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Utility Curvature and Unemployment Volatility*

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Can we resolve the unemployment volatility puzzle (Shimer 2005) despite the cyclical opportunity cost of employment? Chodorow-Reich and Karabarbounis (2016) found that the opportunity cost of employment is highly procyclical, which poses significant challenges to the models of labor market fluctuations. Introducing procyclical opportunity cost inevitably weakens wage rigidity regardless of the exact types of wage bargaining, and it dampens the labor market volatility. We study the roles of the utility curvature and the intensive margin of labor supply, which not only induces the opportunity cost of employment procyclical but also generates additional sources of labor market fluctuations - cyclical stochastic discount factor and hours worked. Our model with alternating-offer wage bargaining can replicate the observed labor market volatility, with the help of high elasticity of intertemporal substitution, despite the cyclical opportunity cost of employment.

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I. Introduction

The labor search and matching model of Mortensen and Pissarides (1994) (MP model hereafter) has become the standard workhorse model of equilibrium with unemployment. As Shimer (2005) showed, however, it is well known that the

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reasonable calibration of the MP model is unable to reproduce the volatility of unemployment and vacancies observed in the postwar U.S. data. The quantitative failure of the MP model is attributed to the way wages are determined: the Nash-bargained wage responds strongly to variation in productivity. Therefore, the literature has proposed numerous modifications of the MP model that generate wage rigidity, among which the small surplus calibration of Hagedorn and Manovskii (2008) and the alternating-offer wage bargaining of Hall and Milgrom (2008) are the leading solutions to the unemployment volatility puzzle.

One big problem in these leading solutions is that they heavily rely on constant opportunity cost of employment to generate wage rigidity.[1] Chodorow-Reich and Karabarbounis (2016) recently find that the empirically measured opportunity cost of employment is highly procyclical - whose elasticity with respect to marginal product of employment is close to one, which shows that the unemployment volatility puzzle cannot be resolved by appealing to the assumption of the constant opportunity cost of employment. Once the cyclicality of the opportunity cost of employment is introduced in those models as in the data, the equilibrium wage will become highly cyclical, which significantly dampens the labor market fluctuations. Intuitively, as the opportunity cost of employment decreases during a recession, the surplus from a new employment increases given wage, which generates downward pressure on the bargained wages and mitigates the increase in unemployment.

Can we resolve the unemployment volatility puzzle despite the procyclical opportunity cost of employment? The goal of this paper is to explore the roles of the curvature of utility and the intensive margin of labor supply to answer this question. If the nonlinear utility over consumption and elastic hours worked are allowed in the MP model, not only becomes the opportunity cost of employment procyclical, but also additional sources of labor market fluctuations - cyclical stochastic discount factor and hours worked - are generated. Combining these factors with the alternating-offer bargaining, the MP model with a high level of elasticity of intertemporal substitution (EIS) - the EIS of 2 - can account for the observed labor market volatility despite the procyclicality of the opportunity cost of employment.

We can better understand the results by analyzing the sources of the labor market volatility. In the standard MP model with linear utility and inelastic labor, wage rigidity is the only source of labor market fluctuations. On the other hand, in a nonlinear model with elastic labor, three channels contribute to the volatility. When a positive productivity shock hits the economy, the firm invests more in posting vacancies, when i) the wage rate rises less, growing the marginal profitability from an additional recruitment more, ii) the stochastic discount factor declines less in

[1] The terminology, "the opportunity cost of employment," is from Chodorow-Reich and Karabarbounis (2016). Hagedorn and Manovskii (2008), Hall and Milgrom (2008), and Hall (2017) use "the flow value of nonmarket activity", "the flow value of nonwork", and "the flow value of unemployment" instead, respectively.

response to consumption growth, making the firm more patient, and iii) hours worked increases more, expanding the accounting profit further. As the opportunity cost of employment becomes procyclical, the wage rigidity channel is inevitably weakened compared to that in a linear model *even if we take the alternating-offer bargaining*. However, a high level of the EIS can generate less responsive stochastic discount factors and procyclicality of hours worked. Our quantitative decomposition shows that all three sources are important to resolve the volatility puzzle. The first two sources play a crucial role in reproducing the unemployment volatility, and the intensive labor supply is important in generating the procyclical opportunity cost of employment.

We further investigate the role of each component. First, in the alternating-offer wage bargaining, since the threat point of the bargaining depends on the cyclical opportunity cost of employment, the extent of wage rigidity is significantly weakened compared to that in Hall and Milgrom (2008). Thus, the alternating-offer bargaining alone cannot resolve the labor market volatility puzzle in the presence of the cyclical opportunity cost of employment. Despite the reduced contribution, the alternating-offer bargaining can still generate somewhat productivity-insulated wages as the worker's credible threat depends on the delay cost and termination probability of the bargaining. Higher bargaining delay cost and lower bargaining termination probability expand a constant proportion of the equilibrium wage.

Next, a higher level of the EIS amplifies the cyclicality of the MP model through (i) the weaker reaction of the stochastic discount factor to consumption growth and (ii) the stronger procyclicality of the labor supply. With regard to the stochastic discount factor, when a positive productivity increases consumption growth, the substitution effect inspires the firm to open more vacancies with higher marginal profitability from an extra recruitment, which could be counterbalanced by the wealth effects as the firms smooth over time with diminishing stochastic discount factor. When it comes to the intensive margin of labor supply, the substitution effect increases hours worked during booms, but this again can be mitigated by counteracting wealth effects. When the EIS is high, the substitution effects outweigh the wealth effects. High EIS not only lowers the sensitivity of the stochastic discount factor to consumption growth, but also reinforces the procyclicality of hours worked, both of which amplify the procyclicality of vacancies opened by the firm.

There is little agreement in the macroeconomics and finance literature about the appropriate magnitude of the EIS. Hall (1988) and Campbell (1999) argue that the EIS is close to zero. On the contrary, Attanasio and Vissing-Jorgensen (2003), Gruber (2006), and van Binsbergen et al. (2012) claim that the EIS is well over one. Also, Bansal and Yaron (2004), Gourio (2012), and Nakamura et al. (2013) find that a low EIS entails counterfactual implications for business cycles and asset prices. In our model, the following results support a high level of the EIS. The EIS parameter of 2.0 generates the EIS estimate close to zero, which may suggest the downward bias of Hall (1988)'s estimation. In addition, a low level of the EIS counterfactually implies the countercyclicality of hours worked. A high level of the EIS is also necessary to reproduce the observed volatility of the risk-free rates and of the excess stock returns.

This paper is built on two strands of the literature. The first group tries to resolve the unemployment volatility puzzle of Shimer (2005) by improving the MP model. Hagedorn and Manovskii (2008) and Hall and Milgrom (2008) are the leading solutions, but the problem is that they depend on the constant opportunity cost of employment. Our paper is closely related to works by Nakajima (2012) and Cairó, Fujita, and Morales-Jiménez (2021), who also introduce nonlinear utility and elastic labor supply to the MP model. Different from our paper, wages in their models are very rigid despite the procyclical opportunity cost of employment, and they mainly depend on the wage rigidity channel to generate the labor market amplification. Nakajima (2012) uses the calibration strategy similar to that in Hagedorn and Manovskii (2008). With cyclical outside value in the Nash bargaining, however, the level of calibrated unemployment benefit needs to be very high to match wage stickiness - but its estimated value is small in Chodorow-Reich and Karabarbounis (2016).[2] In Cairó, Fujita, and Morales-Jiménez (2021), the procyclical opportunity cost of employment does *not* weaken the wage rigidity channel due to the special form of the wage determination which decouples wage from the values of non-market activities.[3]

The second group tries to account for the business cycles by introducing the search and matching frictions in the labor market into the real business cycle model, which is pioneered by Merz (1995) and Andolfatto (1996). Chéron and Langot (2004) extend the labor market search model by introducing nonseparable preferences over consumption and leisure proposed by Rogerson and Wright (1988). They show that the preferences can generate countercyclical component in the Nash-bargained wage and thus result in endogenous wage rigidity.[4] More recently,

[2] Nakajima (2012) also assumes the preferences with no income effects on labor supply, which imposes labor supply channel to increase the labor market fluctuations. Our paper allows both substitution and wealth effects of the labor supply channel, and shows that higher EIS makes the substitution effects stronger.

[3] More precisely, Cairó, Fujita, and Morales-Jiménez (2021) extend MP model to incorporate the labor force participation margin, and the opportunity cost of employment is the value of nonparticipation (out of the labor force). The procyclicality of opportunity cost of employment in their model is generated by the elasticity of substitution between market-produced goods and home-produced goods and the elasticity of nonparticipation. Also, the focus of their paper is to understand the cyclicality of participation margin.

[4] Note that in Chéron and Langot (2004), the opportunity cost of employment is (weakly) procyclical despite the countercyclical component. The countercyclial component - the difference

some studies, such as Petrosky-Nadeau, Zhang, and Kuehn (2018), Kilic and Wachter (2017), and Hall (2017) emphasize the link between the labor market and the financial market in the context of the real business cycle model.

The paper proceeds as follows. Section 2 presents a simple model to explain the sources of labor market fluctuations. Section 3 illustrates the full model. Section 4 parameterizes the model. Section 5 presents the quantitative result. Section 6 investigates the role of each component for generating labor market volatility in the MP model. Section 7 concludes.

II. Sources of Labor Market Fluctuations: Simple Model

In this section, we use a simple model to investigate possible sources of labor market fluctuations. We highlight that the leading solutions to the unemployment volatility puzzle solely rely on the wage rigidity channel, which crucially depends on constant opportunity cost of employment. Can we resolve the volatility puzzle despite the cyclical opportunity cost of employment as in the data? The model that solely depends on the wage rigidity channel cannot, because introducing highly procyclical opportunity cost of employment inevitably weakens the wage rigidity. We show that introducing nonlinear utility and elastic labor supply can do the job because we can also exploit other channels of the labor market fluctuations.

The firm produces output y using labor as its only input according to the following linear production function: $y = xhn$, where h is hours worked, n is number of employed workers, and x_t is labor productivity. Suppose that labor productivity x takes one of discrete points $G^x = \{x^1, \cdots, x^{T_x}\}$ and follows a Markov process. Let $\Pi(x' \mid x)$ denote the transition probability of labor productivity from x to x'.

The risk-neutral firm discounts future payoffs with the stochastic discount factor M. Taking the vacancy-filling rate q and the path of prices as given, the firm maximizes cum-dividend value by posting vacancies v, subject to the employment evolution condition with exogenous separation rate ϕ:

$$S(n,x) = \max_{v} y - whn - \kappa v + \sum_{x' \in G^x} \Pi(x' \mid x)[M(n'(n,x), x' \mid n, x) S(n'(n,x), x')]$$

$$s.t. \quad n' = (1-\phi)n + qv ,$$

between the utility of unemployed and employed denominated by marginal utility of consumption - crucially depends on the underlying assumption of the Rogerson-Wright preferences that market goods are preferred to leisure. Thus, the wage rigidity in Chéron and Langot (2004) depends on the strong relative preferences consumption over leisure - which also implies high consumption ratio between the employed and unemployed $(\frac{c_u}{c_n} = 0.16)$.

where w is wage rate and κ is the cost of posting each vacancy.

The first order condition yields the intertemporal job creation condition:

$$\frac{\kappa}{q(n,x)} = \sum_{x' \in G^x} \Pi(x' \mid x) M(n'(n,x), x' \mid n,x)$$
$$\left\{ [x' - w(n'(n,x),x')] h(n'(n,x),x') + \frac{\kappa}{q(n'(n,x),x')}(1-\phi) \right\}, \tag{1}$$

where the marginal cost of hiring an additional employee equals the expected discounted profits from the recruitment. Log linearization around the deterministic steady state converts equation (1) into the form

$$\hat{q} = -\mathbb{E}\hat{M}' + \frac{\beta h_{ss} q_{ss}}{\kappa}[w_{ss}\mathbb{E}\hat{w}' - x_{ss}\mathbb{E}\hat{x}'] - (1-\beta(1-\phi))\mathbb{E}\hat{h}' + \beta(1-\phi)\mathbb{E}\hat{q}', \tag{2}$$

where the percentage deviation from the steady state is denoted by a hat above the variable and a prime on a variable denotes the value of the variable in the next period. We also note that $\beta = M(n_{ss}, x_{ss} \mid n_{ss}, x_{ss})$ is the stochastic discount factor in the steady state. This log linearized equation shows that the vacancy-filling rate q is determined by profit margin per hour $x - w$, the stochastic discount factor M, and hours worked h.

From (2), we identify that there can be three sources of increasing the labor market fluctuations. When productivity x rises and thus employment n increases, the vacancy-filling rate $q(n,x)$ declines more, i) if the wage rate $w(n',x')$ goes up less, ii) if the stochastic discount factor $M(n',x' \mid n,x)$ declines less, and iii) if hours worked $h(n',x')$ grows more in the equilibrium.

The literature on the unemployment volatility puzzle typically assumes that utility is linear and hours worked are inelastic, and thus focuses on the wage rigidity channel. As an example, consider Nash bargaining for the wage determination. Let $\omega \in (0,1)$ to be a relative bargaining power of the worker. Then the equilibrium wage in period t is set by

$$w_t = \frac{1}{h_t}\{\omega(x_t h_t + \theta_t \kappa) + (1-\omega) z_t\}, \tag{3}$$

where θ_t is the labor market tightness, κ is the vacancy posting cost per vacancy, and z_t is the opportunity cost of employment. See appendix B for the derivation. Given the values of parameters ω and z (assuming constant z_t) obtained from the standard calibration in the search literature, the wage is too closely linked to productivity even with constant z_t. This is the unemployment volatility puzzle suggested by Shimer (2005).[5]

In the leading solutions to the unemployment volatility puzzle - Hagedorn and Manovskii (2008) and Hall and Milgrom (2008), their linear models also generate volatility solely relying on the wage rigidity with constant stochastic discount factor and hours worked. More importantly, their utility assumption implies constant flow value of nonworking - additional utility of workers quitting a job to enjoy non-working time is constant, which plays a crucial role for wage rigidity in the wage bargaining. However, Chodorow-Reich and Karabarbounis (2016) find that the empirical elasticity of the opportunity cost of employment is close to one, which poses significant challenges to these models.

The key question of this paper is: can we develop a model that can resolve the volatility puzzle, but that is free from the criticism of Chodorow-Reich and Karabarbounis (2016)? Once the procyclical opportunity cost of employment is introduced, the equilibrium wage inevitably becomes more cyclical regardless of the exact types of wage bargaining. That is, we cannot resolve the volatility puzzle solely based on the wage rigidity channel. Relaxing the assumption of linear utility and inelastic labor hours can do the job, however, because it makes not only the opportunity cost but also the stochastic discount factor and hours worked cyclical, which can also contribute to the labor market fluctuations.

III. Model

We embed the labor market search and matching frictions of Mortensen and Pissarides (1994) and the alternating-offer bargaining of Hall and Milgrom (2008) into a real business cycle model with both extensive and intensive margins of labor supply. Time is discrete and infinite. Consumption is the numeraire good. The economy is populated by a representative firm and a representative household family. The firm is owned by the household, produces output with labor, and pays out profits as dividends. The household family is made up of a continuum of identical workers of mass one, and it perfectly insures its members against personal income variations.[6] The derivation of the equations is given in appendix B.

[5] The search literature typically calibrates ω by appealing to the Hosios (1990) condition - opening a vacancy is socially efficient when the bargaining power of the worker equals the unemployment elasticity parameter of the Cobb-Douglas matching function. Shimer (2005) and Pissarides (2009) use $\omega = 0.4$ and $\omega = 0.5$, respectively. As a proxy for the opportunity cost of employment z, it is common to use the average ratio of the unemployment benefit to wages. The average replacement rate is generally estimated to be 0.2 in the U.S. and 0.7 in Europe.

[6] The perfect insurance assumption is widely used for analytical simplicity in the literature (Merz 1995, Andolfatto 1996, Hall 2009, Eusepi and Preston 2014, etc.). Without the assumption, we should track an individual state variable, wealth, of all employed and unemployed workers for aggregation as in Bils, Chang, and Kim (2011).

3.1. Search and Matching Frictions in the Labor Market

In each period t, a fraction n_t of workers are employed. A remaining fraction $u_t = 1 - n_t$ of workers are unemployed and searching for a job. At the beginning of period t, the firm posts job vacancies v_t at a cost κ per vacancy.

The flow of successful matches m_t is determined by a constant-return-to-scale matching function $m(u_t, v_t)$, which is increasing and strictly concave in u_t and v_t. The matching function represents labor market frictions, such as lack of coordination, imperfect information, and heterogeneity of vacancies and workers. We adopt the functional form introduced by den Haan, Ramey, and Watson (2000).[7]

$$m_t = m(u_t, v_t) = \frac{u_t v_t}{(u_t^\alpha + v_t^\alpha)^{1/\alpha}}, \quad \alpha > 0 \tag{4}$$

Let θ_t denote the vacancies/unemployment ratio, v_t / u_t, which represents labor market tightness from a firm's standpoint. From the matching function (4), the vacancy-filling rate q_t of the firm and the job-finding rate f_t of workers are given by

$$q_t = q(\theta_t) = \frac{m_t}{v_t} = \frac{1}{(1+\theta_t^\alpha)^{1/\alpha}} \quad \text{and} \tag{5}$$

$$f_t = f(\theta_t) = \frac{m_t}{u_t} = \frac{1}{(1+\theta_t^{-\alpha})^{1/\alpha}} = \theta_t q_t . \tag{6}$$

The tighter labor market makes it more difficult for the firm to recruit a worker ($q'(\theta_t) < 0$), whereas easier for job-seekers to become employed ($f'(\theta_t) > 0$). q_t and f_t are the endogenous outcomes in the labor market, but the household and the firm take them as a given.

At the beginning of next period $t+1$, matched workers and the firm haggle over hours worked h_{t+1} and a wage rate w_{t+1}, whose determination is described in section 3.4. Employed workers exogenously lose their job with a separation rate ϕ. Therefore, employment evolves as follows:

$$n_{t+1} = (1-\phi) n_t + q_t v_t . \tag{7}$$

[7] Unlike the standard Cobb-Douglas specification, this functional form ensures that the vacancy-filling rate and the job-finding rate lie between zero and one for all u_t and v_t.

3.2. Production and Firm's Decisions

As in the simple model, the firm produces output y_t with linear production function $y_t = x_t h_t n_t$, where h_t is hours worked, and x_t is labor productivity whose log value follows a AR(1) process with a persistence ρ and a normal disturbance ε_t.

$$\log x_t = \rho \log x_{t-1} + \varepsilon_t, \quad \varepsilon_t \sim iid\, N(0,\sigma^2) \tag{8}$$

To focus on the labor market and gain computational simplicity, we abstract from physical capital in the production following the literature.[8]

If the firm employs n_t workers and posts v_t vacancies, it receives profits $d_t = y_t - w_t h_t n_t - \kappa v_t$ in period t. The firm is risk neutral and it discounts future payoffs with the same stochastic discount factor M_{t+1} as the household does, which will be discussed in section 3.3.[9] Taking the labor market outcomes, the path of prices, and the state vector $\Phi_t = (n_t, x_t)$ as given, the firm maximizes cum-dividend value by posting vacancies v_t, subject to the employment evolution condition and the nonnegative vacancy condition:

$$S_t = \max_{v_t} d_t + \mathbb{E}_t[M_{t+1} S_{t+1}] \tag{9}$$

$$s.t. \quad n_{t+1} = (1-\phi) n_t + q_t v_t$$

$$v_t \geq 0, \tag{10}$$

where $S_t = S(\Phi_t)$, and $\mathbb{E}_t$ is the expectation conditional on the information at period t.[10]

Let π_t and $\zeta_t q_t$ denote Lagrangian multipliers on the employment evolution condition and the nonnegative vacancy condition, respectively. Then the first order condition for v_t yields the intertemporal job creation condition:

$$\frac{\kappa}{q_t} - \zeta_t = \mathbb{E}_t\left[M_{t+1} \left\{ x_{t+1} h_{t+1} - w_{t+1} h_{t+1} + \left(\frac{\kappa}{q_{t+1}} - \zeta_{t+1} \right)(1-\phi) \right\} \right], \tag{11}$$

[8] See Shimer (2005), Pissarides (2009), Petrosky-Nadeau, Zhang, and Kuehn (2018), etc. Because physical capital shows smooth cyclical variations, it may have little impact on the marginal product of employment and thus on unemployment volatility.

[9] See Danthine and Donaldson (2004) for a case in which this assumption does not have to hold.

[10] As in Petrosky-Nadeau, Zhang, and Kuehn (2018), we impose the nonnegative vacancy condition (10), because it is occasionally binding when productivity is low but employment is high. Also, it facilitates obtaining numerical solutions by preventing the vacancy-filling rate larger than one. But this constraint is not essential because it never binds in simulations based on our calibration.

which shows the three sources of labor market fluctuations - wage rigidity, stochastic discount factor, and hours worked - as we discussed in section 2. We denote the marginal value of an employed worker to the firm by $S_{n,t} = \partial S_t / \partial n_t$, and it is given by

$$S_{n,t} = x_t h_t - w_t h_t + \mathbb{E}_t[M_{t+1} S_{n,t+1}(1-\phi)]. \tag{12}$$

Similarly, we denote the marginal value of a posted vacancy to the firm $S_{v,t} = \partial S_t / \partial v_t$. The assumption on free entry yields $S_{v,t} = 0$. In sum, the firm gets the surplus of $S_{n,t} - S_{v,t} = S_{n,t}$, when it recruits an additional worker by filling a vacancy.

3.3. Household's Decisions

Taking the labor market outcomes, the path of prices, and the state vector $\Phi_t = (n_t, x_t)$ as given, the household family maximizes utility by choosing consumptions of employed and unemployed workers, $c_{n,t}$ and $c_{u,t}$.

$$J_t = \max_{c_{n,t}, c_{u,t}} n_t U(c_{n,t}, h_t) + u_t U(c_{u,t}, 0) + \beta \mathbb{E}_t[J_{t+1}] \tag{13}$$

where $J_t = J(\Phi_t)$, β is the discount factor, and $U(c_t, h_t)$ is a period utility. We use the utility specification of Hall and Milgrom (2008):

$$U(c_t, h_t) = \frac{c_t^{1-1/\psi}}{1-1/\psi} - \tau \frac{c_t^{1-1/\psi}}{1-1/\psi} \frac{(h_t + \bar{h})^{1+1/\chi}}{1+1/\chi} - \varphi \frac{(h_t + \bar{h})^{1+1/\chi}}{1+1/\chi}, \tag{14}$$

where c_t is consumption, ψ controls the EIS, and τ sets the complementarity between consumption and hours worked. τ should be smaller than 0 to guarantee a higher level of consumption to employed workers than to unemployed workers ($U_{ch} > 0$). χ determines the Frisch elasticity of labor supply along the intensive margin, and φ governs the disutility from hours worked. Finally, $\bar{h}$ parameterizes the fixed time cost associated with working.[11]

The budget constraint of the household is

$$n_t c_{n,t} + u_t c_{u,t} + \bar{c} + T_t + \frac{b_{t+1}}{R_t^f} + a_{t+1} e_t = w_t h_t n_t + \eta u_t + b_t + a_t (d_t + e_t) \tag{15}$$

[11] We set $\bar{h}$ to be zero in the baseline calibration, while we assign it a positive value to target the certain level of the opportunity cost of employment in the sensitivity analysis.

where $\overline{c}$ is the expenditures for the public good within the household, R_t^f is a risk-free rate, b_t is holdings of risk-free assets, a_t is holdings of equity shares, e_t is an ex-dividend equity value, η is the unemployment benefit per unemployed worker, d_t is dividends, and T_t is lump-sum taxes to finance the public benefit.[12] Let λ_t denote a Lagrange multiplier on the budget constraint. Then the stochastic discount factor M_{t+1} is given by

$$M_{t+1} = \beta \frac{\lambda_{t+1}}{\lambda_t} = \beta \left(\frac{c_{u,t+1}}{c_{u,t}} \right)^{-1/\psi} = \beta \left(\frac{c_{n,t+1}}{c_{n,t}} \right)^{-1/\psi} \left(\frac{1 - \tau \frac{\left(h_{t+1} + \overline{h}\right)^{1+1/\chi}}{1+1/\chi}}{1 - \tau \frac{\left(h_t + \overline{h}\right)^{1+1/\chi}}{1+1/\chi}} \right) \tag{16}$$

For notational simplicity, define $U_{n,t} = U(c_{n,t}, h_t)$ and $U_{u,t} = U(c_{u,t}, 0)$. We denote the marginal value of an unemployed worker to household by $J_{u,t} = \partial J_t / \partial u_t$ and denote the marginal value of an employed worker to the household by $J_{n,t} = \partial J_t / \partial n_t$. Then the surplus of an additional employed member is

$$\frac{J_{n,t} - J_{u,t}}{\lambda_t} = w_t h_t - \left[\eta - (c_{u,t} - c_{n,t}) + \left(\frac{U_{u,t} - U_{n,t}}{\lambda_t} \right) \right] + (1 - \phi - f_t) \mathbb{E}_t \left[M_{t+1} \left\{ \frac{J_{n,t+1} - J_{u,t+1}}{\lambda_{t+1}} \right\} \right], \tag{17}$$

where the second bracketed term of (17) represents the opportunity cost of employment per person denoted by z_t:

$$z_t = \eta + \frac{[U_{u,t} - \lambda_t c_{u,t}] - [U_{n,t} - \lambda_t c_{n,t}]}{\lambda_t} = \eta + \varrho_t. \tag{18}$$

Note that z_t contains not only the unemployment benefit η, but also the flow value of non-working time in units of consumption ϱ_t.

The opportunity cost of employment z_t is procyclical in the model. Intuitively, when productivity increases, the relative value of non-working time (ϱ_t) gets higher because (i) λ_t decreases as consumption grows, and (ii) the contribution of unemployed to the household relative to that of the employed increases as the

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[12] Note that the public consumption within the household $\overline{c}$ does not enter the utility of the household. We model $\overline{c}$ to match the target levels of consumption of the emplyed and unemployed which are estimated in the data.

response of hours worked of the employed increases. Chodorow-Reich and Karabarbounis (2016) show that (a) η is countercyclical but takes up only a small portion, and (b) ϱ_t is highly procyclical. Therefore, the opportunity cost of employment in total is procyclical and volatile over the business cycle.

3.4. Bargaining on Hours Worked and Wages

A bargaining between the matched worker and the firm determines contract terms on hours worked and the wage rate. Let $\Lambda_t = \frac{J_{n,t} - J_{u,t}}{\lambda_t} + S_{n,t} - S_{v,t}$ denote the joint surplus from an additional match in terms of consumption. Hours worked h_t is efficiently selected to maximize the surplus Λ_t which satisfies

$$x_t \lambda_t = -\frac{\partial U_{n,t}}{\partial h_t}. \tag{19}$$

The wage rate is selected by the alternating-offer wage bargaining proposed by Hall and Milgrom (2008). The matched worker and the firm alternate in making wage proposals. The firm makes the first offer w_t. The worker responds to it by taking one of the three options: (a) accept the firm's offer, (b) reject it, prolong the bargain, and make a counter-offer $\hat{w}_{t+1}$ in the next period, and (c) abandon the negotiation and exercise the outside option. When the bargaining is delayed, the worker receives the unemployment benefit η while the bargaining delay incurs cost ξ to the firm, and the firm becomes a responding party with the same options in the next period. When the bargaining is terminated, the worker becomes unemployed and contributes $J_{u,t} / \lambda_t$ to the household, while the firm obtains $S_{v,t} = 0$. However, we assume that the outside options are less favorable for both parties than the agreement, which will be accomplished by the calibration.[13] Therefore, taking the outside options is not a credible threat, and matters only when the negotiation breaks down exogenously with the bargaining termination probability δ. In equilibrium, the firm proposes the just acceptable offer to the worker and the firm's initial offer becomes the equilibrium wage.

In appendix B, we derive the wage offers from the firm and the worker respectively:

[13] To make the bargainers never abandon, the joint value from an agreement should be larger than the joint value from the outside options. Also, it should outweigh the present value from prolonging the negotiation infinitely. Because the joint value from the outside options is bigger than the present value from delaying infinitely, we need to check whether the numerical solution satisfies the following inequality.

$$\frac{J_{n,t}}{\lambda_t} + \left\{ x_t h_t - w_t h_t + \left(\frac{\kappa_t}{q_t} - \zeta_t \right)(1-\phi) \right\} > \frac{J_{u,t}}{\lambda_t}$$

$$w_t^f = \frac{1}{h_t}\left\{ z_t + (1-\delta)\mathbb{E}_t\left[M_{t+1}\left(\frac{J_{n,t+1}^h}{\lambda_{t+1}} - \frac{J_{u,t+1}}{\lambda_{t+1}} \right)\right] - (1-\phi-\delta f_t)\mathbb{E}_t\left[M_{t+1}\left(\frac{J_{n,t+1}^f}{\lambda_{t+1}} - \frac{J_{u,t+1}}{\lambda_{t+1}} \right)\right]\right\}. \quad (20)$$

$$w_t^h = \frac{1}{h_t}\left\{ x_t h_t + (1-\phi)(1-\delta)\mathbb{E}_t\left[M_{t+1}\left\{ -\xi + \left(\frac{\kappa}{q_{t+1}} - \zeta_{t+1} \right)\right\}\right] - (1-\delta)\left[-\xi + \left(\frac{\kappa}{q_t} - \zeta_t \right)\right]\right\}. \quad (21)$$

The key difference from the original wage equations of Hall and Milgrom (2008) is that the opportunity cost of employment z_t in (20) is not constant but procyclical because of the curvature of utility over consumption and intensive labor supply. Therefore, the equilibrium wage responds more to productivity shock, which inevitably weakens the wage rigidity.

3.5. Recursive Equilibrium

The equilibrium of this economy is standard. Families and firms solve their problems given the prices and labor market outcomes. Labor market outcomes are endogenously determined so that the given vacancy-filling rate and job-finding rate are indeed the rates in the equilibrium, and the wage rate is determined by the alternating-offer wage bargaining. See appendix A for the formal definition of a recursive equilibrium.

IV. Calibration

To assess the cyclical performance of the MP model, we conduct the quantitative analysis by calibrating the parameters. See appendix C and D for the detail of the data sources and computation. We solve the model numerically using the policy function iteration with the finite element method. The main goal of the solution algorithm is to find the equilibrium vacancy-filling rate q_t satisfying the intertemporal job creation condition (11) over the state variables, n_t and z_t, which we discretize into an equidistant grid. Log-linearization is usually used for quantitative analysis in the search literature. However, the local solution method is not suitable to study the effect of utility curvature on unemployment volatility. Petrosky-Nadeau and Zhang (2017) also show that log-linearization understates the mean and volatility of unemployment, and overstates the correlation between unemployment and vacancies in the MP model. Therefore, we use the global solution method for quantitative analysis.

Table 1 summarizes the parameter values for the calibration. Because of nonlinearity, we calibrate the model not only by relying on the steady state equilibrium but also by matching moments from simulated data with corresponding targets from observed data. Throughout the paper, we obtain the moments of the model from 10,000 artificial samples, each of which has 868 observations. Because we discard the first 100 observations to eliminate the effect of the initial conditions, the samples span 768 months or 64 years. The sample period of the observed data is from 1951 to 2014.[14] As the model's period is one month, we time-aggregate the model-generated data properly in accordance with the target's frequency.

[Table 1] Parameter values (monthly)

Parameter	Interpretation	Value
Technology		
ρ	Persistence of productivity	0.935
σ	Volatility of productivity	0.006
Preference		
ψ	Consumption curvature	2.0
$\bar{h}$	Fixed time cost	0.0
χ	Hours worked curvature	0.652
φ	Disutility of hours worked	1.8752
τ	Complementarity in utility	-0.3116
$\bar{c}$	Household public consumption	0.2604
β	Time discount factor	0.9993
Labor market		
η	Unemployment benefit	0.058
ϕ	Separation rate	0.025
α	Elasticity of matching	1.05
κ	Vacancy-posting cost	0.254
Wage bargaining		
ξ	Bargaining delay cost to employer	0.5354
δ	Bargaining termination probability	0.027

Using the HP-filtered real output per hour in the nonfarm business sector, we find that quarterly labor productivity has an autocorrelation of 0.72 and a standard deviation of 0.011. This requires setting $\rho = 0.935$ and $\sigma = 0.006$ at monthly

[14] We pick 1951 as the beginning year of the sample period, following the literature. In 1951, the Conference Board began to construct the help-wanted advertising index, which Shimer (2005) uses as a proxy for the stock of vacancies.

frequency. We approximate the productivity process (8) with the 41-state Markov chain, using the method of Tauchen (1986).

Among the preference parameters, we take the EIS parameter $\psi = 2.0$ as in Barro (2009) and Gourio (2012). This value of ψ corresponds to the Frisch elasticity of consumption demand of -2.1 in our utility specification. We set the fixed time cost $\bar{h}$ to zero, and pick the curvature parameter of hours worked $\chi = 0.652$ to generate the Frisch elasticity of labor supply of 0.7, following Pistaferri (2003) and Hall (2009).[15] We calibrate the disutility parameter of hours worked $\varphi = 1.8752$ so that hours worked are normalized to be one in the steady state. Chodorow-Reich and Karabarbounis (2016) show that consumptions of employed and unemployed workers ($c_{n,t}$ and $c_{u,t}$) are estimated to be 0.681 and 0.540 relative to the marginal product of employment $(x_t h_t)$ on average respectively.[16] We determine the complementarity parameter $\tau = -0.3116$ and the public consumption within the household $\bar{c} = 0.2604$ to accomplish these targets in the steady state. We choose the time discount factor $\beta = 0.9993$ to match the 3-month T-bill rate of 0.87% per annum.

Among the labor market parameters, we set the public benefit to be $\eta = 0.058$, which is the estimate of Chodorow-Reich and Karabarbounis (2016). We neglect the countercyclicality of the public benefit, because the portion of the public benefit in the opportunity cost of employment is quite small. To calibrate the separation rate ϕ, we calculate monthly separation rates as the ratio of the number of unemployed workers who are unemployed for fewer than five weeks in the next month to the number of employed workers in the current month, and set ϕ to be the average of 0.025.[17] To choose the elasticity parameter of the matching function

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[15] The fixed time cost $\bar{h}$ is measured in terms of utility, whereas the unemployment benefit η is in terms of consumption. Thus, $\bar{h}$ is divided by the marginal utility of consumption λ_t in the opportunity cost of employment z_t. When $\bar{h}$ constitutes a large proportion of z_t in exchange for η, a higher level of the EIS causes z_t to be less procyclical through the less countercyclicality of λ_t. Accordingly, a positive value of $\bar{h}$ strengthens the relationship between the EIS and unemployment volatility.

[16] Chodorow-Reich and Karabarbounis (2016) estimate the consumptions of employed and unemployed workers using the model with the wage tax rate τ_w and the consumption tax rate τ_c. Under the conditions that hours worked and wages are determined by the Nash bargaining, we derive the same equilibrium equations from our model without the tax rates by replacing the Lagrangian multiplier λ_t with $\lambda_t/(1+\tau_c)$ and by multiplying x_t, κ, ξ, and w_t by $(1-\tau_w)/(1+\tau_c)$. Therefore, we adopt the estimates of Chodorow-Reich and Karabarbounis (2016) as the calibration targets without modification. In appendix E, the robustness analysis with respect to the utility specifications used by Chodorow-Reich and Karabarbounis (2016) also confirms that calibrating the MP model excluding the tax system with those consumption estimates yields the exactly same value of the utility parameters as in Chodorow-Reich and Karabarbounis (2016).

[17] Shimer (2005) points out that this procedure understates the separation rates, because it ignores workers who lose a job but find new one within a month. However, an adjustment of this time-aggregation bias is not consistent with the employment evolution condition, and thus impedes matching targets. Chodorow-Reich and Karabarbounis (2016) show that the bias is negligible because

α, we resort to monthly job-finding rates and vacancy-filling rates. We compute the job-finding rates using the alternative version of the employment evolution condition (7): $f_t = 1-(u_{t+1} - u^s_{t+1})/u_t$. And we obtain the vacancy-filling rates by inverting the DHI-DFH Mean Vacancy Duration Measure estimated by the method of Davis, Faberman, and Haltiwanger (2013).[18] We find that the job-finding rates and the vacancy-filling rates are 0.29 and 0.74 on average over 2001-2014 respectively. These figures require setting $\alpha = 1.05$. The level of α also matches the average job-finding rate of 0.41 in the data from 1951 to 2014. We calibrate the vacancy-posting cost $\kappa = 0.254$ to match the monthly marginal cost of hiring (κ / q_t) of 0.42 (0.14 quarterly) following Hall and Milgrom (2008).[19]

For the wage bargaining parameters, we follow Hall and Milgrom (2008). We take the bargaining delay cost $\xi = 0.5354$ to match the average unemployment rate of 5.9% in data. And we set the bargaining termination probability $\delta = 0.027$, which generates the observed unemployment volatility of 0.13.

Table 2 shows that with the calibration, the model matches the target moments in the data quite well.

[Table 2] Target moments of the calibration

	AC($\tilde{x}_t$)	SD($\tilde{x}_t$)	h^{ss}	c_n^{ss}	c_u^{ss}
Target	0.72	0.011	1.0	0.681	0.540
Model	0.719	0.0113	1.0	0.681	0.540
	E(r_t^f)	E(f_t)	E(κ / q_t)	E(u_t)	SD($\tilde{u}_t$)
Target	0.0087	0.41	0.42	0.059	0.13
Model	0.0083	0.414	0.419	0.0593	0.129

Notes: $\tilde{x}$ is the log deviation of x from its trend. We obtain the trend using the HP-filter with a smoothing parameter of 1,600, following Ravn and Uhlig (2002). E(x), AC(x) and SD(x) denote the mean, autocorrelation and standard deviation of x, respectively. Superscript ss represents the steady state value.

V. Quantitative Result

Table 3 reports labor market statistics from the simulated model with the labor productivity shocks and their empirical counterparts from the U.S. data. The search literature generally regards the marginal product of employment as an exogenous

the separation rates estimated at monthly frequency and averaged at a quarterly level are similar to those estimated at quarterly frequency.

[18] We treat all months as having 26 working days as in Davis, Faberman, and Haltiwanger (2013), and convert the average daily vacancy-filling rate into the monthly value by $q_m = 1-(1-q_d)^{26}$.

[19] Hall and Milgrom (2008) relies on Silva and Toledo (2009) who estimate the marginal cost of hiring using the cost per hire and the compensation per employee provided by the PwC.

shock. On the contrary, we use labor productivity as the driving force instead, because hours worked are determined endogenously in the model. We use the real output per hour in the nonfarm business sector as a proxy for labor productivity. We measure vacancies by the number of job openings for total nonfarm. As the Job Openings and Labor Turnover Survey (JOLTS) reports the job openings only after December 2000, we extend the series using two more sources as in Petrosky-Nadeau and Zhang (2021): the metropolitan life insurance company help-wanted advertising index and the composite help-wanted index of Barnichon (2010b).[20] For the vacancy/unemployment ratios, we divide vacancies by the number of unemployed workers.

In Table 3, the model matches the observed labor market fluctuations quite well: the volatility of unemployment, vacancies, and labor market tightness is in line with the data. We also confirm two well-known drawbacks of the MP model: i) the correlation between tightness and labor productivity is too high, and ii) vacancies are less persistent compared to the data. Another common challenge in the standard search model is the negative correlation between unemployment and productivity in the model is not consistent with the low correlation - close to zero - over the post-war period which is caused by a sign switch in the mid-1980s from significantly negative to significantly positive (Barnichon 2010a; Biddle 2014).[21] And our global solutions are consistent with Petrosky-Nadeau and Zhang (2017) in that the negative correlation between unemployment and vacancies, or the slope of the Beveridge curve, is much lower than that in the previous studies using log-linearization.

[Table 3] Labor market moments (quarterly)

		Panel A: Data				Panel B: Model			
		$\tilde{u}_t$	$\tilde{v}_t$	$\tilde{\theta}_t$	$\tilde{x}_t$	$\tilde{u}_t$	$\tilde{v}_t$	$\tilde{\theta}_t$	$\tilde{x}_t$
Standard deviation		0.129	0.141	0.267	0.011	0.129	0.149	0.246	0.011
Autocorrelation		0.881	0.905	0.904	0.716	0.807	0.457	0.716	0.719
Correlation matrix	$\tilde{u}_t$	-	-0.904	-0.952	0.012	-	-0.518	-0.838	-0.841
	$\tilde{v}_t$	-	-	0.982	0.133	-	-	0.890	0.872
	$\tilde{\theta}_t$	-	-	-	0.078	-	-	-	0.980

Notes: $\tilde{x}$ is the log deviation of x from its trend. We obtain the trend using the HP-filter with a smoothing parameter of 1,600, following Ravn and Uhlig (2002).

[20] Extending the series using only the composite help-wanted index, or using only the composite help-wanted index as a measure for vacancies alters the labor market statistics little.

[21] To explain the changes in unemployment's cyclicality, a wide range of theories have developed: e.g., increased flexibility, changes in economy's structure, and shifts in relative variances of technology and demand shocks (Fernald and Wang 2016).

5.1. Quantitative Decomposition of Three Sources

As we investigated in section 2, there are three sources of labor market fluctuations - (i) wage rigidity generated by the alternating-offer bargaining, (ii) less responsive stochastic discount factor, and (iii) procyclical hours worked - in our model. To quantify the contribution of each source in generating the labor market fluctuations, we carry out the quantitative analysis by adding each component of the model - alternating-offer bargaining, nonlinear utility, and intensive labor supply - one by one. Table 4 summarizes this decomposition. Here we briefly discuss the results, then in section 6, we inspect the role of each mechanism in more detail.

To quantify the role of the alternating-offer bargaining only, we first compare three models (M1–M3) with different wage bargaining processes where discount factor is constant (linear utility) and hours worked are fixed (inelastic intensive labor supply). Since the purpose of the paper is to resolve the volatility puzzle despite the cyclical opportunity cost of employment (z), we introduce an exogenously *cyclical* z with $\mathcal{E}(z_t, x_t) = 0.884$ to these linear models (M1–M3), where $\mathcal{E}(z_t, x_t)$ is the elasticity of z_t with respect to x_t.[22] Table 4 shows that relative to the standard Nash bargaining models (M1 and M2), the alternating-offer bargaining model (M3) generates higher unemployment volatility showing the role of wage rigidity caused by the alternating-offer bargaining. It also shows that the

[Table 4] Cyclicality of unemployment under procyclical opportunity cost of employment

Model	M1	M2	M3	M4	M5
Wage bargaining	Shimer	Hagedorn-Manovskii	alternating offer	alternating offer	alternating offer
Discount factor	constant	constant	constant	stochastic	stochastic
Hours worked	inelastic	inelastic	inelastic	inelastic	elastic
$\mathcal{E}(z_t / h_t, x_t)$	0.884	0.884	0.884	0.578	0.884
$\mathcal{E}(w_t, x_t)$	0.988	0.999	0.827	0.647	0.669
$\mathcal{E}(u_{t+1}, x_t)$	-0.631	-1.277	-6.217	-10.787	-10.663
SD $(\tilde{u}_t)$	0.007	0.007	0.075	0.131	0.129

Notes: $\tilde{x}$ is the log deviation of x from its trend. We obtain the trend using the HP-filter with a smoothing parameter of 1,600, following Ravn and Uhlig (2002). SD(x) denote the standard deviation of x, respectively. $\mathcal{E}(x_1, x_2)$ is the elasticity of x_1 to x_2, or the regression coefficient of $\tilde{x}_1$ on $\tilde{x}_2$.

[22] These are the replicates of Table 8 in Chodorow-Reich and Karabarbounis (2016) - the Nash bargaining with $E(z) = 0.71$ (Shimer), the Nash bargaining with $E(z) = 0.93$ (Hagedorn-Manovskii), and the alternating-offer bargaining with $E(z) = 0.71$. Note that we slightly modify their model and set the elasticity $\mathcal{E}(z_t, x_t) = 0.884$ (rather than $\mathcal{E}(z_t, x_t) = 1.0$ in Chodorow-Reich and Karabarbounis (2016)) to be comparable to the results of our baseline model. Parameter values are set using the same calibration strategies in section 6.1.1 for the Nash wage bargaining and those in section 4 for the alternating-offer bargaining.

alternating-offer bargaining alone cannot generate the observed labor market fluctuations ($\mathrm{SD}(\tilde{u}_t) = 0.13$).

We then add the stochastic discount factor channel to the alternating-offer bargaining model while keeping the hours worked inelastic (M4) and finally introduce elastic hours worked (M5 - the benchmark model with all three components). Both M4 and M5 generate the high labor market fluctuations in the data, showing the role of the stochastic discount factor channel. But the relatively low elasticity of z_t / h_t with respect to productivity in M4 shows that an intensive labor supply channel is also important in generating a highly cyclical opportunity cost of employment. We investigate the role of each channel in detail in the next section.

VI. Mechanism of the Labor Market Fluctuations

6.1. Role of Alternating-Offer Wage Bargaining

As we discussed in section 2, once we introduce procyclical z_t, the wage rigidity channel is inevitably weakened as the equilibrium wage becomes more cyclical regardless of the types of bargaining. In this section, we show that the dampening effect of procyclical z_t is much smaller in the alternating-offer bargain compared to the effects in the Nash bargain.

The wage rigidity in Hagedorn and Manovskii (2008) heavily depends on the constant opportunity cost of employment z_t, as they generate it by lowering the worker's bargaining weight ω, which increases the weight on the z_t. With procyclical z_t, the wage rigidity is significantly reduced. As the productivity and z_t comove together, the equilibrium wage also moves proportionally regardless of the size of the bargaining weight.[23]

In the alternating-offer bargaining, however, the worker's credible threat is not the outside option - the outside option is relevant only when the bargaining is terminated - but the disagreement payoffs which depend not only on z_t but also on the relative patience of the bargainers. Then the dampening effects of procyclical z_t might be much weaker in the alternating-offer bargain compared to those in the Nash bargain due to the following reasons.

First, different from the Nash bargain, the wage gives some weight to the

[23] More precisely, Hagedorn and Manovskii (2008) set ω and z_t to match the labor market tightness and the elasticity of wages to the marginal product of employment in the data. In (3), with constant z_t, lower ω causes w_t more inelastic to the movements of labor productivity and market tightness. Moreover, higher level of z_t increases w_t, leading to a smaller surplus from the match. With small firm's profits $(x_t - w_t)h_t$, even a modest increase in productivity generates large percentage increase in profit, thus the firm has more incentive to change the number of vacancies.

bargaining delay cost ξ due to the present bias of the bargainers. Since ξ does not vary with the state, higher ξ makes the wage less sensitive to the labor market condition, especially when the bargaining termination probability δ is low. Second, note that when productivity is high, higher market tightness decreases the household's wage proposal by lowering the vacancy-filling rate in (21), whereas it increases the firm's offer by lifting up the job-finding rate in (20). Lower δ suppresses the role of the job-finding rate, which is originated from $J_{u,t}$, in determining the equilibrium wage. In contrast, lower δ reinforces the role of the vacancy-filling rate by inducing the marginal cost of hiring in the third term of (21) to reduce the impact of productivity changes on the equilibrium wage. Thus, higher ξ and lower δ expand constant proportion of the equilibrium wage. In appendix E, we investigate sensitivity analysis with respect to the key parameters ξ and δ.

6.1.1. Comparison to the Nash Wage Bargaining

To see the role of the alternative-offer wage bargaining on unemployment volatility, we carry out the same quantitative analysis but with the Nash bargaining wage determination - both the standard calibration and the calibration of Hagedorn and Manovskii (2008). The parameter values are listed in Table 5. See appendix C for the discussion of calibration.

[Table 5] Parameter values for the Nash wage bargaining (monthly)

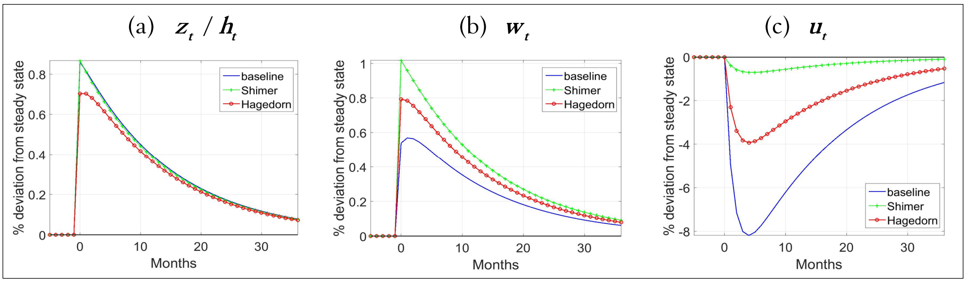
	ω	$\bar{h}$	φ	τ	$\bar{c}$	κ
Shimer	0.5	0.000	1.8752	-0.3116	0.2404	0.755
Hagedorn-Manovskii	0.052	1.314	0.4372	-0.0372	0.2590	0.263

Figure 1 illustrates the impulse response of labor market variables to 1 percent increase in productivity for the different wage bargaining processes, and confirms that wages become procyclical due to the procyclical z_t regardless of the types of bargaining, but the extent to which the cyclicality of z_t affects the cyclicality of wage is larger in the Nash bargaining. Figure 1b shows that the standard calibration (Shimer) of the Nash bargaining leads to higher reaction of wages to productivity than that in the alternating-offer bargaining, although the elasticities of z_t (per hour) to productivity are similar in all bargaining (figure 1a).[24] Therefore, the response of unemployment to productivity is quite small in the standard Nash (figure 1c). The small surplus calibration of Hagedorn and Manovskii (2008) also shows stronger response of wages to productivity relative to that in the benchmark,

[24] The opportunity cost of employment per hour z_t / h_t is more relevant to our model with the intensive margin of labor supply, because the wage rate is per unit of hour. In contrast, the opportunity cost of employment per person z_t is more related to the model without the intensive margin of labor supply, where the wage rate is per unit of person.

which dampens the unemployment volatility.[25] Table 6 also confirms that both calibration strategies of the Nash bargaining model fail to generate enough labor market volatility due to more procyclical movement of wages. In appendix E, we show that the effects of different types of wage bargaining do not depend on the baseline utility specification.

[Figure 1] Impulse response of variables to 1% increase in productivity



[Table 6] Sensitivity analysis to wage bargaining processes (quarterly)

	Baseline	Shimer	Hagedorn-Manovskii
E(u_t)	0.059	0.059	0.059
E(f_t)	0.41	0.40	0.40
E (κ_t / q_t)	0.42	1.19	0.42
E(z_t)	0.461	0.461	0.980
$\mathcal{E}(\lambda_t, x_t)$	-1.104	-0.853	-0.984
$\mathcal{E}(h_t, x_t)$	0.218	0.329	0.274
$\mathcal{E}(z_t / h_t, x_t)$	0.884	0.869	0.790
$\mathcal{E}(q_t, x_t)$	-8.033	-0.612	-3.461
$\mathcal{E}(w_t, x_t)$	0.669	1.036	0.872
$\mathcal{E}(u_{t+1}, p_t)$	-10.650	-0.829	-4.584
SD ($\tilde{u}_t$)	0.129	0.010	0.054
SD ($\tilde{v}_t$)	0.149	0.011	0.061
SD ($\tilde{\theta}_t$)	0.246	0.018	0.102

Notes: $\tilde{x}$ is the log deviation of x from its trend. We obtain the trend using the HP-filter with a smoothing parameter of 1,600, following Ravn and Uhlig (2002). E(x) and SD(x) denote the mean and standard deviation of x, respectively. $\mathcal{E}(x_1, x_2)$ is the elasticity of x_1 to x_2, or the regression coefficient of $\tilde{x}_1$ on $\tilde{x}_2$.

[25] Compared to the standard calibration case, the wage rate reacts less because a constant proportion from the positive fixed time cost insulates the opportunity cost of employment partly from changes of productivity.

6.2. Role of High Elasticity of Intertemporal Substitution

We now investigate the other two sources of labor market fluctuations -stochastic discount factor channel and labor supply channel. As we analyzed in section 2, the firm has more incentive to post vacancies in response to a positive productivity shock when the firm becomes more patient with a less declining stochastic discount factor and when the firm's profit increases with more hours worked. This section demonstrates that a high level of the EIS amplifies unemployment volatility by reducing the sensitivity of the stochastic discount factor to consumption growth and by intensifying the procyclicality of hours worked.

6.2.1. Sensitivity Analysis: Elasticity of Intertemporal Substitution

In this section, we first verify that a high level of the EIS is necessary to account for the observed labor market fluctuations. In the following sections, we investigate the two mechanisms through which high EIS amplifies the volatility.

First of all, we conduct a sensitivity analysis with respect to the EIS parameter. We choose $\psi = 0.4$ from Hall and Milgrom (2008) and $\psi = 1.0$ that leads to log utility over consumption.[26] We recalibrate the parameters to match the targets and table 7 summarizes the parameter values. Depending on the level of ψ, we vary χ to generate the Frisch elasticity of labor supply of 0.7, and alter $\overline{h}$ to obtain the same average opportunity cost of employment of 0.461 as in the baseline result. We choose κ to match the observed unemployment rate of 5.9%. We set φ, τ, and $\overline{c}$ with the same strategy of the baseline calibration. Other parameters not in table 7 remain unchanged.

[Table 7] Parameter values for alternative levels of the EIS (monthly)

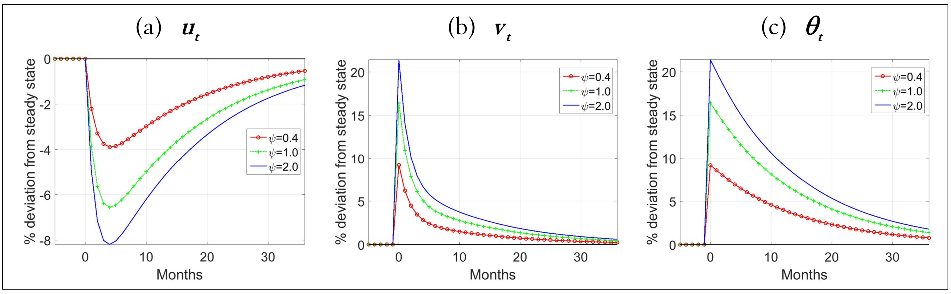
	χ	$\overline{h}$	φ	τ	$\overline{c}$	κ
$\psi = 0.4$	0.495	0.110	1.7249	-1.7321	0.2595	0.259
$\psi = 1.0$	0.590	0.043	1.4830	-0.6282	0.2599	0.257
$\psi = 2.0$ (baseline)	0.652	0.000	1.8752	-0.3116	0.2604	0.254

Figure 2 depicts the impulse response of the labor market variables to a one-time productivity shock. Along the qualitative dimension, the model performs well for all the levels of EIS: in booms, unemployment rate declines, and the firm posts more vacancies, boosting labor market tightness. However, the magnitude of the labor market fluctuations is very different. 1 percent increase of productivity leads to about 20 percent increase in tightness under $\psi = 2.0$. This elasticity is more than 2

[26] $\psi = 0.4$ and $\psi = 1.0$ imply the Frisch elasticity of consumption demand of -0.5 and -1.1, respectively.

times as large as the result under $\psi = 0.4$.

[Figure 2] Impulse response of variables to 1% increase in productivity



[Table 8] Labor market moments with respect to the EIS (quarterly)

	$\psi = 0.4$	$\psi = 1.0$	$\psi = 2.0$ (baseline)
E(u_t)	0.059	0.059	0.059
E(f_t)	0.40	0.41	0.41
E(κ_t / q_t)	0.41	0.42	0.42
E(z_t)	0.461	0.461	0.461
$\mathcal{E}(\lambda_t, x_t)$	-2.730	-1.767	-1.104
$\mathcal{E}(h_t, x_t)$	-0.588	-0.087	0.218
$\mathcal{E}(z_t / h_t, x_t)$	0.863	0.903	0.884
$\mathcal{E}(q_t, x_t)$	-3.415	-6.077	-8.033
$\mathcal{E}(w_t, x_t)$	0.888	0.752	0.669
$\mathcal{E}(u_{t+1}, p_t)$	-4.573	-8.045	-10.650
SD$(\tilde{u}_t)$	0.054	0.096	0.129
SD$(\tilde{v}_t)$	0.060	0.109	0.149
SD$(\tilde{\theta}_t)$	0.101	0.181	0.246

Notes: $\tilde{x}$ is the log deviation of x from its trend. We obtain the trend using the HP-filter with a smoothing parameter of 1,600, following Ravn and Uhlig (2002). E(x) and SD(x) denote the mean and standard deviation of x, respectively. $\mathcal{E}(x_1, x_2)$ is the elasticity of x_1 to x_2, or the regression coefficient of $\tilde{x}_1$ on $\tilde{x}_2$.

Table 8 reports labor market statistics from the model simulations with the alternative levels of EIS. The opportunity cost of employment per hour is procyclical and as volatile as labor productivity for all the levels of EIS.[27]

[27] Because the marginal utility of consumption balances both movements in hours worked and in the relative value of non-working time to consumption, the sensitivity of the opportunity cost of

Nevertheless, lower ψ involves smaller labor market fluctuations, which is consistent with the impulse response results in figure 2. We remark that although ψ controls both risk aversion and EIS, what matters for the labor market outcome is the EIS (see appendix G).

6.2.2. Role of EIS: Stochastic Discount Factor Channel

In the intertemporal job creation condition (11), the stochastic discount factor links the firm's incentive to open vacancies with the propensity to consumption smoothing. From the standpoint of the firm which takes the household's consumption decision as given, the percent increase in the discount rate is proportional to the percent change in consumption growth given the complementarity between consumption and hours worked.[28]

When a positive persistent productivity shock increases consumption growth, there are two offsetting effects on the firm's decision.[29] On the one hand, with limited response of wage to the productivity shock, the marginal profitability from an additional hire increases. Then the substitution effect encourages the firm to invest more in hiring instead of paying out dividends. On the other hand, increase in the future payoffs for fixed investment in hiring induces the stochastic discount factor to diminish. Lower stochastic discount factor makes the firm smooth larger future payoffs over time and thus the firms hesitate to post vacancies, which we call wealth effect.

The trade-off of a positive productivity shock crucially depends on the magnitude of the household's desire to smooth consumption. When the EIS is higher, the substitution effect prevails over the wealth effect more. Figure 3 and 4 display log consumption growth and log stochastic discount factor along the alternative levels of the EIS, and confirm that with higher ψ, stochastic discount factor reacts less to productivity shock despite the more response of consumption growth.[30] Thus during booms with positive productivity shocks, the firms with higher ψ have

employment per hour to productivity differs little along the different levels of ψ.

[28] If the fixed time cost $\bar{h}$ equals zero, (16) is restated by

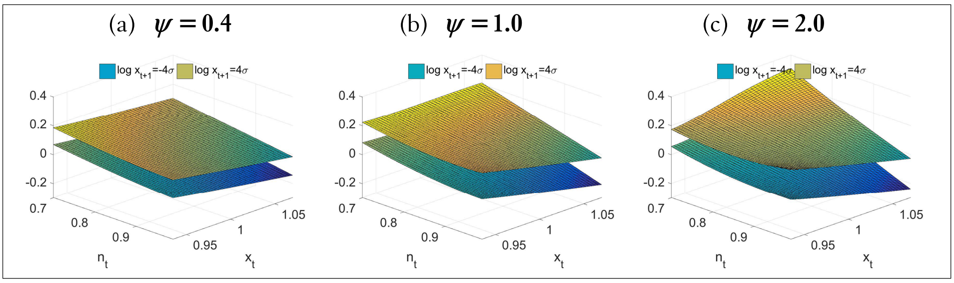
$$\begin{aligned}\log M_{t+1} - \log\beta &= -\frac{1}{\psi}(\log c_{u,t+1} - \log c_{u,t}) \\ &= -\frac{1}{\psi}(\log c_{n,t+1} - \log c_{n,t}) + \left[\log\left(1-\tau\frac{h_{t+1}^{1+1/\chi}}{1+1/\chi}\right) - \log\left(1-\tau\frac{h_{t}^{1+1/\chi}}{1+1/\chi}\right)\right]\end{aligned}$$

[29] In the impulse response, a one-time productivity shock results in positive consumption growth through higher employment in the next period for all levels of ψ.

[30] Higher ψ causes log consumption growth to vary more over the state variables, because future employment and thus future consumption show larger fluctuations.

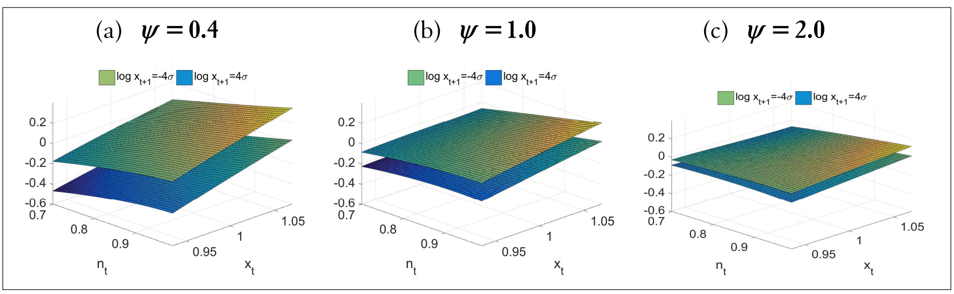
more patience and tend to increase future employment by investing more in posting vacancies.

[Figure 3] Log consumption growth



Notes: Each surface denotes log consumption growth ($\log c_{u,t+1} - \log c_{u,t}$) when $\log x_{t+1} = -4\sigma$ and $\log x_{t+1} = 4\sigma$ respectively.

[Figure 4] Log stochastic discount factor



Notes: Each surface denotes log stochastic discount factor ($\log M_{t+1}$) when $\log x_{t+1} = -4\sigma$ and $\log x_{t+1} = 4\sigma$ respectively.

6.2.3. Role of EIS: Labor Supply Channel

Hours worked are set by the hours bargaining condition (19), which is restated as follows:

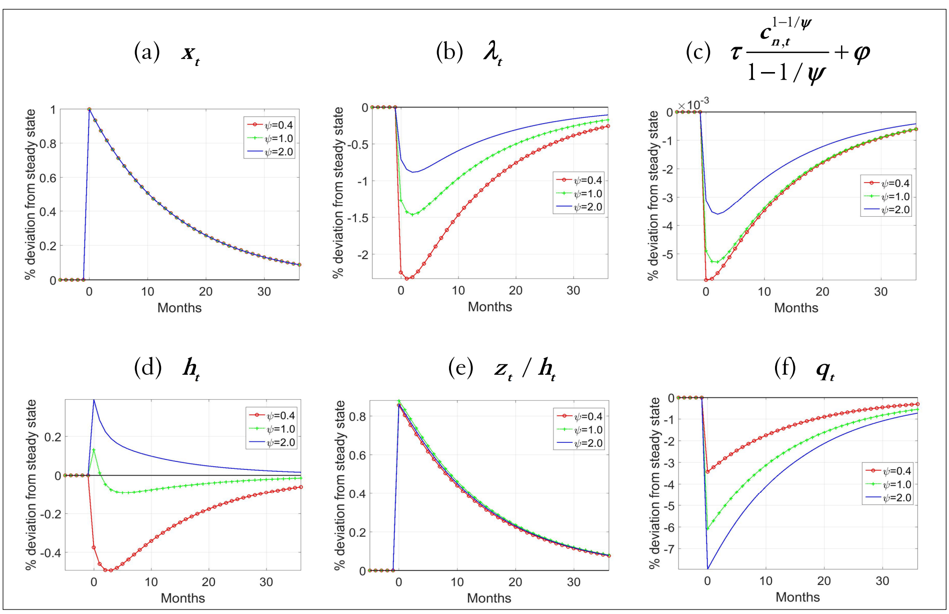
$$\lambda_t x_t = \left(\tau \frac{c_{n,t}^{1-1/\psi}}{1-1/\psi} + \varphi \right) h_t^{1/\chi}, \tag{22}$$

where the marginal utility of consumption from working an additional hour equals the marginal disutility of working. Figure 5 displays the impulse response of the components of (22) to a productivity shock.

The response of labor supply to the productivity shock is mostly through the change in marginal benefit of labor. Although marginal cost of labor decreases when productivity increases as larger consumption makes working an extra hour less painful due to the complementarity, its quantitative effects are small as in Figure 5c.[31] Whether a positive productivity shock leads to increase in labor supply depends on the dominance between the substitution and wealth effects. The substitution effect is that the productivity change increases hours worked by raising the marginal benefit to the surplus directly. The wealth effect is that the productivity movement decreases hours worked by lowering the marginal utility of consumption.

With higher EIS, labor supply is likely to show procyclical movement to the productivity shock because higher EIS implies that marginal utility of consumption falls less in response to a positive productivity shock, mitigating the wealth effect. In Figure 5a, 5b and 5d, higher ψ causes the marginal utility of consumption to fluctuate less than the labor productivity does, and thus hours worked to increase more. In the intertemporal job creation condition (11), larger procyclicality of hours worked enlarges the sensitivity of a firm's profit to the productivity shock. On the other hand, the opportunity cost of employment per hour differs little along the alternative levels of ψ in Figure 5e. As a consequence, higher ψ amplifies the countercyclicality of the vacancy-filling rate via the intensive margin of labor in Figure 5f.

[Figure 5] Impulse response of hours worked to 1% increase in productivity



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31 If the EIS is higher, the complementarity gets weaker, as the marginal utility of consumption responds less to consumption changes. However, the impulse response of the coefficient term in the right-hand side of (22) in Figure 5c shows not only that the different levels of ψ result in little variation of the complementarity, but also that the cyclical effect of the complementarity on hours worked itself is negligible.

We further inspect the role of the elastic labor supply by comparing the results with inelastic labor supply to the benchmark result.[32] Table 9 shows that even if we shut down the labor supply channel the labor market fluctuations do not change much from the benchmark result. However, inelastic labor supply also dampens the procyclicality of the opportunity cost of employment significantly, and thus the criticism of Chodorow-Reich and Karabarbounis (2016) applies again. This result shows that to resolve the volatility puzzle while generating a highly cyclical opportunity cost of employment, the labor supply channel is important.

[Table 9] Labor market moments without the intensive margin of labor supply (quarterly)

	benchmark	inelastic labor
$\mathcal{E}(\lambda_t, x_t)$	-1.104	-1.013
$\mathcal{E}(h_t, x_t)$	0.218	0.000
$\mathcal{E}(z_t / h_t, x_t)$	0.884	0.578
$\mathcal{E}(q_t, x_t)$	-8.033	-8.164
$\mathcal{E}(w_t, x_t)$	0.669	0.647
$\mathcal{E}(u_{t+1}, p_t)$	-10.650	-10.789
SD ($\tilde{u}_t$)	0.129	0.131
SD ($\tilde{v}_t$)	0.149	0.151
SD ($\tilde{\theta}_t$)	0.246	0.249

Notes: $\tilde{x}$ is the log deviation of x from its trend. We obtain the trend using the HP-filter with a smoothing parameter of 1,600, following Ravn and Uhlig (2002). SD(x) denotes the standard deviation of x. $\mathcal{E}(x_1, x_2)$ is the elasticity of x_1 to x_2, or the regression coefficient of $\tilde{x}_1$ on $\tilde{x}_2$.

6.2.4. Discussion: Evidences for the high EIS

There is a considerable debate in the macroeconomics and finance literature about the magnitude of the EIS. Hall (1988) and Campbell (1999) estimate the EIS to be close to zero using the aggregate data. Attanasio and Weber (1993) also estimate the EIS to be below one using the household-level data, although their estimate is higher than those from the aggregate data. On the contrary, Attanasio and Vissing-Jorgensen (2003), Gruber (2006), and van Binsbergen et al. (2012) estimate the EIS to be in excess of one. In addition, many challenge a low level of the EIS, because it incurs counterfactual implications in some models. In the long-run risk model of Bansal and Yaron (2004), the EIS below one causes higher expected growth and lower uncertainty to decrease asset prices. In the disaster-risk

[32] For the inelastic labor supply case, we exclude the hours bargaining condition (19) by assuming that hours worked always equal one.

model of Gourio (2012) and Nakamura et al. (2013), the low EIS induces the risk premium to be procyclical. In our result, the following observations provide evidence against a low level of the EIS.

First, we regress the quarter $t+1$ consumption growth rate on the quarter t risk-free rate with the data generated by the model as in as in Hall (1988). We obtain the EIS estimate of 0.33 with the EIS parameter of $\psi = 2.0$. This estimate is substantially lower than one.[33] Bansal and Yaron (2004) also obtain the EIS estimate of 0.62 in the long-run risk model with the EIS parameter value of 1.5, while Gourio (2012) gets the EIS estimate of 0.36 in the disaster risk model with the EIS parameter value of 2.0. These results support the argument that the regression of Hall (1988) may be misspecified and create the downward bias.[34]

Second, a low level of the EIS is inconsistent with the observed behavior of hours worked. It is well-known that hours worked are highly correlated with output and employment.[35] However, Figure 16 illustrates that $\psi = 0.4$ results in the countercyclicality of hours worked - the wealth effect overwhelms the substitution effect - in contrast to the result under $\psi = 2.0$.[36]

Third, a high level of the EIS is necessary to account for the observed volatility of risk-free rates and of excess stock returns. When the EIS is higher, the households would like to save more. This allows investment in hiring to change more, and thus reinforces the procyclicality of the stock price and the countercyclicality of the stock return. In appendix F, we show the implications of a high ESI on the financial market in more detail.

VII. Conclusion

Recent empirical findings by Chodorow-Reich and Karabarbounis (2016) - highly cyclical opportunity cost of employment - challenged the studies that resolve the unemployment volatility puzzle by heavily relying on the constant opportunity cost of employment. In this paper, we show that by introducing utility curvature over consumption and intensive margin of labor supply into the MP model with alternating-offer wage bargaining can resolve the volatility puzzle while generating

[33] The EIS parameters of $\psi = 0.4$ and $\psi = 1.0$ generate the EIS estimate of 0.08 and 0.20, respectively.

[34] Guvenen (2006) shows that the downward bias can be corrected by including the conditional variance of consumption growth in the estimation.

[35] See Ohanian and Raffo (2012), Nakajima (2012), and Chodorow-Reich and Karabarbounis (2016) for more details

[36] In the appendix, we also gain the same outcomes with the utility specifications used by Chodorow-Reich and Karabarbounis (2016) in Table 5, which allows for only a low level of ψ to get the complementarity between consumption and hours worked.

procyclical opportunity cost of employment. This result can be understood by investigating the three sources of the labor market fluctuations: (i) wage-rigidity channel, (ii) stochastic discount factor channel, and (iii) labor supply channel. Once we introduce cyclical opportunity cost of employment, wage-rigidity channel is inevitably mitigated even in an alternating-offer wage bargain, which dampens the labor market volatility. However, high EIS can make the firm more patient with less cyclical stochastic discount factor and also make labor supply procyclical, through which the labor market fluctuations can be amplified.

As we mention above, the MP model has the well-known shortcoming that the correlation between labor market tightness and productivity is too high compared to the data. This is the reason why the equilibrium wage is necessary to be insulated both from labor market tightness and productivity in order to resolve the unemployment volatility puzzle. But the employment evolution condition (7) indicates that unemployment changes only by movements in labor market tightness.[37] Therefore, if we model the sluggish response of labor market tightness to productivity as in Fujita and Ramey (2007), or the alternative driving force to labor productivity behind labor market volatility as in Kilic and Wachter (2017), the equilibrium wage is required to be inelastic only to labor market tightness. In such models, the Nash-bargained wage under the small surplus calibration and the alternating-offer-bargained wage may produce larger unemployment fluctuations. The link between unemployment volatility and internal propagation in the MP model could be an intriguing research direction.

[37] The employment evolution condition (7) and $n_t = 1 - u_t$ are combined by

$$u_{t+1} = \phi(1-u_t) + (1 - f(\theta_t))u_t$$

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효용의 비선형성과 실업 변동성*

이 동 원** · 박 예 나***

초 록 Chodorow-Reich and Karabarbounis (2016)는 취업에 따른 기회비용이 실증적으로 경기순응적이며, 이는 낮은 임금경직성을 의미하기 때문에 임금경직성을 통해 노동시장의 실업 변동성 퍼즐(Shimer, 2005)을 해소하고자 했던 기존연구들이 현실에 부합하지 않는다고 주장하였다. 그러나 노동시장 매칭모형에 비선형 효용함수를 도입할 경우 취업에 따른 기회비용의 경기순응성에도 불구하고, 확률할인인자(stochastic discount factor) 및 노동시간도 경기변동적이 되어 실업변동성이 확대되는 것으로 나타났다. 비선형 효용함수와 다기간 임금협상을 도입한 노동매칭모형을 이용하여 정량분석을 실시한 결과, 높은 기간별 대체탄력성이 적용되는 경우, 실제 통계자료 수준의 실업 변동성이 생성되는 것을 확인하였다.

핵심 주제어: 노동매칭모형, 다기간 임금협상, 실업 변동성, 고용에 따른 기회비용
경제학문헌목록 주제분류: E24, E32, J64

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* 본 논문의 내용은 집필자의 개인의견이며 소속기관의 공식견해와는 무관하다. 논고 작성에 유익한 논평을 주신 조재호 교수님, 장용성 교수님, 김영식 교수님 및 김형석 교수님께 감사를 표한다. 또한 논문에 대해 통찰력 있는 제안을 해 주신 편집위원과 두 명의 심사자께도 감사드린다.
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