. The common-effort model also does the best in matching observed wage cyclicality, with elasticities for newly-hired wages and aggregate wages with respect to output of respectively 0.22 and 0.09.

The models with individual effort predicts wages and productivity that are far too cyclical and employment that is far too acyclical. Notice this pattern also holds for these models under productivity shocks. Therefore, there is no mix of the shocks for which this model can reasonably match the data. The models with fixed effort generate extremely procyclical TFP for productivity shocks, but acyclical for preference. So, under the right mix of shocks, they could potentially be in the ballpark of the data. The model with common effort will fit the data reasonably well regardless of the relative mix of the two shocks.

6 Cross-Industry Test of the Model

The model provides a channel for wage stickiness to affect productivity, and thereby affect the number of workers hired. It is difficult to test those predictions from aggregate data without knowing the underlying shocks to the economy. For instance, our model predicts that productivity responds less to disturbances to productivity than under flexible wages. But, without knowing the true shocks to productivity, it is hard to evaluate the model based on cyclicality of measured productivity. Instead, we examine *cross-industry* patterns in the cyclicality of wages, hours, and productivity, stratifying industries by the stickiness of each industry's wage rates. We construct empirical proxies across 50 U.S. industries for flexibility in wage rates based on individual data on wage rates over time. The next two subsections describes our cross-industry data panel and the measure of wage stickiness. We then test whether productivity is less procyclical for industries we measure to have stickier wages.

6.1 KLEMS Data for Industry Wage, Hours, and Productivity

The U.S. KLEMS (http://www.bls.gov/mfp/) data provide nominal and real values for gross output, inputs of intermediates, labor, and capital annually from 1987 to 2016 for 60 industries. The KLEMS data exclude the government, nonprofit, and private household sectors. Some of the 60 KLEMS industries are quite small. For this reason, we combined certain industries (e.g., three mining industries are combined into a single mining sector) in order to measure wage stickiness by sector more reliably. Our resulting data reflect 50 distinct industries, with 22 producing goods, including 18 manufacturing. These are listed, with value-added shares, in Table 3.

The KLEMS data provide industry productivity, as measured by real gross output relative to real inputs (gross output TFP). We also construct value-added TFP measured by real value added relative to inputs of capital and labor. Industry real value added and its deflator are constructed using the divisia method from values and prices for gross output and intermediate inputs as described by Basu and Fernald (1997). In this construction we equate intermediate inputs cost shares with their revenue shares; so, implicitly we assume a zero rate of profit. We adjust TFP for the impact of procyclical utilization of capital as done in Bils, Klenow, and Malin's (2012, BKM for short). BKM employ data on utilization rates of capital constructed by Gorodnichenko and Shapiro (2011) for two-digit manufacturing for 1974 to 2004. BKM find that a one-percent increase in the labor to capital stock ratio is associated with a one-third percent increase in the utilization rate of capital. So we adjust TFP by subtracting capital's share multiplied by one-third times movements in the labor-capital ratio.

6.2 Measuring Wage Flexibility

We construct measures of wage flexibility–frequency of wage change–for each of our 50 industries based on the Survey of Income and Program Participation (SIPP). Appendix C describes our SIPP sample and variable constructions in detail. We calculate frequency of wage changes over the 4-month intervals between SIPP interviews for workers who remain with the same employer. Employed respondents report monthly earnings. We also calculate a weekly wage, dividing monthly earnings by weeks worked. A little over half of workers additionally report an hourly rate of pay. We define a worker's wage as not changing if any of these three measures remains the same across surveys.

A concern with micro data on wage changes is that some changes reflect measurement errors. Barattieri, Basu, and Gottschalk (2014), for instance, count only wage changes in the SIPP that can be viewed as a structural shift for the worker's wage series. We also allow for measurement error in wages, but adopt a simpler treatment. We assume an industry-specific Calvo probability of wage change over four months of α, while also allowing an industry-specific probability that the wage is measured with error. By comparing frequencies of wage changes over 4 versus 8 months, we can identify the 4-month probability of a change as:

$$\alpha = \frac{\Delta_8 - \Delta_4}{1 - \Delta_4}, \tag{18}$$

where Δ_4 and Δ_8, are probabilities of observing a wage change over 4 and 8-month intervals.[27]

To illustrate, Table 4 presents results for the 1990-1993, 1996, and 2001 SIPP panels pooling industries.[28] Consider results for the 1990-93 panels. These show very high rates of wage changes, 69 percent over 4 months and 78 percent over eight. Under Calvo, a *true* 69 percent 4-month frequency would imply a 90 percent frequency over 8 months, rather than 78 percent. Our approach rationalizes observed rates if the true 4-month frequency is 0.30 and the probability of measurement error equals 0.33. The 1996 and 2001 panels show higher frequencies. Our estimates interpret this as reflecting slightly higher measurement error for these panels and modestly more flexible wages (Calvo parameters of 0.38 and 0.33 for the 1996 and 2001 panels.) The bottom of the table aggregates the panels. The calculated Calvo parameter is 0.33. Inverting this frequency, and multiplying by the period of 4 months, would imply a wage duration of 12 months.[29]

Table 3 reports the Calvo duration of wages (in months) for each KLEMS industry. That duration varies from a low of 10.1 months for wood products and for petroleum and coal products to a high of 20.7 months for water transportation. The median wage stickiness across industries, weighting by industry value added, is 12.8 months.

6.3 Cyclicality of Wages, Hours, and TFP by Wage Stickiness

[27]The true probability of wage change over 8 months should equal $(2 - \alpha)$ times the 4-month probability. But, probability of changes in *measured* wages, Δ_4 and Δ_8 equal:

- $\Delta_4 = \alpha + (1-\alpha)(2\phi - \phi^2)$
- $\Delta_8 = (2\alpha - \alpha^2) + (1 - 2\alpha - \alpha^2)(2\phi - \phi^2)$,

where ϕ is the probability a wage is measured with error. These yield α as in (18); and ϕ solves the equation, $0 = \phi^2 - 2\phi + \frac{2\Delta_8 - \Delta_4^2 - \Delta_4}{1-\Delta_4}$. This identification assumes: (i) zero probability of a true wage change, followed by an exactly offsetting true wage change; (ii) zero probability that change in measurement error exactly offsets a true wage change.

[28]Beginning with the 2004 panel, the SIPP carries employment information forward from the prior survey if a respondent states that their employment and earnings are basically unchanged. This raises concern that wage changes, especially smaller ones, are missed. For this reason, we restrict attention to the 1990 through 2001 panels.

[29]We find similar frequencies if we separate hourly and salaried workers–Calvo parameter 0.35 for hourly versus 0.31 for salaried. While the frequency of wage change is higher for salaried workers, our approach interprets this as reflecting their greater frequency of measurement errors.

To contrast industry cyclicality by wage stickiness, we construct time series for real wages, TFP, and total hours separately grouping industries with wage stickiness greater than the median and grouping those at or below the median. Real output, and therefore TFP, is presumably better measured for goods industries than for services, as it is particularly difficult to measure output quality for services. Furthermore, we anticipate goods industries to be much more cyclically affected, especially those producing durable goods. For this reason we first separate the industries between the 22 goods industries (manufacturing, construction, agriculture, and mining) and 28 service industries, before further dividing by wage stickiness.[30,31] We measure the cycle by the behavior of HP-filtered annual U.S. real output (smoothing parameter of 6.25). Aggregate real output is for the nonfarm business sector (BLS Labor Productivity and Costs program). The time series for real wages, TFP, and total hours constructed from the KLEMS data are similarly HP-filtered.[32]

Results for the goods industries are presented in the top panel of Table 5. The top row shows that hours worked for sticky-wage goods industries display an elasticity of 2.00 with respect to aggregate real output. The real wage and TFP are both modestly countercyclical for these industries, though these relations are not statistically significant. The next two rows give results for the flexible-wage industries, then for the differences between series for the sticky and flexible-wage industries. Jumping to the differences, we see that hours are more procyclical for the sticky-wage industries. By contrast, real wages and TFP are more countercyclical for the sticky-wage goods industries. The difference for TFP is especially large and statistically significant–a one percent increase in aggregate output is associated with a 0.90 percent (s.e. of 0.15 percent) relative decrease in relative TFP for these in-

[30]Setting the cutoff at 12.8 months, coincidentally, divides industries into those below and above median duration (weighting by value-added) both for the 22 goods industries and for the 28 non-goods industries. It also does so for the 14 durable goods industries we consider below.

[31]Wage rigidity matters more for our model if effort choices are tied across workers. This is another reason we divide goods industries from services. While we cannot measure dependence of effort across workers, supplemental questions in the May 1997, 2001, and 2004 Current Population Surveys ask workers, "Do you have flexible hours that allow you to vary or make changes in the time you begin/end work?" Dependent choices for hours arguably correlates with dependent effort. It may suggest importance of team production that requires coordinating efforts. Hours of work is an important dimension of effort choice for salaried workers. So tying hours of work across workers to an important extent ties effort choices. We see that hours choices are more often dependent in goods industries (73.6 percent of workers) than in services (63.4 percent of workers).

[32]Annual growth rates for hours and real wages for these aggregates weight industry growth rates by their relative Tornqvisted hours; industry TFP growth rates are weighted by Tornqvisted industry value added. These growth rates are then integrated to yield the series for real wages, hours, and TFP.

dustries versus those with flexible wages, even while their relative hours increase by 0.58 percent (s.e. 0.10 percent). The impact on wages (-0.18 percent) is smaller and not statistically significant. So for the goods industries the patterns conform to the model–wages and TFP are more countercyclical for industries with stickier wages, while hours are more procyclical–though the impact on wages is less significant. Particularly striking are the relative movements in TFP across the two groups of industries from 2007 to 2009, reflecting the Great Recession. TFP *rose* by 4.0 percent for the sticky-wage industries, whereas TFP declined for the flexible-wage industries by 3.7 percent.

The middle panel of Table 5 restricts the sample to the 14 industries that produce durable goods, dividing these between those with stickier versus less sticky wages. We anticipate durable goods expenditure to be much more cyclical than for nondurable goods. So restricting to durables eliminates some of this heterogeneity. The results are qualitatively similar to that for all goods industries, but with a somewhat larger impact of stickiness on TFP and real-wage cyclicality. A one percent increase in aggregate output is associated with a relative decrease in TFP for stickier-wage industries of 1.34 percent (s.e. of 0.37 percent) and a relative wage decrease of 0.36 percent (s.e. 0.21 percent). So again these result align with the model, though the impact on real wages is not statistically significant.

Lastly, the bottom panel of Table 5 gives results for the nongoods industries. These do not conform. Most notably, the wages for the industries measured to have stickier wages, based on the SIPP, actually display more procyclical wages. This upends the exercise. Together with more procyclical wages, industries expected to have stickier wages have less cyclical hours and perhaps slightly more procyclical TFP. Though the latter effect is estimated to be small and insignificant.

7 Conclusion

We start from what we view as a reasonable depiction of wage setting with wages sticky for many current workers, but flexible for new hires. We depart from standard treatments of sticky wages by allowing worker effort to respond to the wage being too high or low. This is consistent with firms making fairly frequent choices for production and work assignments, more frequent than wages are re-bargained.

The model has several implications for cyclicality of wages and employment. One is that wage stickiness in existing matches does matter for employment, in contrast to models with fixed effort. A higher wage in existing contracts, by driving up worker effort, crowds out hiring. We also find that wage setting in our model places much less weight on future desired wage rates because deviations from future target wages will be partially undone by effort's response. Thus it weakens the forward-looking element of wage setting, even though expectations are fully rational. If we constrain choices for effort to be common across workers then the model generates a great deal of wage inertia—for our benchmark calibration, only after six quarters does the aggregate wages achieve the same decline that is achieved in one quarter under sticky wages with fixed effort. Finally, relative volatility in employment is greatly increased in the face of shocks to labor demand because effort magnifies the shock's impact on employment, while masking it for labor productivity. By contrast, effort's response makes labor productivity more procyclical for preference shocks that affect labor supply.

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Table 1: Benchmark Parameter Values

Parameter	Description
$\lambda = 3/4$	Prob. for wage not renegotiated
$\alpha = 0.64$	Labor share in production function
$\beta = 0.99$	Discount factor
$\widetilde{\gamma} = 0.5$	Frisch elasticity of labor supply
$\delta = 0.04$	Job separation rate
$\eta = 0.5$	Elasticity of matching w.r.t. vacancy
$\chi = 0.6$	Scale parameter in matching function
$R = 0.035$	User cost of capital
$\psi = 0.5936$	Scale parameter for utility from leisure
$b = 0.4367$	Unemployment insurance benefits
$\kappa = 0.1345$	Vacancy posting cost
$\rho_z = 0.95$	Persistence of aggregate productivity
$\rho_\xi = 0.95$	Persistence of preference shock

Table 2: Cyclicality Under Various Sticky-Wage Models

	Data	Models under Productivity Shocks (z)			
		Fixed Effort	Individual Effort	Common Effort	G-T (2009)
Employment*	0.59 (0.03)	0.12	0.14	0.46	0.21
TFP	0.39 (0.03)	0.89	0.90	0.65	0.85
Newly-Hired Wage	0.48 (0.10)	0.69	1.09	0.35	0.33
Aggregate Wage	-0.03 (0.05)	0.35	0.73	0.16	0.33

	Data	Models under Preference Shocks (ξ)		
		Fixed Effort	Individual Effort	Common Effort
Employment*	0.59 (0.03)	1.31	0.23	0.50
TFP	0.39 (0.03)	0.00	0.83	0.60
Newly-Hired Wage	0.48 (0.10)	-1.03	0.90	0.22
Aggregate Wage	-0.03 (0.05)	-0.61	0.59	0.09

Notes: Coefficients are projection of $\ln(X)$ on log aggregate output, where X takes roles of employment, wages, and TFP. "G-T (2009)" refers to the standard staggering-wage model (with fixed effort), such as Gertler and Trigari (2009), where wages of newly-hired are partially sticky (see text for the calibration of this model). All logged variables are quarterly and HP-filtered with smoothing parameter 1,600. Data are based on 1959:I-2017:IV. For wages (both aggregate and newly-hired), the estimates are based on a shorter time period of 1978:I-2013:IV when the newly-hired wages from Basu et al. (2016) are available. *The projection coefficient of total hours, as opposed to employment, on aggregate output is 0.77 (0.03).

Table 3: KLEMS Industries

INDUSTRY	NAICS Code	VA Share	Wage Duration (months)
Crop and Animal Production	111,112	1.6	14.6
Forestry and Fishing	113-115	0.3	13.0
Mining	211-213	1.9	15.4
Utilities, Pipeline Transportation, Waste Management	22,486,562	3.2	13.0
Construction	23	6.0	14.3
Food, Beverage, and Tobacco	311,312	2.1	10.8
Textile Mills and Textile Products	313,314	0.4	14.8
Apparel and Leather products	315,316	0.3	14.8
Wood products	321	0.4	10.1
Paper Products	322	0.9	10.4
Printing and Publishing	323,511,516	2.3	13.3
Petroleum and Coal products	324	1.0	10.1
Chemical products	325	2.8	11.4
Plastics and Rubber products	326	0.8	12.0
Nonmetallic Mineral Products	327	0.6	13.3
Primary Metals	331	0.7	14.4
Fabricated Metal products	332	1.6	11.1
Machinery	333	1.6	13.1
Computer and Electronic products	334	2.6	11.1
Electrical Equipment and Appliances	335	0.7	11.5
Transportation Equipment	336	2.8	12.0
Furniture and related products	337	0.4	10.4
Miscellaneous Manufacturing	339	0.8	11.0
Wholesale Trade	42	6.8	13.0
Retail Trade	44,45	7.8	12.4
Air Transportation	481	0.5	12.5
Rail Transportation	482	0.4	13.3
Water Transportation	483	0.1	20.7

Truck Transportation	484	1.2	13.6
Transit and Ground Passenger Transportation	485	0.2	14.1
Other Transportation, Warehousing and Storage	487,488,492, 493	1.3	11.3
Motion Picture and Recording Industries	512	0.9	15.8
Broadcasting and Telecommunications	515,517	2.7	11.4
Information Processing, Computer Systems, Misc. Professional, Scientific, Technical Services, Management of Enterprises	518,519,5412-5414,5415, 5416-5419,55	9.7	12.1
Credit Intermediation and Related Activities	521,522	3.6	12.8
Securities, Commodities, Investments, Funds, Trusts, and other Financial Vehicles	523,525	2.4	16.7
Insurance Carriers and Related Activities	524	2.6	12,9
Real Estate	531	4.7	12.7
Rental and Leasing Services	532,533	1.7	16.8
Legal Services	5411	1.9	13.8
Administrative and Support Services	561	3.3	12.6
Educational Services	61	0.3	10.5
Ambulatory Health Care Services	621	3.9	13.4
Hospitals, Nursing, Residential Care Facilities	622,623	1.3	10.8
Social Assistance	624	0.3	10.4
Performing Arts, Spectator Sports, Museums, and Related Activities	711,712	0.5	11.1
Amusements, Gambling, and Recreation	713	0.5	13.4
Accommodation	721	0.8	12.5
Food Services and Drinking Places	722	2.0	12.8
Other Services, except Government	81	2.6	13.8

Table 4: Frequency of Wage Changes SIPP, 1990-2004

	4-month Freq	8-month Freq	Calvo 4-mo Parameter	Error Rate
1990-1993 Panels (Approx. 1990-1995)	0.69	0.78	0.30	0.33
1996 Panel (Approx. 1996-1999)	0.74	0.83	0.38	0.34
2001 Panel (Approx. 2001-2004)	0.74	0.82	0.33	0.37
Average 1990 to 2001 Panels	0.71	0.81	0.33	0.35

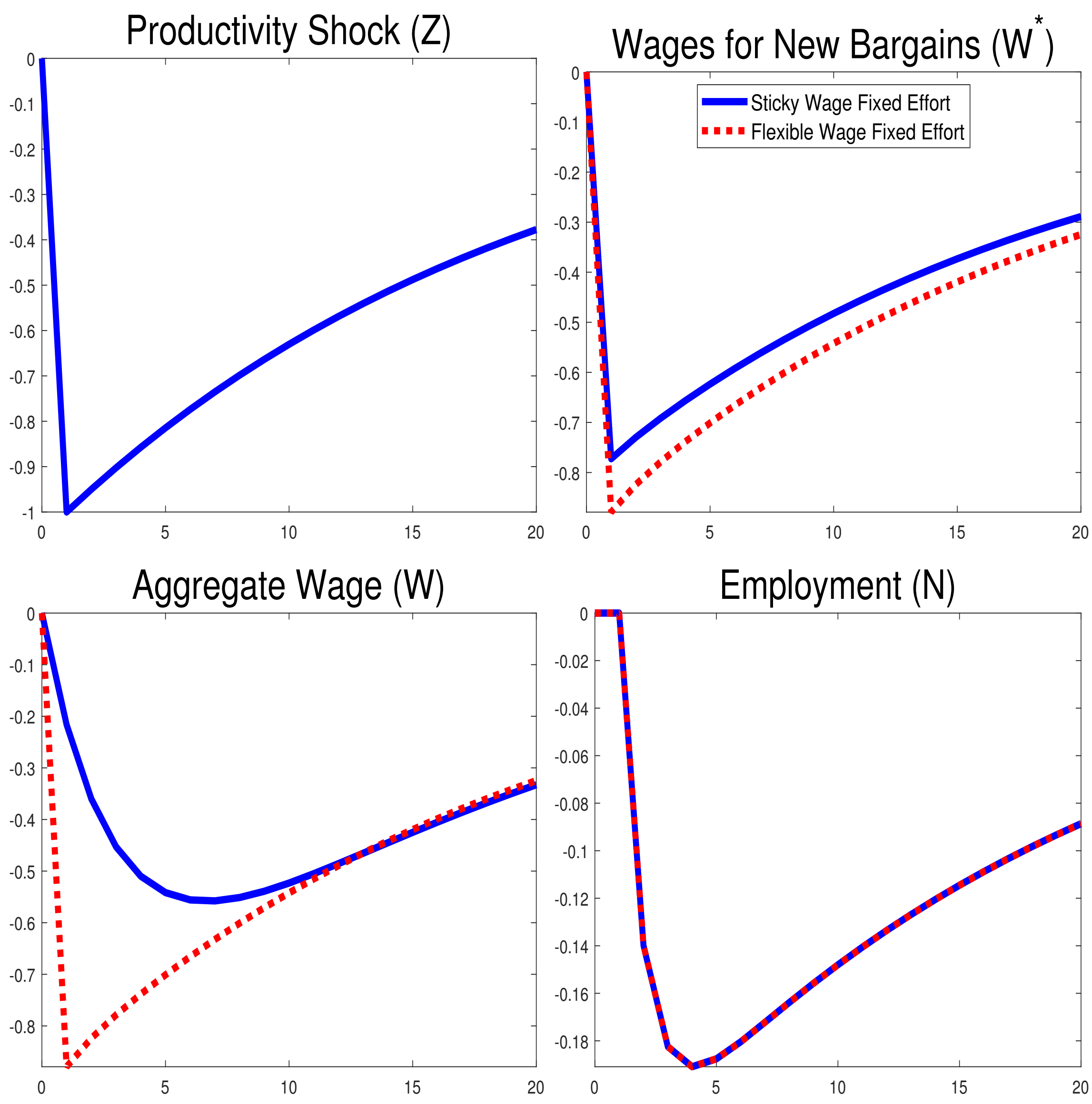
Notes: Observation by panel (top to bottom) are 218,819, 86,086, 46,894, and 351,799. Observations are weighted both by the SIPP sampling weight and by the worker's relative monthly earnings. In aggregating panels, the 1990-1993 panels, which span about 6 years, are given 1.5 times the weight of the others, each spanning about 4 years.

Table 5: Industry Cyclicality by Wage Stickiness

	Dependent Variable:		
	Hours	Wage	TFP
		Goods industries	
Sticky-wage Industries	2.00	−0.14	−0.44
	(.15)	(.13)	(.25)
Flexible-wage Industries	1.42	0.04	0.46
	(.08)	(.18)	(.16)
Difference	0.58	−0.18	−0.90
	(.10)	(.13)	(.15)
		Durable Goods Industries	
Sticky-wage Industries	2.25	−0.28	−0.37
	(.15)	(.13)	(.11)
Flexible-wage Industries	1.78	0.09	0.97
	(.09)	(.19)	(.23)
Difference	0.46	−0.36	−1.34
	(.13)	(.21)	(.37)
		Non-goods Industries	
Sticky-wage Industries	0.57	0.18	0.03
	(.04)	(.09)	(.08)
Flexible-wage Industries	1.01	−0.19	−0.12
	(.07)	(.07)	(.15)
Difference	−0.44	0.37	0.15
	(.13)	(.15)	(.22)

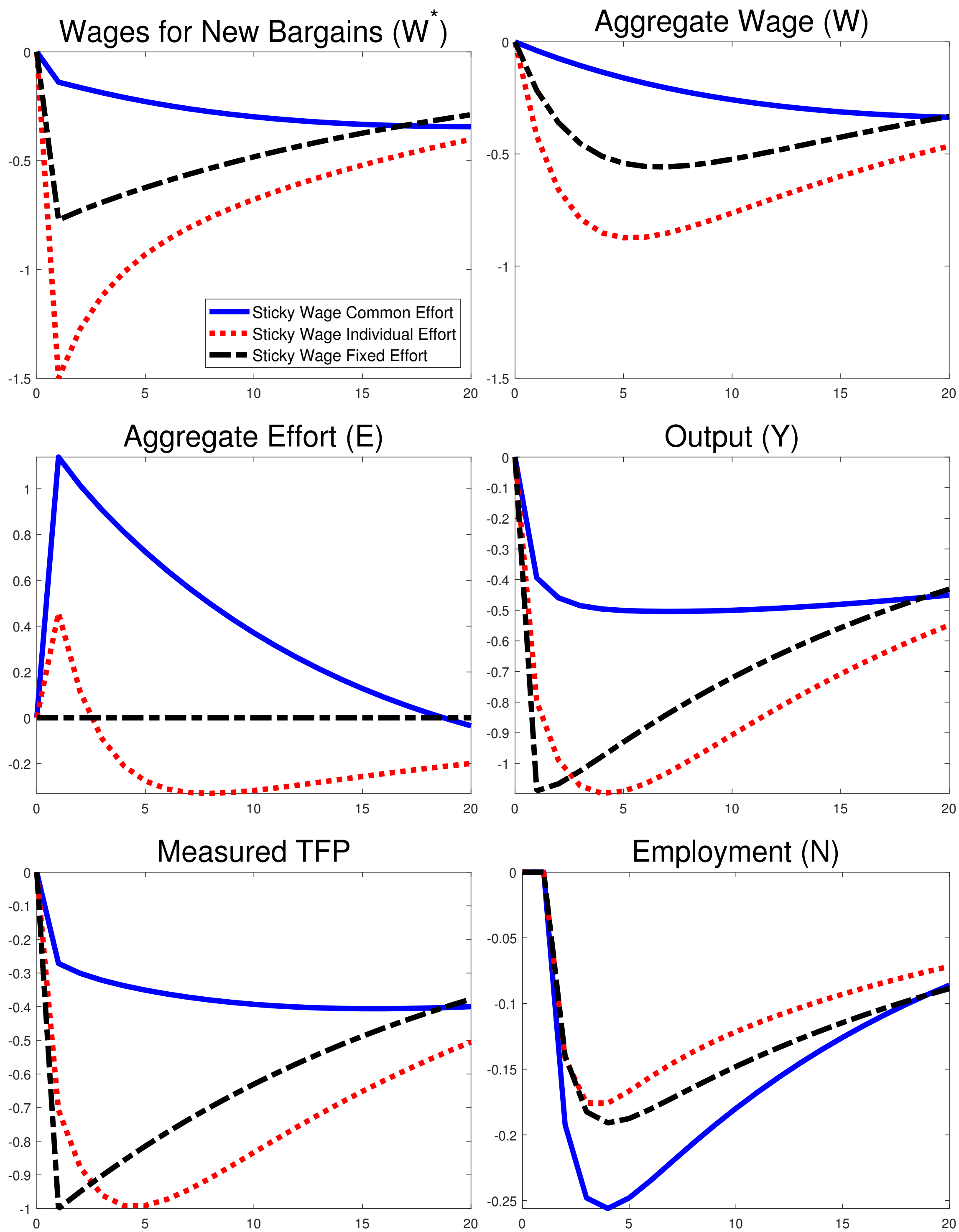
Notes: Data are for 1987 to 2016; all series are HP-filtered. The cyclical measure is HP-filtered aggregate output. TFP measures are adjusted for estimated capital utilization. Newey-West adjusted standard errors are in parentheses.

Figure 1: Model with Fixed Effort



Notes: Productivity decreases by 1% in period 1 with auto-correlation of 0.95. The dotted line represents the model with flexible wages. The solid line represents the model with sticky wages. The x axis represents periods (in quarters) and y axis represents percentage deviation from the steady state.

Figure 2: Sticky Wage Models: Negative Productivity Shock



Notes: Productivity decreases by 1% in period 1 with auto-correlation of 0.95. The dash-dot line (−.) represents the sticky wage model with fixed effort. The dotted line represents the sticky wage model with individual effort choice. The solid line represents the sticky wage model with common effort choice. All models feature $\alpha = 0.64$, $\widetilde{\gamma} = 0.5$, $\lambda = 3/4$, and $\widetilde{e} = 0.5$.

Figure 3: Efforts in Individual Effort Choice Model

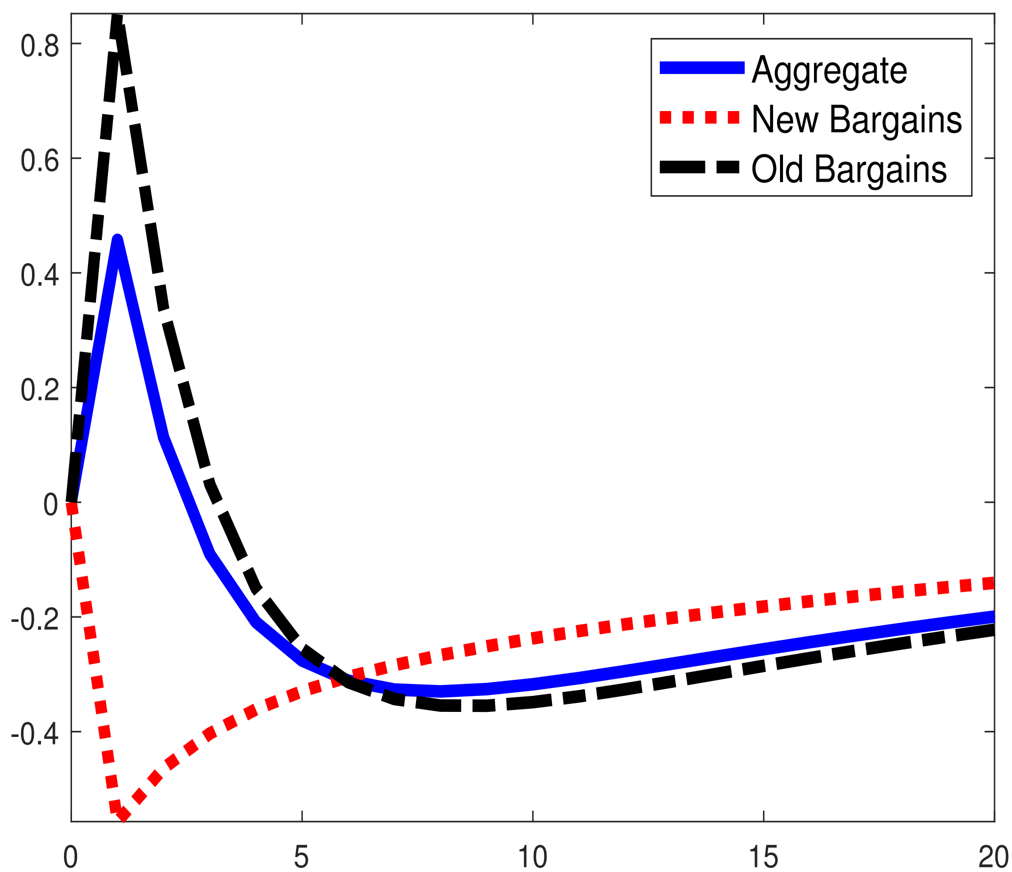
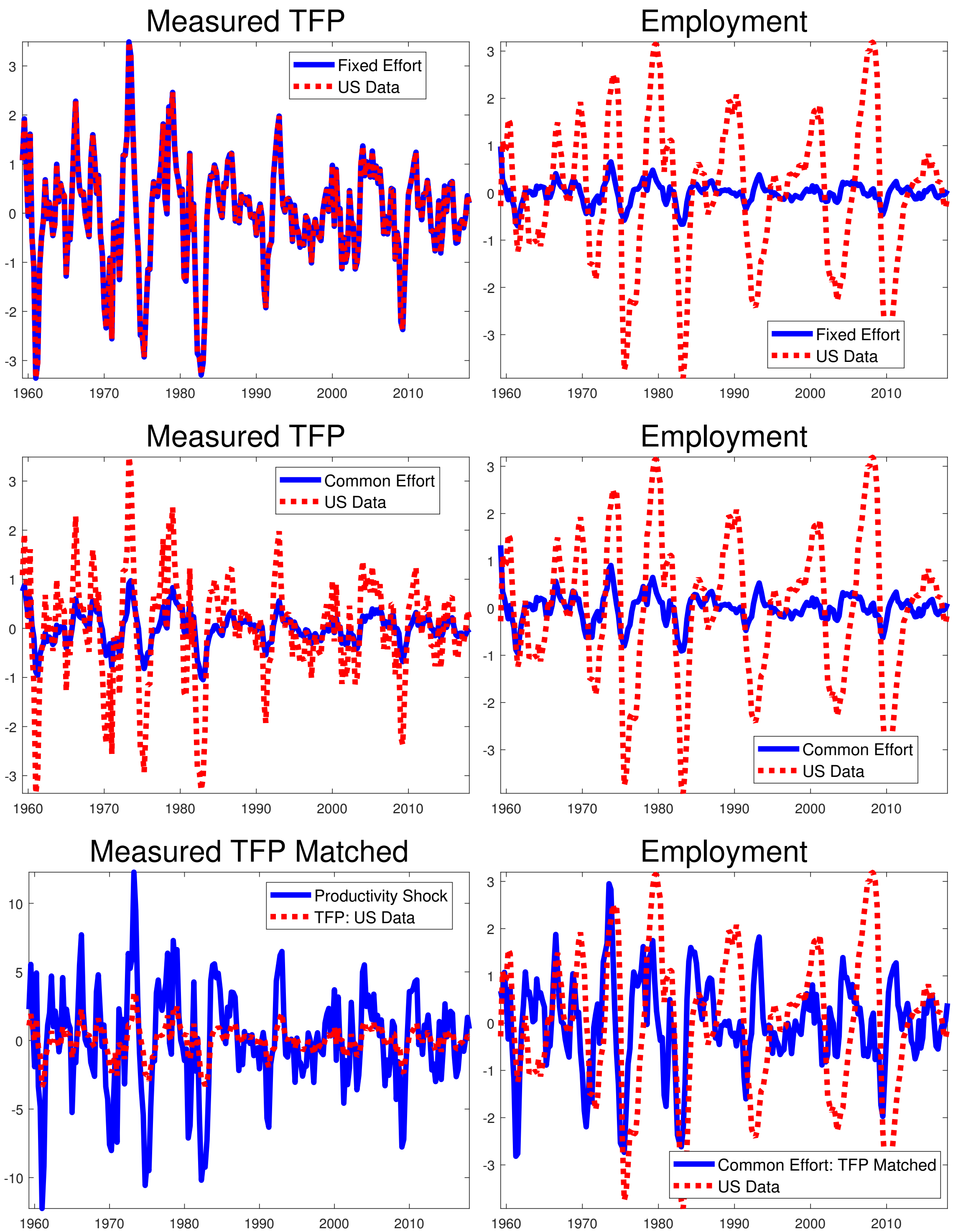
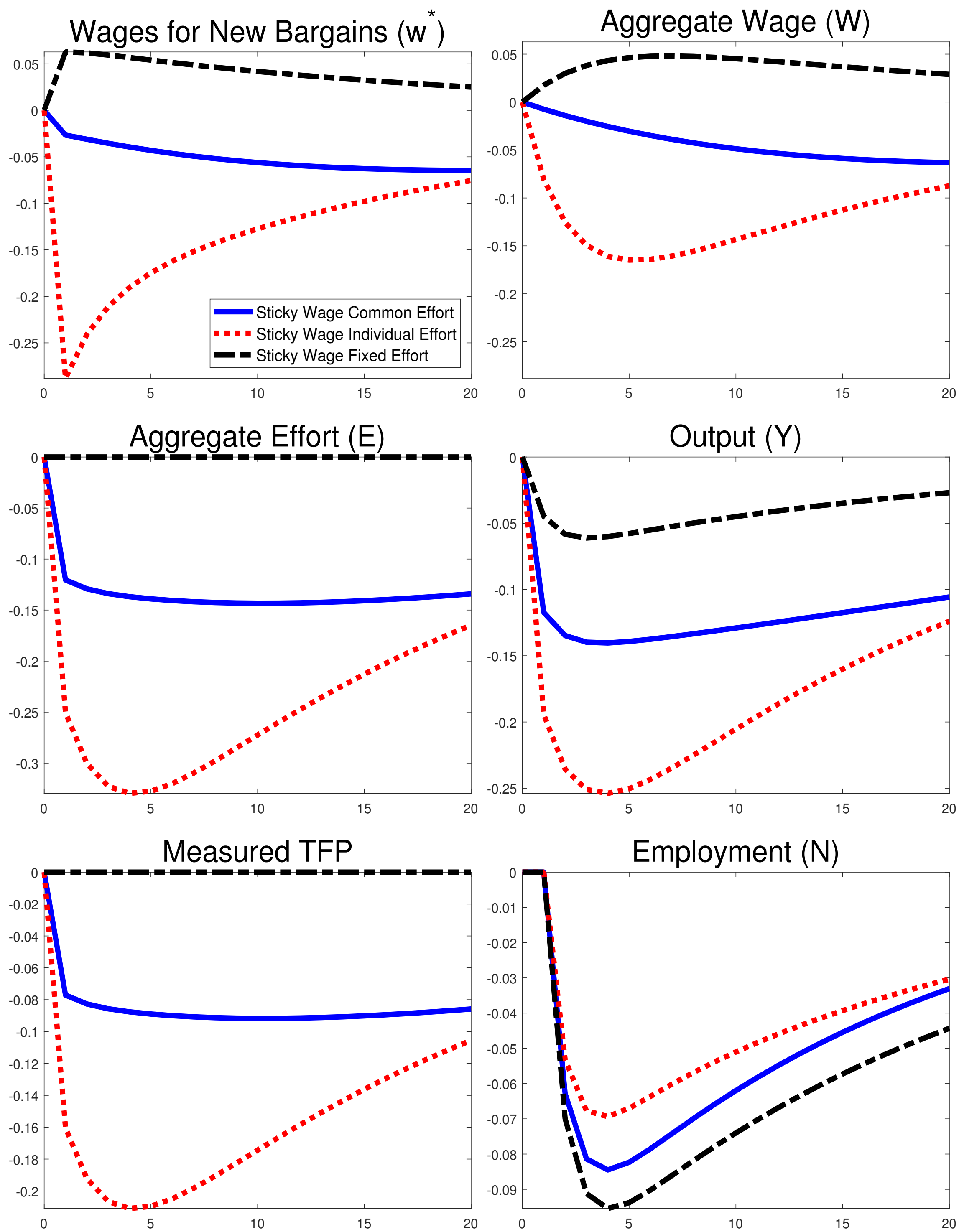


Figure 4: Measured TFP, Productivity Shock, and Employment



Notes: The top panel features the fixed effort model (flexible wages) when the productivity shock mimics the US TFP. The middle panel features the sticky wage with common effort model (also under the productivity shock that mimics the US TFP). In the bottom panel, productivity shocks are re-calibrated so that the measured TFP (in the sticky wage with common effort model) exactly matches the measured U.S. TFP.

Figure 5: Sticky Wage Models: Positive Preference Shock



Notes: Preference shock decreases by 1% in period 1 with auto-correlation 0.95. The dash-dot line (−.) represents the sticky wage model with fixed effort. The dotted line represents the sticky wage model with individual effort choice. The solid line represents the sticky wage model with common effort choice. All models feature $\alpha = 0.64$, $\widetilde{\gamma} = 0.5$, $\lambda = 3/4$, and $\widetilde{e} = 0.5$.

Appendices

For Online Publication

A Log-Linearized Dynamics of the Models

In this appendix, we derive the log-linearized dynamics of key variables around the steady state for all 5 model specifications: 2 models under flexible wages (with fixed and variable effort) and 3 models under sticky wages (fixed, individual, and common effort). Production is subject to technology shocks (z) and the utility from leisure is subject to preference shocks (ξ). We assume that z and ξ follows AR(1) process in logs. For variable x, $\hat{x}$ denotes the percentage deviation from its steady state $\tilde{x}$.

A.1 Log-Linearized Equations

Sticky Wage with Individual Effort Choice Given the first-order Taylor approximation of worker's match surplus, $H(w, \mathbf{s}) - H(w^{*\prime}, \mathbf{s}) = \dfrac{\partial H(w^*, \mathbf{s})}{\partial w}\big(w - w^{*\prime}\big)$. The value of match surplus of a worker (3) is expressed as:

$$\begin{aligned} H(w, \mathbf{s}) = {} & w - b + \xi\psi\frac{(1-e)^{1-1/\gamma} - 1}{1 - 1/\gamma} + \beta(1-\delta)\lambda\mathbb{E}\big[\epsilon(w^{*\prime}, \mathbf{s}')(w - w^{*\prime})|\mathbf{s}\big] \\ & + \beta\big(1 - \delta - p(\theta)\big)\mathbb{E}\big[H(w^{*\prime}, \mathbf{s}')|\mathbf{s}\big] \end{aligned} \tag{A.1}$$

where $\epsilon(w^*, \mathbf{s})$ denotes the increase in the worker's surplus (for a newly-negotiated match) from a marginal increase of wage:

$$\epsilon(w^*, \mathbf{s}) = \frac{\partial H(w^*, \mathbf{s})}{\partial w} = 1 - \xi\psi(1-e)^{-1/\gamma}\Lambda(w^*, \mathbf{s}) + \beta(1-\delta)\lambda\mathbb{E}\big[\epsilon(w^{*\prime}, \mathbf{s}')|\mathbf{s}\big], \tag{A.2}$$

where $\Lambda(w^*, \mathbf{s}) = \partial e(w^*, \mathbf{s})/\partial w$ denotes the effort change induced by a wage increase. Analogously, the value of match surplus for the firm (4) is:

$$J(w, \mathbf{s}) = \alpha z k^{1-\alpha} e - w + \beta(1-\delta)\lambda\mathbb{E}\big[\mu(w^{*\prime}, \mathbf{s}')(w - w^{*\prime})|\mathbf{s}\big] + \beta(1-\delta)\mathbb{E}\big[J(w^{*\prime}, \mathbf{s}')|\mathbf{s}\big], \tag{A.3}$$

where $\mu(w^*, \mathbf{s})$ denotes the decrease in firm's surplus (for a newly-negotiated match) due to a marginal increase in wage:

$$\mu(w^*, \mathbf{s}) = -\frac{\partial J(w^*, \mathbf{s})}{\partial w} = 1 - \alpha z k^{1-\alpha}\Lambda(w^*, \mathbf{s}) + \beta(1-\delta)\lambda\mathbb{E}\big[\mu(w^{*\prime}, \mathbf{s}')|\mathbf{s}\big]. \tag{A.4}$$

The log-linearized dynamics of $H(w, \mathbf{s})$, $J(w, \mathbf{s})$, and $\mu(w^*, \mathbf{s})/\epsilon(w^*, \mathbf{s})$ are:

$$\widehat{H} = \frac{1}{\widetilde{H}}\Bigg\{\widetilde{w}\widehat{w} + \widetilde{B}\widehat{\xi} - \psi(1-\widetilde{e})^{-1/\gamma}\widetilde{e}\widehat{e} + \beta(1-\delta)\lambda\widetilde{\epsilon}\widetilde{w}\big(\widehat{w} - E\widehat{w}^{*\prime}\big)$$
$$+ \left(\frac{\eta}{1-\eta}\right)\left(\left[\frac{(1-\delta)\eta\kappa}{\widetilde{q}} - \kappa\widetilde{\theta}\right]\widehat{\theta} - \left[\frac{(1-\delta)\kappa}{\widetilde{q}} - \kappa\widetilde{\theta}\right]E\big[\widehat{\mu}' - \widehat{\epsilon}'\big]\right)\Bigg\}, \tag{A.5}$$

$$\widehat{J} = \frac{1}{\widetilde{J}}\Bigg\{\alpha\widetilde{y}\big(\widehat{z} + (1-\alpha)\widehat{k} + \widehat{e}\big) - \widetilde{w}\widehat{w} - \beta(1-\delta)\lambda\widetilde{\mu}\widetilde{w}\big(\widehat{w} - E\widehat{w}^{*\prime}\big) + \frac{(1-\delta)\eta\kappa}{\widetilde{q}}\widehat{\theta}\Bigg\}, \tag{A.6}$$

$$\widehat{\mu} - \widehat{\epsilon} = -\frac{\widetilde{\gamma}\alpha\widetilde{y}}{\eta\widetilde{J}}\left[\widehat{z} + (1-\alpha)\widehat{k} - \widehat{\xi} - \frac{1}{\widetilde{\gamma}}\widehat{e}\right] + \beta(1-\delta)\lambda E\big[\widehat{\mu}' - \widehat{\epsilon}'\big], \tag{A.7}$$

where $\widetilde{B} = \psi\dfrac{(1-\widetilde{e})^{1-1/\gamma} - 1}{1-1/\gamma}$ and $\widetilde{\epsilon} = \widetilde{\mu} = \dfrac{\eta\widetilde{J}}{\widetilde{\gamma}\alpha\widetilde{y} + \eta\widetilde{J}\big(1-\beta(1-\delta)\lambda\big)}$.

The F.O.C.'s of wage and effort bargaining, (7) and (9), yield:

$$\widehat{\mu} - \widehat{\epsilon} = \widehat{z} + (1-\alpha)\widehat{k} - \widehat{\xi} - \frac{1}{\widetilde{\gamma}}\widehat{e} = \left(\frac{\eta\widetilde{J}}{\widetilde{\gamma}\alpha\widetilde{y} + \eta\widetilde{J}}\right)\beta(1-\delta)\lambda E\big[\widehat{\mu}' - \widehat{\epsilon}'\big]. \tag{A.8}$$

This implies that $\widehat{\mu} = \widehat{\epsilon}$ for all $\mathbf{s}$. Given the generalized Nash bargaining for matches whose wage are re-negotiated, the increased surplus of a worker is proportional to the decreased surplus of a firm.[33] Therefore, when the wage is renegotiated, i.e., $\widehat{w} = \widehat{w}^*$, the change in effort equals the Frisch elasticity multiplied by the change in marginal product of labor:

$$\widehat{e}(\widehat{w}^*) = \widetilde{\gamma}\Big(\widehat{z} + (1-\alpha)\widehat{k} - \widehat{\xi}\Big). \tag{A.9}$$

The F.O.C. for effort bargaining (9) yields:

$$\widehat{J} + \frac{1}{\widetilde{\gamma}}\widehat{e} = \widehat{H} + \widehat{z} + (1-\alpha)\widehat{k}. \tag{A.10}$$

Substituting (A.5) and (A.6) into (A.10) with $\widehat{\mu} = \widehat{\epsilon}$ yields the individual effort choice as:

$$\left(\frac{\widetilde{\gamma}\alpha\widetilde{y} + \eta\widetilde{J}}{\widetilde{\gamma}}\right)\widehat{e} = \frac{\widetilde{w}}{1-\tau_i}\widehat{w} - \frac{\tau_i\widetilde{w}}{1-\tau_i}E\widehat{w}^{*\prime} - \eta\kappa\widetilde{\theta}\widehat{\theta}$$
$$+ \Big((1-\eta)\widetilde{B} - \eta\widetilde{J}\Big)\widehat{\xi} + \eta\left(\widetilde{J} - \alpha\widetilde{y}\right)\left(\widehat{z} + (1-\alpha)\widehat{k}\right), \tag{A.11}$$

[33]Note that the first-order condition for the wage bargaining, (7), does not necessarily imply $\mu(w^*, \mathbf{s}) = \epsilon(w^*, \mathbf{s})$ for all $\mathbf{s}$. It only implies that the surplus of each party changes in a proportion to a first-order approximation: $\widehat{\mu} = \widehat{\epsilon}$.

where $\tau_i = \dfrac{\beta(1-\delta)\lambda\widetilde{\mu}}{1+\beta(1-\delta)\lambda\widetilde{\mu}} = \left(\dfrac{\eta\widetilde{J}}{\widetilde{\gamma}\alpha\widetilde{y}+\eta\widetilde{J}}\right)\tau.$

Integrating (A.11) over the wage distribution $G(w)$ and applying the definitions for aggregate effort, $\overline{e} = \displaystyle\int e(w)dG(w)$, and aggregate wage, $\overline{w} = \displaystyle\int wdG(w)$, and $\widehat{k} = -\big(\widehat{n}+\widehat{\overline{e}}\big)$ yields the following expression for aggregate effort:

$$\begin{aligned}\Xi\widehat{\overline{e}} =& \frac{\widetilde{w}}{1-\tau_i}\widehat{\overline{w}} - \frac{\tau_i\widetilde{w}}{1-\tau_i}E\widehat{w}^{*\prime} - \eta\kappa\widetilde{\theta}\widehat{\theta} \\ &+ \Big((1-\eta)\widetilde{B}-\eta\widetilde{J}\Big)\widehat{\xi} + \eta\left(\widetilde{J}-\alpha\widetilde{y}\right)\left(\widehat{z}-(1-\alpha)\widehat{n}\right),\end{aligned} \tag{A.12}$$

where $\Xi = \big(1-\eta(1-\alpha)\big)\alpha\widetilde{y} + \left(\dfrac{1}{\widetilde{\gamma}}+1-\alpha\right)\eta\widetilde{J}.$

Log-linearizing the first-order condition for the wage bargaining, (7), and substituting (A.5) and (A.6) for $\widehat{J}$ and $\widehat{H}$, respectively, with $\widehat{\mu}-\widehat{\epsilon}=0$ yields the Nash-bargained wage:

$$\begin{aligned}\widehat{w}^* = (1-\tau_i)\Bigg\{&\alpha\left(\frac{\widetilde{y}}{\widetilde{w}}\right)(\eta+\widetilde{\gamma})\big(\widehat{z}+(1-\alpha)\widehat{k}\big) \\ &+\eta\kappa\left(\frac{\widetilde{\theta}}{\widetilde{w}}\right)\widehat{\theta} + \left(\frac{\widetilde{\gamma}\alpha\widetilde{y}+(1-\eta)\widetilde{B}}{\widetilde{w}}\right)\widehat{\xi}\Bigg\} + \tau_i E\widehat{w}^{*\prime}.\end{aligned} \tag{A.13}$$

Substituting (A.12) for $\widehat{\overline{e}}$ in $\widehat{k} = -(\widehat{n}+\widehat{\overline{e}})$ shows that the Nash-bargaining wage depends on its future expectation $E\widehat{w}^{*\prime}$, the aggregate wage $\widehat{\overline{w}}$, and the wage rate under the flexible wage $\widehat{w}_F^*$ (described below):

$$\widehat{w}^* = \left(1-\frac{\varphi_1}{\widetilde{\gamma}\Xi}\right)\widehat{\overline{w}} + \frac{\varphi_1}{\widetilde{\gamma}\Xi}\Big\{(1-\tau_i)\widehat{w}_F^* + \tau_i E\widehat{w}^{*\prime}\Big\}, \tag{A.14}$$

where $\varphi_1 = \big(1+\widetilde{\gamma}(1-\alpha)\big)\big(\widetilde{\gamma}\alpha\widetilde{y}+\eta\widetilde{J}\big)$. The law of motion for total wage payment, $n'\overline{w}' + (1-\delta)\lambda n\overline{w} + mw^{*\prime}$, and that for employment, $\widehat{n}' = (1-\delta)\widehat{n}+\delta\widehat{m}$, yields the aggregate wage as a weighted average of newly-negotiated wage and its lagged value $\widehat{\overline{w}}_{-1}$:

$$\widehat{\overline{w}} = \big(1-\lambda(1-\delta)\big)\widehat{w}^* + \lambda(1-\delta)\widehat{\overline{w}}_{-1} = (1-(1-\delta)\lambda)\widehat{w}^* + (1-\delta)\lambda\widehat{\overline{w}}_{-1}.$$

Substituting (A.14) for $\widehat{w}^*$ expresses the aggregate wage in terms of its future expectation $E\widehat{w}^{*\prime}$, its lagged value, and the wage under the flexible wage $\widehat{w}_F^*$:

$$\widehat{\overline{w}} = \frac{\varphi_1}{\varphi_1-\varphi_2}(1-(1-\delta)\lambda)\Big\{(1-\tau_i)\widehat{w}_F^* + \tau_i E\widehat{w}^{*\prime}\Big\} + \frac{\widetilde{\gamma}\Xi}{\varphi_1-\varphi_2}(1-\delta)\lambda\widehat{\overline{w}}_{-1}, \tag{A.15}$$

where $\varphi_2 = (1-\delta)\lambda(1-\alpha)(\eta+\widetilde{\gamma})\widetilde{\gamma}\alpha\widetilde{y}$.

Finally, log-linearizing the free entry condition (5) using (A.6) yields the forward-looking difference equation for $\widehat{\theta}$:

$$\frac{\eta\kappa}{\widetilde{q}}\widehat{\theta} = \beta E\left[\alpha\widetilde{y}\Big(\widehat{z}' + (1-\alpha)\widehat{k}' + \widehat{e}'\Big) - \frac{\widetilde{w}}{1-\tau_i}\widehat{w}^{*\prime} + \frac{\tau_i\widetilde{w}}{1-\tau_i}\widehat{w}^{*\prime\prime} + \frac{\eta\kappa}{\widetilde{q}}(1-\delta)\widehat{\theta}'\right]. \tag{A.16}$$

Substituting (A.13) and (A.9) into (A.16) yields the dynamics of the labor market tightness, v/u:

$$\frac{\eta\kappa}{\widetilde{q}}\widehat{\theta} = \beta E\left[(1-\eta)\alpha\widetilde{y}\big(\widehat{z}' + (1-\alpha)\widehat{k}'\big) + \frac{\eta\kappa}{\widetilde{q}}(1-\delta-\widetilde{p})\widehat{\theta}' + (1-\eta)\widetilde{B}\widehat{\xi}'\right]. \tag{A.17}$$

Sticky Wage with Common Effort Choice Match surpluses under sticky wages with common effort choice are identical to those in the individual effort model: (A.1) and (A.3). So are their log-linearized equations: (A.5) and (A.6). However, the effects of the wage bargaining on the match surpluses differ slightly from (A.2) and (A.4), reflecting the assumption that individual wage bargains do not influence the common effort choice, i.e. $\Lambda(w^*, \mathbf{s}) = \frac{\partial e(w^*,\mathbf{s})}{\partial w} = 0$. Thus, the surplus gain to a worker and loss to a firm from a wage increase are simply:

$$\epsilon(w^*, \mathbf{s}) = \frac{\partial H(w^*, \mathbf{s})}{\partial w} = 1 + \beta(1-\delta)\lambda\mathbb{E}\big[\epsilon(w^{*\prime}, \mathbf{s}')|\mathbf{s}\big], \tag{A.18}$$

$$\mu(w^*, \mathbf{s}) = -\frac{\partial J(w^*, \mathbf{s})}{\partial w} = 1 + \beta(1-\delta)\lambda\mathbb{E}\big[\mu(w^{*\prime}, \mathbf{s}')|\mathbf{s}\big]. \tag{A.19}$$

It is clear that $\epsilon(w^*, \mathbf{s}) = \mu(w^*, \mathbf{s})$ for all $\mathbf{s}$, with $\widetilde{\epsilon} = \widetilde{\mu} = \dfrac{1}{1-\beta(1-\delta)\lambda}$; so $\widehat{\mu} - \widehat{\epsilon} = 0$ for all $\mathbf{s}$.[34]

The log-linearized first-order condition for common effort bargaining is given by:

$$\frac{1}{\widetilde{\gamma}}\widehat{e} = \widehat{z} + (1-\alpha)\widehat{k} + \int \Big[\widehat{H} - \widehat{J}\Big]dG, \tag{A.20}$$

and $\widehat{H} - \widehat{J}$ is obtained from (A.5) and (A.6) as:

$$\begin{aligned}\widehat{H} - \widehat{J} = \frac{1}{\eta\widetilde{J}}\Big\{&(1-\eta)(\widetilde{w}-b)\widehat{\xi} + \big(1+\beta(1-\delta)\lambda\widetilde{\mu}\big)\widetilde{w}\widehat{w} - \beta(1-\delta)\lambda\widetilde{\mu}E\widehat{w}^{*\prime} \\ &- \eta\kappa\widetilde{\theta}\widehat{\theta} - \alpha\widetilde{y}\widehat{e} - \eta\alpha\widetilde{y}\big(\widehat{z} + (1-\alpha)\widehat{k}\big) - \frac{\eta\kappa}{\widetilde{q}}(1-\delta-\widetilde{p})E\big[\widehat{\mu}' - \widehat{\epsilon}'\big]\Big\}.\end{aligned} \tag{A.21}$$

[34] Thus, the F.O.C. of wage bargaining, (8), holds exactly (not to a first-order approximation) in the common effort model.

Integrating (A.21) over the wage distribution, substituting the resulting expression into (A.20), and applying the equilibrium condition, $\widehat{e} = \widehat{\overline{e}}$, yields the log-linearized expression for aggregate effort. That expression is identical to (A.12) except now $\tau = \beta(1-\delta)\lambda$.

The log-linearized first-order condition for the wage bargaining is given by $\widehat{H} = \widehat{J}$. Substituting (A.5), (A.6) and (A.12) for $\widehat{H}$, $\widehat{J}$ and $\widehat{\overline{e}}$, respectively, yields the log-linearized expression for the bargained wage:

$$\widehat{w}^* = \left(1 - \frac{\varphi_3}{\widetilde{\gamma}\Xi}\right)\widehat{\overline{w}} + \frac{\varphi_3}{\widetilde{\gamma}\Xi}\Big\{(1-\tau)\widehat{w}^*_{FV} + \tau E\widehat{w}^{*\prime}\Big\}, \tag{A.22}$$

where $\varphi_3 = \big(1 + \widetilde{\gamma}(1-\alpha)\big)\eta\widetilde{J}$.

Substituting (A.22) into $\widehat{\overline{w}} = (1-(1-\delta)\lambda)\widehat{w}^* + (1-\delta)\lambda\widehat{\overline{w}}_{-1}$ and rearranging terms yields the log-linearized expression for the aggregate wage:

$$\widehat{\overline{w}} = \frac{\varphi_3}{\varphi_3 + \varphi_4}(1-(1-\delta)\lambda)\Big\{(1-\tau)\widehat{w}^*_F + \tau E\widehat{w}^{*\prime}\Big\} + \frac{\widetilde{\gamma}\Xi}{\varphi_3+\varphi_4}(1-\delta)\lambda\widehat{\overline{w}}_{-1}, \tag{A.23}$$

where $\varphi_4 = (1-\delta)\lambda\big(1-\eta(1-\alpha)\big)\widetilde{\gamma}\alpha\widetilde{y}$.

The dynamics of v/u ratio in the common effort model is characterized by the same equation as (A.17). In fact, the log-linearized expressions for v/u ratio are identical regardless of the specifications of wage and effort bargaining. Note that, despite the identical expressions for v/u ratio across models, its quantitative properties differ considerably because the models exhibit different dynamics of wages and effort.

Flexible Wage with Variable Effort If wages are perfectly flexible, i.e., $w = w^*$, match surpluses and their derivatives with respect to wage are:

$$H(w^*, \mathbf{s}) = w^* - b + \xi\psi\frac{(1-e)^{1-1/\gamma} - 1}{1-1/\gamma} + \beta(1-\delta-p(\theta))\mathbb{E}\big[H(w^{*\prime}, \mathbf{s}')|\mathbf{s}\big], \tag{A.24}$$

$$J(w^*, \mathbf{s}) = \alpha z k^{1-\alpha} e - w^* + \beta(1-\delta)\mathbb{E}\big[J(w^{*\prime}, \mathbf{s}')|\mathbf{s}\big], \tag{A.25}$$

$$\epsilon(w^*, \mathbf{s}) = 1 - \xi\psi(1-e)^{-1/\gamma}\Lambda(w^*, \mathbf{s}), \tag{A.26}$$

$$\mu(w^*, \mathbf{s}) = 1 - \alpha z k^{1-\alpha}\Lambda(w^*, \mathbf{s}). \tag{A.27}$$

Note that with $\lambda = 0$ these expressions are identical to (A.1), (A.3), (A.2) and (A.4).

The F.O.C. for the effort choice, combined with (A.26) and (A.27), is:

$$\widehat{\mu} - \widehat{\epsilon} = \widehat{z} + (1-\alpha)\widehat{k} - \widehat{\xi} - \frac{1}{\widetilde{\gamma}}\widehat{e} = -\frac{\eta \widetilde{J}}{\widetilde{\gamma}\alpha\widetilde{y}}\Big(\widehat{\mu} - \widehat{\epsilon}\Big),$$

which implies $\widehat{\mu} = \widehat{\epsilon}$ for all $\mathbf{s}$, and $\widehat{e} = \widetilde{\gamma}\big(\widehat{z} + (1-\alpha)\widehat{k} - \widehat{\xi}\big)$. Substituting $\widehat{k} = -(\widehat{n} + \widehat{e})$ yields:

$$\widehat{e} = \frac{\widetilde{\gamma}}{1 + \widetilde{\gamma}(1-\alpha)}\Big(\widehat{z} - (1-\alpha)\widehat{n} - \widehat{\xi}\Big). \tag{A.28}$$

The (log-linearized) first-order condition for the bargained wage becomes:

$$\begin{aligned}\widehat{w}_F^* = \alpha\left(\frac{\widetilde{y}}{\widetilde{w}}\right)\left(\frac{\eta + \widetilde{\gamma}}{1 + \widetilde{\gamma}(1-\alpha)}\right)\big(\widehat{z} - (1-\alpha)\widehat{n}\big) + \eta\kappa\left(\frac{\widetilde{\theta}}{\widetilde{w}}\right)\widehat{\theta} \\ - \left(\frac{\widetilde{\gamma}\alpha\widetilde{y}\big(1 - \eta(1-\alpha)\big)}{\big(1 + \widetilde{\gamma}(1-\alpha)\big)\widetilde{w}} + \frac{(1-\eta)\widetilde{B}}{\widetilde{w}}\right)\widehat{\xi}\end{aligned} \tag{A.29}$$

Flexible Wage with Fixed Effort Under flexible wages and fixed effort, the worker and firm match surpluses are identical to (A.24) and (A.25) respectively, with $e = \widetilde{e}$ and $\epsilon(w^*, \mathbf{s}) = \mu(w^*, \mathbf{s}) = 1$ for all $\mathbf{s}$. Then, the Nash bargained wage is:

$$\widehat{w}_F^* = \eta\alpha\left(\frac{\widetilde{y}}{\widetilde{w}}\right)\big(\widehat{z} - (1-\alpha)\widehat{n}\big) + \eta\kappa\left(\frac{\widetilde{\theta}}{\widetilde{w}}\right)\widehat{\theta} - \left(\frac{(1-\eta)\widetilde{B}}{\widetilde{w}}\right)\widehat{\xi}, \tag{A.30}$$

which is identical to the expression for $\widehat{w}_F^*$ in (A.29) when $\widetilde{\gamma} = 0$.

Sticky Wage with Fixed Effort Under the standard sticky-wage with effort fixed, match surpluses for worker and firm are identical to (A.1) and (A.3) respectively, with $e = \widetilde{e}$. Because $\epsilon(w^*, \mathbf{s}) = 1 + \beta(1-\delta)\lambda\mathbb{E}[\epsilon(\mathbf{s}')|\mathbf{s}]$ and $\mu(w^*, \mathbf{s}) = 1 + \beta(1-\delta)\lambda\mathbb{E}[\mu(\mathbf{s}')|\mathbf{s}]$, we have $\epsilon(w^*, \mathbf{s}) = \mu(w^*, \mathbf{s})$ for all $\mathbf{s}$, where $\widetilde{\epsilon} = \widetilde{\mu} = \dfrac{1}{1 - \beta(1-\delta)\lambda} = \dfrac{1}{1-\tau}$. This implies that the increase (decrease) in the match value for a worker (firm) due to wage increase is simply 1.

The log-linearized first-order condition for wage bargaining is:

$$\widehat{w}^* = (1-\tau)\widehat{w}_F^* + \tau E\widehat{w}^{*\prime}. \tag{A.31}$$

where $\widehat{w}_F^*$ is the bargained wage under flexible wage with fixed effort in (A.30). Then, the aggregate wage becomes:

$$\widehat{\overline{w}} = (1 - (1-\delta)\lambda)\Big\{(1-\tau)\widehat{w}_F^* + \tau E\widehat{w}^{*\prime}\Big\} + (1-\delta)\lambda\widehat{\overline{w}}_{-1}. \tag{A.32}$$

Other Aggregate Variables Given the aggregate wage $\widehat{\overline{w}}$, effort $\widehat{\overline{e}}$, and the labor-market tightness $\widehat{\theta}$, the dynamics of other aggregate variables are:

$$\begin{aligned}
\widehat{z} &= \rho_z \widehat{z}_{-1} + \widehat{\varepsilon}_z \\
\widehat{\xi} &= \rho_\xi \widehat{\xi}_{-1} + \widehat{\varepsilon}_\xi \\
\widehat{y} &= \widehat{z} + \alpha \left(\widehat{n} + \widehat{\overline{e}}\right) \\
\widehat{v} &= \widehat{\theta} + \widehat{u}_{-1} \\
\widehat{u} &= -\frac{\widetilde{n}}{1-\widetilde{n}} \widehat{n} \\
\widehat{n} &= (1-\delta)\widehat{n}_{-1} + \delta \widehat{m} \\
\widehat{m} &= (1-\eta)\widehat{\theta} + \widehat{u}_{-1} \\
\widehat{TFP} &= \widehat{z} + \alpha \widehat{\overline{e}}.
\end{aligned}$$

A.2 Dynamics of Aggregate Wage in Sticky Wage Models

We now derive the dynamics of aggregate wage. By iterating (A.14), the Nash bargained wage in the individual effort model can be written as:

$$\begin{aligned}
\widehat{w}^* =& \sum_{j=0}^{\infty} \left(\frac{\varphi_1 \tau_i}{\widetilde{\gamma}\Xi}\right)^j \left\{ \frac{\varphi_1}{\widetilde{\gamma}\Xi}(1-\tau_i)\widehat{w}^*_{F,t+j} + \left(1 - \frac{\varphi_1}{\widetilde{\gamma}\Xi}\right) \widehat{\overline{w}}_{t+j} \right\} \\
=& \varphi \left(\frac{1}{\tau_i} - 1\right) \frac{E\widehat{w}^*_{F,t}}{1-\varphi\mathbb{F}} + \left(1 - \frac{\varphi}{\tau_i}\right) \frac{E\widehat{\overline{w}}_t}{1-\varphi\mathbb{F}},
\end{aligned} \tag{A.33}$$

where $\varphi = \dfrac{\varphi_1 \tau_i}{\widetilde{\gamma}\Xi}$ and $\mathbb{F}$ is a forward operator, i.e., $\mathbb{F}x_t = Ex_{t+1}$. Analogously, iterations of (A.22) yields the Nash-bargaining wage under common effort (where $\varphi_1 \tau_i = \varphi_3 \tau$) (which (16) in the main text):

$$\begin{aligned}
\widehat{w}^* =& \sum_{j=0}^{\infty} \left(\frac{\varphi_3 \tau}{\widetilde{\gamma}\Xi}\right)^j \left\{ \frac{\varphi_3}{\widetilde{\gamma}\Xi}(1-\tau)\widehat{w}^*_{F,t+j} + \left(1 - \frac{\varphi_3}{\widetilde{\gamma}\Xi}\right) \widehat{\overline{w}}_{t+j} \right\} \\
=& \varphi \left(\frac{1}{\tau} - 1\right) \frac{E\widehat{w}^*_{F,t}}{1-\varphi\mathbb{F}} + \left(1 - \frac{\varphi}{\tau}\right) \frac{E\widehat{\overline{w}}_t}{1-\varphi\mathbb{F}}.
\end{aligned} \tag{A.34}$$

While the two expressions appear nearly identical, τ_i in the individual effort model differs from the τ in the common effort model.

The Nash-bargaining wage under the fixed effort is readily obtained by setting the Frisch elasticity of effort to zero, $\widetilde{\gamma} = 0$:

$$\widehat{w}^* = (1-\tau)\sum_{j=0}^{\infty} \tau^j E\widehat{w}^*_{F,t+j} = (1-\tau)\frac{E\widehat{w}^*_{F,t}}{1-\tau\mathbb{F}}. \tag{A.35}$$

Substituting (A.33) into $\widehat{\overline{w}}_t = (1-(1-\delta)\lambda)\widehat{w}^*_t + (1-\delta)\lambda\widehat{\overline{w}}_{t-1}$, and multiplying both sides by $1-\varphi\mathbb{F}$, yields the aggregate wage in the individual effort model:

$$\widehat{\overline{w}}_t = \pi_1^i \widehat{\overline{w}}_{t-1} + \pi_2^i E\widehat{\overline{w}}_{t+1} + (1-\pi_1^i-\pi_2^i)\widehat{w}^*_{F,t},$$

where $\pi_1^i = \dfrac{(1-\delta)\lambda}{1+\varphi(1-\delta)\lambda-(1-(1-\delta)\lambda)(1-\varphi/\tau_i)}$ and $\pi_2^i = \dfrac{\varphi}{1+\varphi(1-\delta)\lambda-(1-(1-\delta)\lambda)(1-\varphi/\tau_i)}$.

Analogous to (A.34) and (A.35), the aggregate wage under common effort (17) is:

$$\widehat{\overline{w}}_t = \pi_1^c \widehat{\overline{w}}_{t-1} + \pi_2^c E\widehat{\overline{w}}_{t+1} + (1-\pi_1^c-\pi_2^c)\widehat{w}^*_{F,t},$$

where $\pi_1^c = \dfrac{(1-\delta)\lambda}{1+\varphi(1-\delta)\lambda-(1-(1-\delta)\lambda)(1-\varphi/\tau)}$, $\pi_2^c = \dfrac{\varphi}{1+\varphi(1-\delta)\lambda-(1-(1-\delta)\lambda)(1-\varphi/\tau)}$.

Similarly, the aggregate wage in the standard sticky wage with fixed effort (15) is

$$\widehat{\overline{w}}_t = \pi_1 \widehat{\overline{w}}_{t-1} + \pi_2 E\widehat{\overline{w}}_{t+1} + (1-\pi_1-\pi_2)\widehat{w}^*_{F,t},$$

where $\pi_1 = \dfrac{(1-\delta)\lambda}{1+\tau(1-\delta)\lambda}$ and $\pi_2 = \dfrac{\tau}{1+\tau(1-\delta)\lambda}$.

Since $\dfrac{\varphi}{\tau} = \dfrac{\varphi_3}{\widetilde{\gamma}\Xi} < 1$ and $\dfrac{\varphi}{\tau_i} = \dfrac{\varphi_1}{\widetilde{\gamma}\Xi} > 1$, $\tau_i < \varphi < \tau$. It follows that $\pi_1^c > \pi_1^i$ and $\pi_2^c > \pi_2^i$. It is also clear that $\pi_2 > \pi_2^c$, as $\tau[1+\varphi(1-\delta)\lambda-(1-(1-\delta)\lambda)(1-\varphi/\tau)] - \varphi[1+\tau(1-\delta)\lambda] = (1-\delta)\lambda(\tau-\varphi) > 0$. The relative sizes of π_1 and π_1^i depends on the sign of $(1-\delta)\lambda(\tau-\varphi)+(1-(1-\delta)\lambda)(1-\varphi/\tau_i)$, which cannot be determined analytically. However, under our benchmark calibration (as well as for a wide range of parameter values), this sign is positive, which implies that $\pi_1^i > \pi_1$. Combining all these results yields $\pi_1^c > \pi_1^i > \pi_1$: the weight on the lagged value is the largest under the common effort choice.

B Additional Results for the Model Economies

In this appendix section we provide extended results for models with fixed versus variable effort under flexible wages to parallel those discussed in the text under sticky wages. We also provide additional business cycle moments from the models, specifically the standard deviations of variables and their correlations with real GDP.

First consider shocks to technology. The model economies are subjected to persistent productivity shocks (auto-correlation of 0.95), with standard deviation chosen so that each model matches the standard deviation of HP-filtered TFP in the data. Because TPF reflects effort responses, this implies that the volatility of the shocks differ across models. For the models with fixed effort the standard deviation of the innovation to technology is 0.86%. For the models with effort fluctuations this standard deviation is respectively 0.69%, 1.06%, and 2.83% under flexible wages, sticky wages with individual effort, and sticky wages with common effort. In addition to the figures discussed in the text, Figure A1 compares the responses of wages, output, and employment under flexible wages for fixed effort and variable effort that reflects a common-effort choice. The models do not differ so sharply under flexible wages. Allowing the effort margin provides an added dimension for labor hours to respond, with effort declining in response to the decline in productity. As a result output (and TFP) respond by about 20 percent more to the shock. Employment actually declines a little less. This reflects that the decline in effort, by increasing labor's marginal product, essentially substitutes for some of the decline in employment.

Table A1 extends Table 2 from the text to provide results for the flexible wage models. The data column and the rightmost four columns are carried forward from Table 2. The top panel provides model moments in response to productivity shocks. Looking at the two flexible wage columns we see that, regardless of whether effort is fixed or responsive, the models produce wage rates that are far too cyclical and employment that is far too acyclical relative to the data.

Table A2 gives additional model moments results across the various models as well as for quarterly statistics for the U.S. economy for 1959:I to 2017:IV (first column) for model economies hit by productivity shocks. The additional moments are standard deviation of a series and its correlation with real output. In addition to output, the variables reported are employment, average hourly earnings, and TFP. Real output, employment, and average earnings are for the U.S. business sector as reported by the BLS program on Labor Productivity and Costs (https://www.bls.gov/lpc/). TFP is constructed from these data, hours (from same source), and the business-sector capital stock from the U.S. Department of

Commerce. The capital series is annual; we interpolate quarterly values. TFP reflects a correction for procyclical capital utilization. In the table we report the newly bargained wage, w^*, for the model, but not the data, as there is no aggregate data series corresponding to w^*. In the text we report cyclicality for an estimate of the new-hire wage based on Basu and House (2016). Much of the volatility of such a series reflects sampling error in the estimates. So the moments in Table A2, standard deviations and correlations with output, would be biased upwards and downwards respectively by these errors. (The cyclical elasticities, based on projections on aggregate output, reported in text Table 2 and Table A1, should not in principle be biased by those errors.) The table provides model results under flexible and sticky wages; but we focus discussion on the models with sticky wages. The standard deviation of employment in the data is 0.75 that for output.[35] But under fixed effort, or with individually chosen effort, model-predicted employment is much less volatile, with standard deviations one-sixth to one-eighth that in output. By contrast, the standard deviation of employment under our preferred model with common effort is 0.56 that in output, much closer to the data than any other models. Directly related, the model with a common effort response matches much better the relative standard deviation of TFP (0.66 versus 0.54 in the data). Finally, while none of the models matches the low correlation of aggregate wages with output in the data (0.16), the common-effort model does much better (0.54) than all other models (between 0.8 and 1).

For comparison, the last column, "G-T (2009)," reports the moments for the standard sticky-wage model with constant effort, but with wages for newly-hired workers tied explicitly to the sticky contracted wages of existing workers as, for instance, in Gertler and Trigari (2009). We calibrate the parameters of this model to be comparable to our benchmark, for instance, with the replacement ratio of 0.75 and a Calvo parameter of $\lambda = 3/4$.

The standard deviation of wages from the G-T economy is 0.45. That is larger than that for newly-hired or aggregate wages from our common effort model. The correlation of wages with output from the G-T economy is 0.74, which falls between those of newly-hired, 0.91, and aggregate wages, 0.54, from our common effort model. The volatility of employment from the G-T economy, 0.30, is about half that from the common effort model. In sum,

[35] All hours fluctuations in the models reflect employment. For the data we also examined statistics on total hours (employment times workweek). Its standard deviation relative to that in output is 0.93; its correlation with output is 0.86.

our model with common effort generates much more inertia in aggregate wages and twice as volatile employment compared to the G-T economy, even though newly-hired wages are completely flexible.

Figures A2 and A3 display model responses to persistent preference shocks. These supplement those in Figure 5 under the sticky wages. The preference shocks have an auto-correlation 0.95. Figure A2 compares flexible versus sticky wage responses under fixed effort. Except for the aggregate wage, the economies behave essentially the same. In particular, wage stickiness has no impact on the responses of employment or output (not pictured). Figure A3 compares responses under flexible wages when effort is fixed versus responsive. Wages behave very differently across the models. Wages go up in response to the negative labor supply under fixed effort, but go down when effort can respond, reflecting the decline in effort driven by the decline in desired labor supply. The decline in effort causes a much larger decline in output than under constant effort, but a somewhat smaller decline in employment, again, reflecting that the decline in effort partially substitutes for a decline in employment.

The bottom panel of Table A1 extends the results from the bottom panel of text Table 2 to give results for the flexible wage models. Results under sticky wages are repeated in the rightmost three columns. The model with flexible wages and variable effort actually responds similarly to that under productivity shocks. Wages and TFP are much more procyclical than in the data, while employment is much more acyclical.

In Table A3 we report the added business cycle moments from our simulated models in the face of preference shocks. The model economies are subjected to preference shocks with auto-correlation 0.95 and a standard deviation of its innovations to 2.83 percent. That standard deviation is set to be the same size as the productivity shocks to our preferred sticky wage model with common effort choice. The table reports the standard deviation for output; for other variables it reports its standard deviation relative to that for output and correlation with output. The table provides model results under flexible and sticky wages; but again we focus discussion on the models with sticky wages. The fixed effort model generates very different fluctuations under preference versus productivity shocks. The volatility of employment now exceeds that in output. Wages are extremely countercyclical, exhibiting correlations with respect to output of -0.88 to -0.98. The moments for models with variable effort closely resemble those generated by productivity shocks (Table A2). In particular, for the model with common effort the volatility of employment versus output is 0.63, compared to 0.56 under productivity shocks. Both fall a little short of the corresponding value in the data of 0.75. But the match to the data is much closer than any other models.

C SIPP Data for Measuring Wage Flexibility

The SIPP is a longitudinal survey of households designed to be representative of the U.S. population. It consists of a series of overlapping longitudinal panels. Each panel is three or more years in duration. Each is large, containing samples of about 20,000 households. Households are interviewed every four months. At each interview, information on work experience (employers, hours, earnings) are collected. Each year from 1984 through 1993 a new panel was begun. New, somewhat longer, panels were initiated in 1996, 2001, 2004, and 2008. In our analysis we employ the 6 panels from 1990 through 2001. (The 1984-1989 panels contain less reliable information on employer changes. The 2004 and 2008 panels carry forward employment information, including the wage rate, if the respondent deems changes to be small.) The SIPP interviews provide employment status and weeks worked for each of the prior four months. But earnings information is only collected for the interview month; so we restrict attention to the survey month observations.

For our purposes the SIPP has some distinct advantages. Compared to a matched CPS sample, we are able to calculate workers' wage changes across multiple surveys and at intervals of four months, rather than 12. It also provides better information for defining employer turnover. The SIPP has both a larger and more representative sample than the PSID or NLS panels and, most importantly, individuals are interviewed every four months.

We restrict our sample to persons of ages 20 to 60. Individuals must not be in the armed forces, not disabled, and not be attending school full-time. We only consider wage rates for workers who usually work more than 10 hours per week and report monthly earnings of at least \$100 and no more than \$25,000 in December 2004 CPI dollars. Any reported hourly wage rates that are imputed, top-coded, or below \$4 in December 2004 dollars are set equal to missing. Although the SIPP panels draw representative samples, in constructing all reported statistics we employ SIPP sampling weights that account for sample attrition. We also weight individuals by their relative earnings in the sample period, as this is consistent with the influence of workers for aggregate labor statistics.

We calculate frequency of wage changes over the 4-month interval between surveys for workers who remain with the same employer for their main job. For the 1990 to 1993 panels we define workers as stayers if the SIPP employer ID remains the same across surveys. We employ the 1990-1993 SIPP revised employer ID's, which have been edited at the Census to be consistent with information available in the non-public Census version of the data. Such edits have not been undertaken for 1996 and later panels. For the later panels a number of changes in employer ID appear (based on wages, et cetera) to not represent an employer change. For the later panels we define stayers based on responses to when the reference job began. More exactly, we define the worker as a new hire if they report that their job began within the last four months, or if in the prior survey they report that the reference job had ended by the survey. (This latter case is relatively rare.) We additionally call the worker a new hire if the employer ID and the industry of employment both change across surveys. We similarly calculate frequency of wage changes across eight-month intervals for those workers we classify as stayers over that 8-month interval. In calculating the Calvo parameter we use 4-month frequencies calculated just for 8-month stayers, so that the 4 and 8-month changes are calculated for the same sample.

Employed respondents report monthly earnings. In addition, just over half report an hourly rate of pay. For each worker we also calculate a weekly wage by dividing monthly earnings by the number of weeks worked in the month. We define a worker's wage as not changing if any of these three measures remains the same across the surveys.

The SIPP provides the worker's 3-digit industry code, allowing us to map SIPP workers to KLEMS industries. The total sample, combining observations from the 1990 to 2001 panels is large. For calculating 4-month and 8-month frequencies of wage changes it equals 350,044 observations; of these, 294,678 map to one of our KLEMS industries.

Table A1: Cyclicality Under Various Model Specifications

	Data	Models under Productivity Shocks (z)					
		Flexible Wages		Sticky Wages			
		Fixed Effort	Variable Effort	Fixed Effort	Individual Effort	Common Effort	G-T (2009)
Employment*	0.59 (0.03)	0.12	0.08	0.12	0.14	0.46	0.21
TFP	0.39 (0.03)	0.89	0.92	0.89	0.90	0.65	0.85
Newly-Hired Wage	0.48 (0.10)	0.78	0.85	0.69	1.09	0.35	0.33
Aggregate Wage	-0.03 (0.05)	0.78	0.85	0.35	0.73	0.16	0.33

	Data	Models under Preference Shocks (ξ)				
		Flexible Wages		Sticky Wages		
		Fixed Effort	Variable Effort	Fixed Effort	Individual Effort	Common Effort
Employment*	0.59 (0.03)	1.31	0.15	1.31	0.23	0.50
TFP	0.39 (0.03)	0.00	0.86	0.00	0.83	0.60
Newly-Hired Wage	0.48 (0.10)	-1.13	0.71	-1.03	0.90	0.22
Aggregate Wage	-0.03 (0.05)	-1.13	0.71	-0.61	0.59	0.09

Notes: Coefficients are projection of $\ln(X)$ on log aggregate output, where X takes roles of employment, wages, and TFP. "G-T (2009)" refers to the standard staggering-wage model (with fixed effort), such as Gertler and Trigari (2009), where wages of newly-hired are partially sticky (see text for the calibration of this model). All logged variables are quarterly and HP-filtered with smoothing parameter 1,600. Data are based on 1959:I-2017:IV. For wages (both aggregate and newly-hired), the estimates are based on a shorter time period of 1978:I-2013:IV when the newly-hired wages from Basu et al. (2016) are available. *The projection coefficient of total hours, as opposed to employment, on aggregate output is 0.77 (0.03).

Table A2: Business Cycle Moments of Models in Response to Productivity Shock

	Data		Flexible Wages				Sticky Wages							
			Fixed Effort		Variable Effort		Fixed Effort		Individual Effort		Common Effort		G-T (2009)	
	S.D.	*cor*	S.D.	*cor*	S.D.	*cor*	S.D.	*cor*	S.D.	*cor*	S.D.	*cor*	S.D.	*cor*
Output	2.01	1.00	1.25	1.00	1.20	1.00	1.25	1.00	1.24	1.00	1.70	1.00	1.27	1.00
Employment	0.75	0.79	0.17	0.69	0.12	0.68	0.17	0.69	0.16	0.86	0.56	0.81	0.30	0.72
Aggregate Wage	0.49	0.16	0.78	1.00	0.85	1.00	0.45	0.79	0.75	0.98	0.30	0.54	0.45	0.74
Newly Hired Wage	–	–	0.78	1.00	0.85	1.00	0.69	1.00	1.24	0.88	0.39	0.91	0.45	0.74
TFP	0.54	0.72	0.89	1.00	0.93	1.00	0.89	1.00	0.90	1.00	0.66	0.99	0.88	0.97

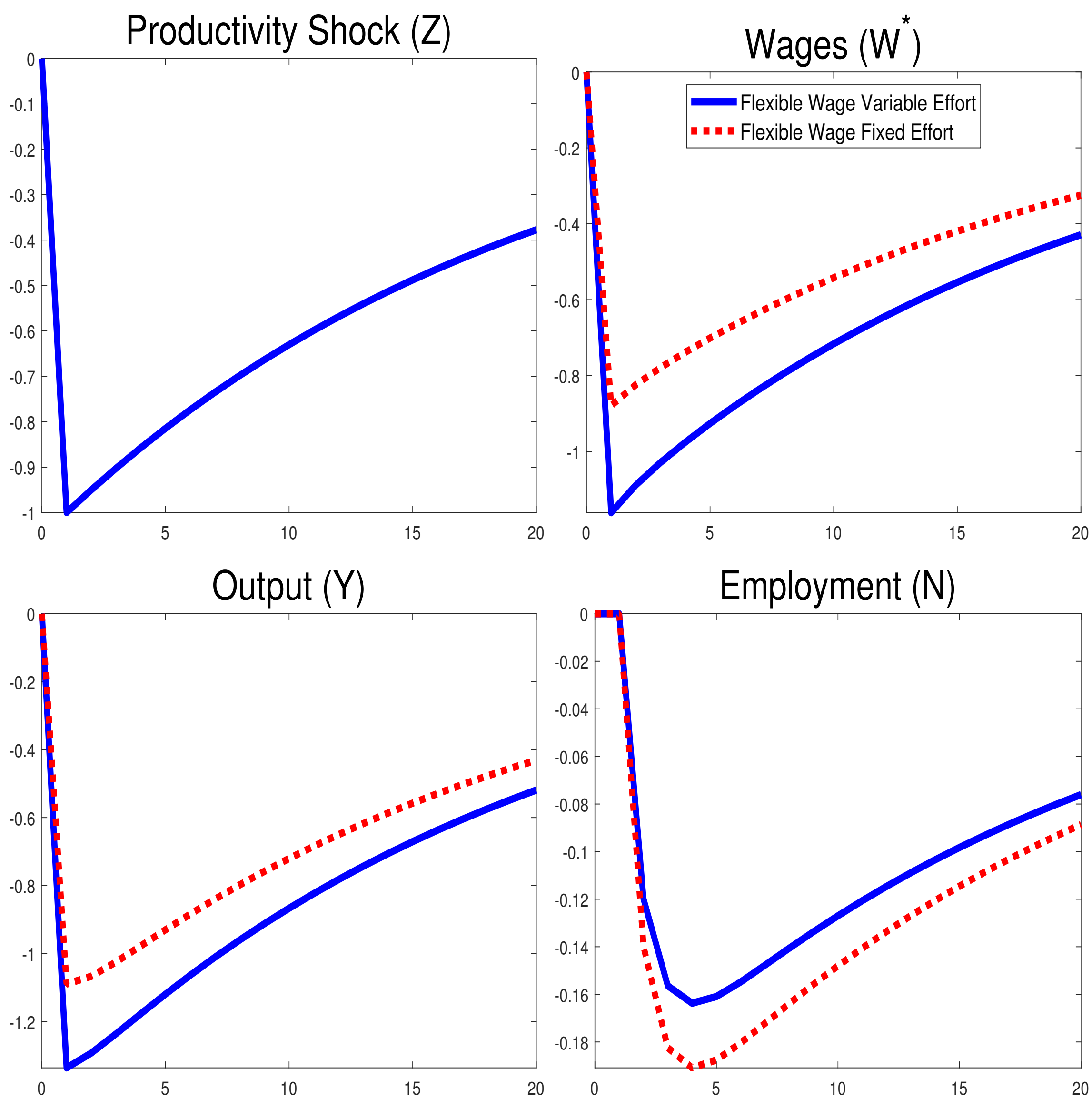
Notes: The standard deviations (S.D.) are relative to output except for output itself. The correlations with output are denoted by *cor*. "G-T (2009)" refers to the standard staggering-wage model (with fixed effort), such as Gertler and Trigari (2009), where the wages of newly-hired are partially sticky (see text for the calibration of this model). All variables are logged and H-P filtered with smoothing parameter 1,600. In all simulations, the auto-correlations of aggregate productivity shock are 0.95 and the standard deviation for innovation is chosen for the model to match the volatility of measured TFP in the U.S. data (see footnote 21 in the text). The S.D. of total hours and its correlation with output are respectively, 0.99 and 0.87. The data statistics are based on 1959:I - 2017:IV. The auto-correlations in the data (H-P filtered) are 0.86, 0.94, 0.68, and 0.74 respectively for output, employment, aggregate wage, and TFP. Those in our preferred benchmark model are 0.8, 0.84, 0.96, and 0.79, respectively.

Table A3: Business Cycle Moments of Models in Response to Preference Shock

	Data		Flexible Wages				Sticky Wages					
			Fixed Effort		Variable Effort		Fixed Effort		Individual Effort		Common Effort	
	S.D.	*cor*	S.D.	*cor*	S.D.	*cor*	S.D.	*cor*	S.D.	*cor*	S.D.	*cor*
Output	2.01	1.00	0.40	1.00	1.99	1.00	0.40	1.00	1.67	1.00	0.89	1.00
Employment	0.75	0.79	1.56	0.84	0.22	0.69	1.56	0.84	0.27	0.84	0.63	0.80
Aggregate Wage	0.49	0.16	1.15	-0.98	0.71	1.00	0.69	-0.88	0.61	0.97	0.19	0.48
Newly Hired Wage	–	–	1.15	-0.98	0.71	1.00	1.06	-0.97	1.01	0.89	0.25	0.87
TFP	0.54	0.72	–	–	0.86	1.00	–	–	0.83	1.00	0.61	0.99

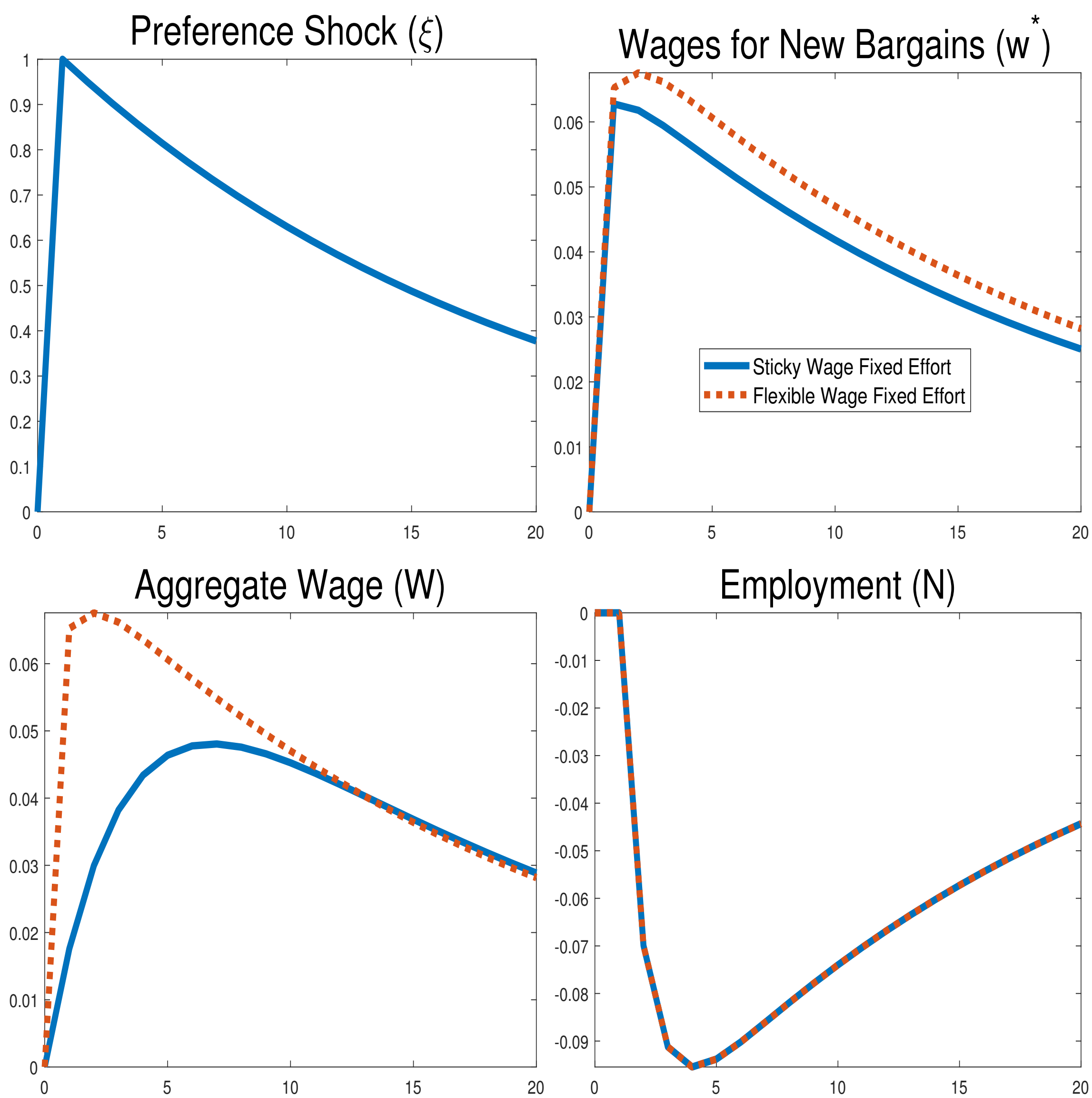
Notes: The standard deviations (S.D.) are relative to output except for output itself. The correlations with output are denoted by *cor*. "G-T (2009)" refers to the standard staggering-wage model (with fixed effort), such as Gertler and Trigari (2009), where the wages of newly-hired are partially sticky (see text for the calibration of this model). All variables are logged and H-P filtered with smoothing parameter 1,600. In all simulations, the auto-correlations of aggregate productivity shock are 0.95 and the standard deviation for innovation is chosen for the model to match the volatility of measured TFP in the U.S. data (see footnote 21 in the text). The S.D. of total hours and its correlation with output are respectively, 0.99 and 0.87. The data statistics are based on 1959:I - 2017:IV. The auto-correlations in the data (H-P filtered) are 0.86, 0.94, 0.68, and 0.74 respectively for output, employment, aggregate wage, and TFP. Those in our preferred benchmark model are 0.8, 0.84, 0.96, and 0.79, respectively.

Figure A1: Flexible Wage Models: Negative Productivity Shock



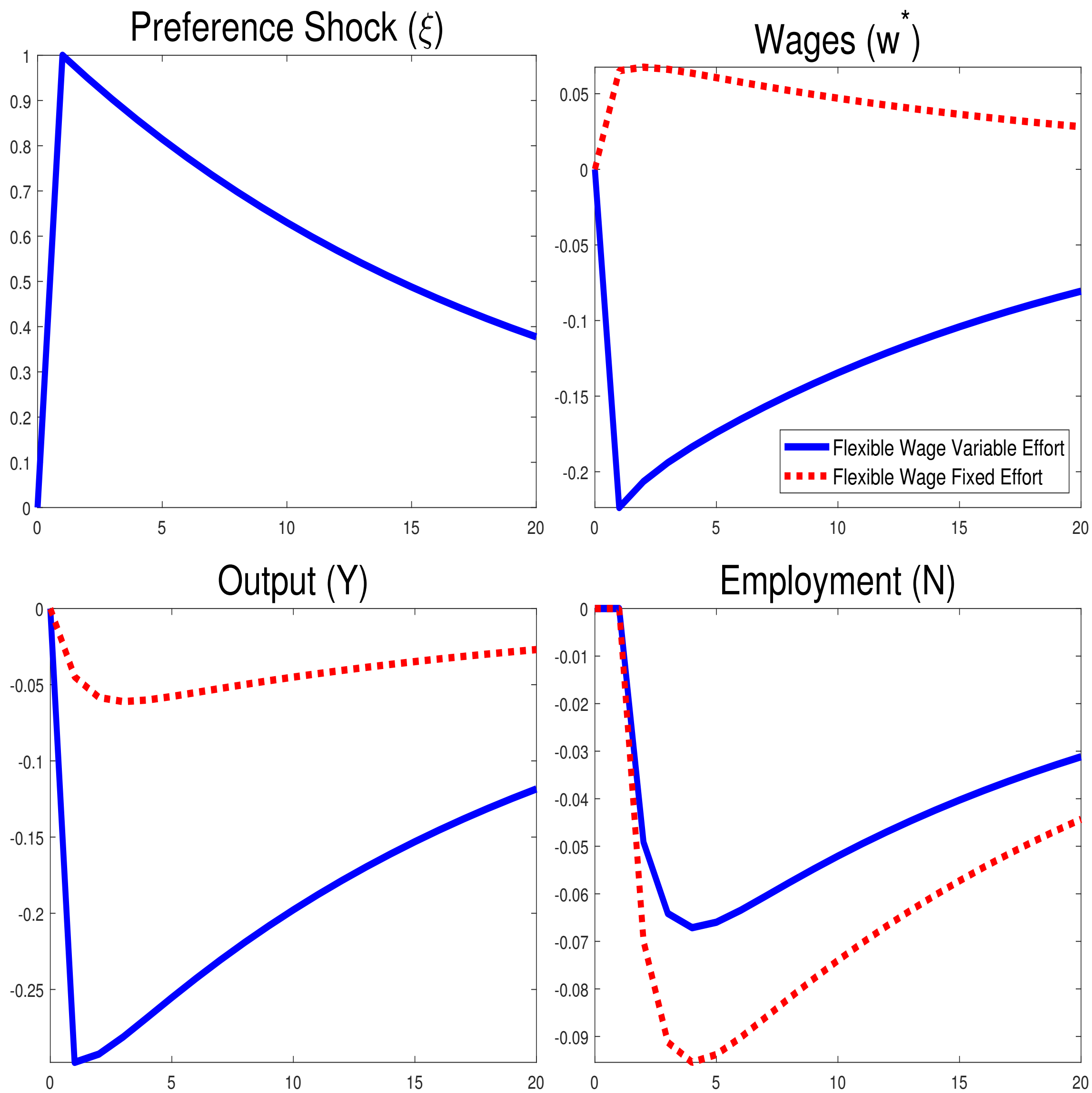
Notes: Productivity decreases by 1% in period 1 with auto-correlation of 0.95. The dotted line represents the model with fixed effort. The solid line represents the model with variable effort. The x axis represents periods (in quarters) and y axis represents percentage deviation from the steady state. All models feature $\alpha = 0.64$, $\widetilde{\gamma} = 0.5$, and $\widetilde{e} = 0.5$.

Figure A2: Models with Fixed Effort: Positive Preference Shock



Notes: Preference shock decreases by 1% in period 1 with auto-correlation of 0.95. The dotted line represents the model with flexible wages. The solid line represents the model with sticky wages. The x axis represents periods (in quarters) and y axis represents percentage deviation from the steady state. All models feature $\alpha = 0.64$, $\widetilde{\gamma} = 0.5$, $\lambda = 3/4$, and $\widetilde{e} = 0.5$.

Figure A3: Flexible Wage Models: Positive Preference Shock



Notes: Preference shock decreases by 1% in period 1 with auto-correlation of 0.95. The dotted line represents the model with fixed effort. The solid line represents the model with variable effort. The x axis represents periods (in quarters) and y axis represents percentage deviation from the steady state. All models feature $\alpha = 0.64$, $\widetilde{\gamma} = 0.5$, and $\widetilde{e} = 0.5$.