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Abstract

This paper investigates the fluctuations in temporary relative to aggregate employment over the business cycle, as well as the underlying driving forces. We develop a dynamic general equilibrium model to investigate the following stylized facts: (i) temporary employment is more volatile than permanent employment, (ii) the share of temporary employment (the ratio of temporary to aggregate employment) exhibits strong pro-cyclicality, (iii) permanent employment lags by two quarters on average, and (iv) the correlation between temporary employment and output is stronger than that involving the permanent counterpart. The quantitative analysis suggests that the proposed channels explain the main facts very well and the model provides a possible prediction based on the counter-factual exercises.

JEL classification: E24, E32

Key Words: Pro-cyclicality of Temporary Employment; Lagged Behavior of Permanent Employment; Labor Productivity; Business Cycles

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1 Introduction

The aim of this paper is to investigate the fluctuations in temporary and permanent employment over the business cycle, and the underlying driving forces. The stylized facts in the US labor market that motivate this paper are (i) temporary employment is more volatile than permanent employment, (ii) the share of temporary employment (the ratio of temporary to aggregate employment) exhibits strong pro-cyclicality, (iii) permanent employment lags by two quarters on average, and (iv) the correlation between temporary employment and output is stronger than that involving the permanent counterpart.

In order to account for the observed cyclical behavior of temporary and permanent employment, we set up a real business-cycle (henceforth RBC) model featured by stochastic total factor productivity (TFP) shocks. However, in contrast to the mainstream modelling framework, we separate the permanent labor input from the temporary alternative, and resort to this separation to explain the stylized facts that characterize the US labor market. In the standard RBC model, there is no distinction between permanent labor and temporary labor, but the evidence shows that the workers employed in permanent jobs currently account for 97–98% of employment in the US labor market. To shed light on this fact, this paper sets up an RBC model that is able to separate permanent labor from the temporary alternative. Temporary labor is hired only for one period and firms can flexibly adjust this part in response to a realized TFP shock (see, e.g., Schreft and Singh, 2003; Stiroh, 2009).

To this end, in this paper three channels regarding the distinction between the temporary and permanent labor inputs are incorporated into the standard RBC model. First, the degree of substitution between them is taken into account. Second, a time-to-build mechanism related to job training is introduced to capture the training time required for new recruits to become permanent employees.[1] Meanwhile, the time-consuming job training leads permanent workers to be more productive than temporary ones. Third, when the firms hire the new recruits, they need to pay labor adjustment costs, which are considered the costs

[1]Note that a proportion of workers in temporary help services do receive some general skills training provided by their staffing and employment agencies for self-selection and screening purposes (Autor, 2001; Acemoglu and Pischke, 1999), whereas Arulampalam et al. (2004) find evidence of a negative relationship between workers with fixed-term (or temporary) contracts and training to be received. A cross-country comparison based on micro-level data (including the US) also suggests that compared to permanent workers, temporary ones have significantly less access to vocational training sponsored by employers (OECD, 2002).

arising from advertising for, screening, and training the new recruits.

Together with the three channels, we find that given a high degree of substitution between temporary and permanent labor, the time-to-build mechanism and the presence of labor adjustment costs can well explain the observed facts in the US labor market. Intuitively, when the economy is hit by a persistent positive TFP shock, a high degree of substitution between temporary and permanent labor will motivate the firms to hire more temporary workers as a short-run substitute for permanent ones during training periods. It follows that temporary employment exhibits more volatile behavior than permanent employment, thereby leading to the emergence of a strong pro-cyclicality of the share of temporary employment. Moreover, given the persistent positive TFP shock, the firms are also inclined to hire more new recruits because they will be treated as an investment in future production. They become permanent and productive workers after receiving training and this explains the multi-quarter lagged behavior of permanent employment and how it smoothly responds to the realized shock.

In addition to formulating an RBC model that replicates the stylized facts characterize the US labor market, this paper also serves as a complement to the existing literature that investigates firms' labor hoarding behavior during 1990–1991, 2001, and 2007–2009 recessions; for example, Galí and Gambetti (2009). Given a high degree of substitutability between temporary and permanent workers, a calibrated version of the model suggests that a negative and less-persistent shock will trigger a less substantial decline in the stock of permanent ones. Instead, the falling share of temporary employment is found to result from long-term considerations for maintaining the trained and productive workers on the payroll.

This paper is also in line with the several studies that explore the related market structure over the business cycles. Jahn and Bentzen (2012) find evidence of the pro-cyclical behavior of temporary employment from an international perspective. Katz and Krueger (1999) argue that the availability of temporary workers contributes to a reduction in matching frictions since it lessens wage pressures in tight labor markets. In addition, Barnichon (2010) and Galí and van Rens (2010) put forth the hypothesis that a flexible labor market could lead to the short-term acyclical behavior of labor productivity. They highlight institutional changes that give rise to an increasing share of temporary employment, which is indicative of a more flexible labor market.

The rest of this paper is organized as follows. Section 2 shows the empirical findings based on aggregate data. Section 3 develops an RBC model and elaborates on the corresponding settings. Section 4 presents the quantitative results based on possible extensions of the benchmark model and discusses the underlying implications. Section 5 concludes this paper.

2 The evidence

Based on the definition by the US Bureau of Labor Statistics (BLS), temporary workers refer to those to be hired by temporary help services agencies and assigned to employers to meet temporary part-time or full-time staffing needs. As stated in Kalleberg (2000), the origin of the service industry in the US may date back to the 1920s, and for a long period its employees only accounts for a small proportion of aggregate employment. However, its share has not only been growing rapidly in the US and European countries but also been very sensitive to business cycles.[2] One of the most reasons is that temporary workers provide the hiring firms with the additional post-production flexibility, since their labor contracts are mostly signed on a fixed-term basis. As a result, a flexible labor market allows firms to adjust their production immediately when an adverse shock hits (see Berton and Garibaldi, 2012).

The time series of temporary workers and the real GDP per capita for the US that we use are obtained from the BLS and the Federal Reserve Economic Data (FRED) maintained by the Federal Reserve Bank of St. Louis. The time series that represents the share of temporary employment to total non-farm employment is subject to the change in industry classification system in the late 1990s, which results in the unavailability of a consistent measure

[2]The number of those in temporary employment has been increasing across OECD countries in recent decades. Compared to the US, the European countries have had a much higher incidence rate of temporary employment since the rates are respectively 4.2% and 14.4% in 2005 based on the OECD Statistics database. An institutional explanation to these differences points to the relaxation of employment protection, and it sheds light on how temporary workers substitute for the regularly-hired ones (see, e.g., Booth et al., 2002; Cahuc et al., 2012; Estevão and Lach, 1999; Jahn and Bentzen, 2012).

over a long spell.[3] Figure 1 illustrates the differences among three related industry categories, and the shaded areas in the figure denote the recessions identified by the NBER. It is obvious that the three series exhibit a similar growth pattern, even though a persistent gap between any two of them exists. For example, the number of temporary workers measured by employment at the industry level, i.e., personnel supply services (SIC-7360), increases at an annual rate of 8.9 percent during 1972–2000. Despite the existence of slight differences across industries, temporary workers in general account for about 2-3 percent of the total non-farm employment in 2000. Nowadays, the share measured by employment by industry of temporary help services (NAICS-56132) is nearly 2.1 percent.

As displayed in Figure 1, the share of temporary to total workers exhibits a strong procyclical pattern, and in particular turns into another growing stage after every recession. To highlight its periodicity, the bandpass (BP)- and Hodrick-Prescott (HP)-filtered cyclical components of GDP per capita are also plotted in Figure 2.[4] Obviously, the share drops significantly during the recent episodes of recessions and it attains higher values before the onsets of subsequent recessions.

Figure 3 further decomposes aggregate employment into de-trended temporary and permanent components. It reveals that temporary employment has a much higher degree of volatility and higher correlation with output, and permanent employment lags behind in the cycles.[5] As a consequence, the share experiences notable decreases almost simultaneously with real GDP per capita during past recessions. One of the possible reasons for this result is that hiring temporary workers functions as a "buffer" device for firms that hesitate to adjust their permanent employment level (see Segal and Sullivan, 1997).

Table 1 reports the descriptive statistics of the relevant macro variables and the results confirm these observations. First, the standard deviation of temporary employment $std(\hat{h}_t) = 6.66$ is higher than that of permanent employment $std(\hat{n}_t) = 1.10$. Second, the share

[3]The industries that could be used as substitutes for NAISC-56132 (temporary help services) in 1990–2014 are SIC-7360 (personnel supply services) in 1972-2003 and SIC-7363 (help supply services) in 1982–2003 due to the availability of data. The number of workers in industry SIC-7360 is noticeably greater than that in the others because this broad classification includes sectoral employment agencies.

[4]The coefficient of correlation between the share of temporary employment and de-trended output during 1990–2014 equals 0.341, whereas the rolling-window correlations display an increasing co-movement pattern between the two variables.

[5]For example, please refer to Holmlund and Storrie (2002) for a detailed discussion on the Sweden case.

of temporary employment and output are highly correlated and the correlation coefficient between them is equal to $corr(e_t, \hat{y}_t) = 0.90$. Third, the correlation coefficient between temporary employment and output $corr(\hat{h}_t, \hat{y}_t) = 0.91$ is higher than that between permanent employment and output $corr(\hat{n}_t, \hat{y}_t) = 0.75$. Fourth, permanent employment is characterized by a lag that is two quarters in length since the value 0.87 is highest for the correlation coefficient between permanent employment and (lagged and leading) output in Table 1.

The complementarity/substitution between temporary and permanent workers can be examined by observing the wage rates. Based on the annual data provided by Occupational Employment Statistics, we obtain time series of annual and hourly wages in terms of all 4-digit sub-industries on a national basis. Figure 4 is used to compare the mean wages of workers in temporary help services and in all industries across occupations. This figure indicates that a notable wage gap between temporary workers and all the others exists since the former group is paid roughly 20-30 percent less than the average. In addition, the wage growth of temporary workers became moderate compared to the average during the Great Recession and even turned negative during 2001–2002.

In order to explore the cyclical feature of the wage gap between temporary workers and all the others in detail, we further use data from the National Employment, Hours, and Earnings database and from the Current Employment Statistics survey. Figure 5 plots the relative hourly wage of temporary to total non-farm employees. We use wage series from industries SIC-7323 and NAICS-56132 corresponding to the periods 1982Q1–2003Q1 and 2006Q4–2014Q4 to address the problem of data availability. It should be noted that the disconnection arises because the two systems have different division structures. Figure 5 presents a similar result to Figure 4 since the two ratios respectively fluctuate between 0.73–0.83 and 0.66–0.72, hence suggesting a manifest wage gap. Another noteworthy finding is that the wage ratios reach peaks during periods of the past recessions, and then drop sharply afterwards. This counter-cyclical behavior justifies our argument that the change in the relative employment is driven by a TFP shock and the substitution between the two types of workers plays an important role.

In order to deliver a clear picture, the descriptive statistics and the extent to which our model fits these numbers will be discussed in Section 4.

3 The model

In this section, we build a real business cycles model and derive the conditions that characterize the general equilibrium. The economy that we consider consists of two types of agents: households and firms. In what follows of this section, we describe the behavior of each of these agents in turn.

3.1 Households

Assume that the economy is populated by a continuum of identical and infinitely-lived households, and the population size is normalized to unity for simplicity. The representative household derives utility from consumption, c_t and incurs disutility from providing temporary and permanent labor services. In line with Rupert et al. (2000), Chang and Kim (2006), and Guner et al. (2012a, 2012b), we suppose that the decisions are made by a family rather than an individual in the household sector. The family consists of two members: one provides temporary labor services h_t and the other provides permanent labor services h_t. Accordingly, the preference is modeled specifically by the expected life-time utility

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{c_t^{1-\theta} - 1}{1-\theta} - \psi \left(\frac{n_t^{1+\chi}}{1+\chi} + \frac{h_t^{1+\chi}}{1+\chi} \right) \right]; \ 1 > \beta > 0, \ \theta > 0, \ \chi > 0, \ \psi > 0, \tag{1}$$

where E_0 denotes expectations that are conditional on information available at time 0. θ stands for the inverse of the intertemporal elasticity of substitution in consumption, χ denotes the inverse of the Frisch elasticity of labor supply, β represents the household's subjective discount rate, and ψ is a parameter that captures the taste for labor supply.

The representative household supplies temporary labor h_t, permanent labor n_t, owns the capital stock k_t, and takes wage rates for temporary and permanent labor, $w_{h,t}$ and $w_{n,t}$, and the rental rate r_t as given. In addition, the household receives dividend income d_t by holding each unit of the firm's outstanding equity z_t at price p_t in each period. For simplicity, the total share of the firm's outstanding equity is normalized to unity. At each instant in time, the household allocates its income to consumption, investment i_t, and the accumulation of additional equities. The household's flow budget constraint can be written as:

$$p_t(z_{t+1} - z_t) = r_t k_t + w_{h,t} h_t + w_{n,t} n_t + d_t z_t - c_t - i_t. \tag{2}$$

Accordingly, the law of motion of the capital stock can be specified as

$$k_{t+1} = (1 - \delta)k_t + i_t; \;\; 1 > \delta > 0, \tag{3}$$

where δ denotes the rate of capital depreciation.

The representative household's problem is to choose the sequences $\{c_t, h_t, n_t, k_{t+1}, z_{t+1}\}_{t=0}^{\infty}$ to maximize the expected life-time utility reported in equation (1), subject to equations (2) and (3). The first-order conditions that characterize solutions to the optimization problem are given by:

$$\psi c_t^{\theta} h_t^{\chi} = w_{h,t}, \tag{4}$$

$$\left(\frac{h_t}{n_t}\right)^{\chi} = \frac{w_{h,t}}{w_{n,t}}, \tag{5}$$

$$1 = \beta E_t \left[\left(\frac{c_t}{c_{t+1}} \right)^{\theta} (r_{t+1} + 1 - \delta) \right], \tag{6}$$

and

$$p_t = \beta E_t \left[\left(\frac{c_t}{c_{t+1}} \right)^{\theta} (p_{t+1} + d_{t+1}) \right]. \tag{7}$$

Equation (4) indicates that the marginal rate of substitution between temporary labor supply and consumption is equal to the wage rate of temporary labor. Equation (5) demonstrates that the household's optimal allocation between temporary and permanent labor supplies rest on their relative wage rate. Equations (6) and (7) are standard Euler equations that state the household's optimal intertemporal holdings on physical capital and the firm's equity.[6]

3.2 Firms

The production sector is composed of many identical and competitive firms, which can be treated as a representative firm. Suppose that the firm hires temporary workers h_t, the stock of permanent workers x_t, and capital services k_t to produce output y_t. The firm produces output according to the following CES production function:

$$y_t = A_t {k_t}^{\alpha}\Big[{x_t}^{\sigma} + (\gamma h_t)^{\sigma}\Big]^{\frac{1-\alpha}{\sigma}}; \;\; 0 < \gamma < 1, \;\; \sigma < 1, \tag{8}$$

where A_t represents the level of total factor productivity, α denotes the share of capital services, and the parameter γ reflects the relative productivity between temporary and permanent labor. The elasticity of substitution between h_t and x_t is constant and equal to $1/(1-\sigma)$ with an imperfect substitute $\sigma < 1$.

In line with Chen and Lai (2015), we assume that in order to accumulate the stock of permanent workers in period $t+1$, the firm needs to hire a flow of new recruits v_t one period before.[7] Accordingly, the law of motion of permanent employment can be written as:

$$x_{t+1} = (1-\mu)x_t + v_t; \;\; 0 < \mu < 1, \tag{9}$$

where μ denotes an exogenous separation rate.

When the firm hires the new recruits, it then incurs extra labor adjustment costs, which are considered to be the induced costs from advertising for, screening, and training the new recruits (see Merz and Yashiv, 2007). The net adjustment costs arising from training the new

[6] It is noteworthy that, by denoting the Lagrange multiplier of the household's flow budget constraint (2) by λ_t, equation (7) can be rewritten as $p_t = \sum_{j=1}^{\infty} \beta^j \frac{\lambda_{t+j}}{\lambda_t} d_{t+j}$, where $\beta^j \frac{\lambda_{t+j}}{\lambda_t}$ is the discount rate for period $t+j$. As a consequence, this expression implies that the equity price equals the discounted present value of the future dividend income that the household will receive.

[7] Chen and Lai (2015) focus on the case in which only permanent workers are hired in the production process and they discuss the relationship between the forward-looking properties of labor demand and news shocks. Different from their study, we assume that the firm hires both temporary and permanent workers to produce final goods in this paper. Consequently, we provide a detailed discussion regarding the division between these two kinds of labor.

recruits are rationalized and examined by Hamermesh (1995). Here, we adopt this narrow definition and focus on net hires, namely, the new recruits net of the dismissed permanent workers. The advantage behind this setting stems from the fact that it not only simplifies the solution at the steady state but is also consistent with the implication that the dismissed workers are presumed to be experienced. As a result, there is no need to provide additional training for them.

On the other hand, the firm accumulates its stock of permanent workers while facing increasing adjustment costs, and without loss of generality the costs are modeled as a quadratic function to depress a rapid adjustment (see, e.g., Blatter et al., 2012; Cooper and Willis, 2009; Galí and van Rens, 2010; Sargent, 1978). The setting of the adjustment costs is crucial for generating the observed lagged behavior of permanent employment, as proposed by Kydland and Prescott (1991), since it diminishes the demand for permanent workers and in turn the demand for currently new recruits.

Accordingly, the firm's profits as well as the household's dividend incomes can be expressed as:

$$d_t = y_t - w_{n,t}n_t - w_{h,t}h_t - r_k k_t - \frac{\phi}{2}\frac{(x_{t+1}-x_t)^2}{x_t}; \;\; \phi \geq 0, \tag{10}$$

where the intensity parameter ϕ governs the size of the net adjustment costs in terms of output. The costs are expressed as a quadratic form of the difference between the stocks of permanent workers in periods t and $t+1$.

Equation (9) specifies that new recruits need one period to accumulate experiences and skills before turning their status into permanent workers in the next period. In fact, we observe in reality that new recruits may need several periods to complete their training. The more general scenario is presented below. Let $l_{i,t}$ denote the new recruits that the firm employs at time t, and they need i periods to accumulate experiences and skills before becoming permanent workers. Let b represent the total number of periods required for each new recruit. Therefore, the aggregate new recruits at time t can be expressed as:

$$v_t = \sum_{i=1}^{b} l_{i,t}. \tag{11}$$

The law of motion of the recruits is given by:

$$l_{i,t+1} = l_{i+1,t}; \;\; i = 1, 2, ..., b-1. \tag{12}$$

Moreover, the law of motion of permanent employment in equation (9) is modified to become:

$$x_{t+1} = (1-\mu)x_t + l_{1,t}; \;\; 0 < \mu < 1. \tag{13}$$

Here we present the general conditions, but in order to discuss the model's implications, we will compare cases corresponding to specific values $b = 0, 4$ in Section 4.

The objective of the representative firm is to maximize a stream of discounted profits π_t, which is the sum of the current profits d_t and the discounted value of expected future profits D_t:

$$\pi_t = d_t + D_t = d_t + E_t\Big[\sum_{j=1}^{\infty} \beta^j \frac{\lambda_{t+j}}{\lambda_t} d_{t+j}\Big], \tag{14}$$

where $\beta^j \frac{\lambda_{t+j}}{\lambda_t}$ is the discount rate for period $t+j$. The firm chooses the sequence $\{k_t, h_t, v_t, x_{t+1}\}$ to maximize (14), subject to equations (8), (9), and (10). Let η_t denote the corresponding Lagrange multiplier. The optimum conditions necessary for the firm with respect to the indicated variables are:

$$k_t : r_t = \alpha \frac{y_t}{k_t}, \tag{15}$$

$$h_t : w_{h,t} = (1-\alpha) \frac{(\gamma h_t)^{\sigma}}{x_t^{\sigma} + (\gamma h_t)^{\sigma}} \frac{y_t}{h_t}, \tag{16}$$

$$l_{1,t+b-1} : E_t \left\{ \frac{1}{\beta^{b-1} \lambda_{t+b-1}} \sum_{a=1}^{b} \beta^{a-1} \lambda_{t+a-1} w_{n,t+a-1} \right\} = E_t \left[\eta_{t+b-1} - \phi\left(\frac{x_{t+b} - x_{t+b-1}}{x_{t+b-1}} \right) \right], \tag{17}$$

and

$$x_{t+1} : \eta_t = \beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} \left[\frac{(1-\alpha)x_{t+1}^{\sigma}}{x_{t+1}^{\sigma} + (\gamma h_{t+1})^{\sigma}} \frac{y_{t+1}}{x_{t+1}} - w_{n,t+1} + \frac{\phi}{2} \left(\frac{x_{t+2} - x_{t+1}}{x_{t+1}} \right)^2 - \phi \left(\frac{x_{t+2} - x_{t+1}}{x_{t+1}} \right) + (1-\mu)\eta_{t+1} \right] \right\}. \tag{18}$$

As indicated in equations (15) and (16), the production inputs k_t and h_t are paid on the basis of their marginal product. Also note that equation (17) illustrates the firm's optimal intertemporal choice regarding the new recruits based on its forward-looking decisions since it takes the current wage, training costs, and the stream of future marginal products into account.

3.3 The competitive equilibrium

The competitive equilibrium condition is defined as a sequence of allocations $\{c_t, h_t, n_t, k_{t+1}, z_{t+1}\}$ of the representative household and $\{k_t, h_t, v_t, x_{t+1}\}$ of the representative firm such that given the prices $\{p_t, r_t, w_{h,t}, w_{n,t}\}$, the household maximizes (1) and the representative firm maximizes (14) and all of the markets are cleared. The market clearing conditions in the equity, permanent labor, and goods markets are given by

$$z_t = 1, \tag{19}$$

$$n_t = v_t + x_t, \tag{20}$$

and

$$c_t + k_{t+1} - (1-\delta)k_t + \frac{\phi}{2}\frac{(x_{t+1} - x_t)^2}{x_t} = A_t {k_t}^{\alpha}\left[{x_t}^{\sigma} + (\gamma h_t)^{\sigma}\right]^{\frac{1-\alpha}{\sigma}}, \tag{21}$$

Equation (19) implies the equilibrium condition for the equity market given that the outstanding equity of the economy is normalized to unity. Equation (20) illustrates that the supply of permanent labor equals the aggregate of new recruits and the workers actually engaged in production. The equilibrium condition for the goods market reported in equation (21) is derived from combining (2), (3), (8), and (9) given (19), in which $z_t = 1$ for all t.

Finally, the logarithm of TFP is set to follow a stationary first-order autoregressive process,

$$\log(A_t) = \rho \log(A_{t-1}) + \varepsilon_t, \tag{22}$$

where ρ is the persistence parameter and the technology shock ε_t is a white noise with variance σ_ε^2.

4 Main results

Given the model's complexity, we resort to numerical methods to solve the model by linearizing the dynamic equations around the steady state.[8] Let a variable with "∧"denote its percentage deviation from the stationary value, namely, $\hat{B}_t = (B_t - B)/B$ for any endogenous variable B_t in our model. We begin by characterizing a benchmark economy, in which the structural parameters are divided into two groups. Every parameter in the first group is either tied to a commonly used value or calibrated to match the US data, and every parameter in the second group is estimated by using the Simulated Method of Moments (SMM). We then show how the model produces aggregate variations in response to a shock to TFP given these parameter values. To better explain the role of each of the main channels, we also compare the model's responses to different structural parameters that bring about implications of interest.

4.1 Benchmark parameterization

We first set the capital share $\alpha = 0.36$ and the intertemporal elasticity of substitution in consumption $1/\theta = 1$ (i.e., $\theta = 1$), and the values are selected by those commonly used in the business cycle literature. In line with Christiano et al. (2008), the subjective discount

[8]A detailed derivation of the stationary values of essential macro variables will be provided in Appendix A.

factor β is set equal to $1.01358^{-0.25}$, so that it matches the average annual real return on three-month Treasury bills of 1.36%. Following Cooley and Prescott (1995), we set the capital depreciation rate $\delta = 0.012$. As for the value of the weight parameter in the utility function ψ, we set it to match the stationary value of the employment rate (the ratio of aggregate employment to population), namely, $N = n + h = 0.61$. As regards the productivity of temporary workers relative to permanent ones γ, we set it to match the stationary value of the wage gap between these two kinds of labor $w_h/w_n = 0.75$.

Moreover, the parameter that governs the intertemporal elasticity of substitution in labor χ is set to match the stationary value of the temporary to aggregate employment ratio $e = h/N = 0.0165$.[9] We follow Hall (2005) and set the monthly separation rate at 3.5%, which corresponds to the quarterly separation rate of permanent labor $\mu = 1-(1-0.035)^3-0.0165 = 0.0849$. In addition, we set the total number of periods required for each new recruit to accumulate the experiences and skills needed to become permanent workers as $b = 4$, which is consistent with the value used by Carneiro et al. (2012). Finally, in line with the value estimated by King and Rebelo (1999), we simply set $\rho = 0.979$. Also note that the calibrated values of ψ, γ, and χ will vary with respect to different SMM estimates of parameters.[10] Panel A of Table 2 reports the values of the calibrated parameters in the first group.

4.2 SMM estimation and the quantitative results

We apply SMM to estimate the set of the remaining parameters in the second group, which is denoted by a 3×1 vector $\Theta = \{\sigma, \phi, \sigma_\varepsilon^2\}$. The parameters are estimated by minimizing the distance between the empirical moments from the data and the simulated moments based on our model. Let m stand for the vector of moments computed from real data, and m^s for the vector of averaged simulated moments over $M = 20$ simulations, the same sample size as for the data. Accordingly, given the sample size of data T, the estimation of the parameters

[9] The share of temporary employment is set at 1.65% which is the stationary value.

[10] Given these data moments used for the calibration in the steady state ($N = 0.61$, $w_h/w_n = 0.75$, and $h/n = 0.165$), we can then simultaneously resolve the values of the parameters ψ, γ and χ by substituting equations (A7), (A8), (A11), (A12) and (A13) into equations (A3), (A5), and (A6).

will proceed by choosing $\tilde{\Theta}$ to solve the optimization problem

$$\tilde{\Theta} = \arg\min J(\Theta) = \frac{TM}{1+M}[m - m^s(\Theta)]W[m - m^s(\Theta)]', \tag{23}$$

where W is a positive-definite weighting matrix, which is computed by the Newey-West estimator.

The four targeted moments that we select are informative for estimating the SMM parameters. The reason for choosing these targeted moments to estimate the vector of parameters $\Theta = \{\sigma, \phi, \sigma_\varepsilon^2\}$ can be briefly stated as follows.

First, the standard deviation of the temporary employment $std(\hat{h}_t)$ is informative in determining the parameter σ, which governs the elasticity of substitution between temporary and permanent employment.[11] Second, the coefficients of correlation between temporary employment and output $corr(\hat{h}_t, \hat{y}_t)$ and between permanent employment and output $corr(\hat{n}_t, \hat{y}_t)$ are closely correlated with the intensity parameter of labor adjustment costs ϕ. Hence, they provide information about the value of ϕ.[12] Third, we will show that the standard deviation of output $std(\hat{y}_t)$ is crucial for determining the variance of the technology shock σ_ε^2. Accordingly, we use $std(\hat{y}_t)$ to estimate the variance of the technology shock σ_ε^2.

Our data are obtained from the BLS and FRED databases during the period 1990Q1–2014Q4 in the quarterly frequency, and we thus have the sample size $T = 100$.[13] Panel B of Table 2 summarizes the SMM estimates of parameters. The targeted and selected (non-targeted) moments for the US data are reported in Table 3, along with the simulated mo-

[11]A high value of σ implies a high degree of substitutability between temporary and permanent employment. If the value of σ is higher, the firm tends to hire more temporary workers than permanent workers in response to a positive technology shock. This effect results in an increase in the volatility of temporary employment.

[12]If the value of ϕ is higher, the firm will hire more temporary workers but fewer permanent ones to produce in response to the positive technology shock. As a result, this effect leads to a rise in the correlation between temporary employment and output and a reduction in the correlation between permanent employment and output.

[13]There are eight time series variables used for the calibration and SMM estimation, which are Nominal Price (f) = GDP Deflator, Population (L) = Civilian Non-institutional Population (defined as persons 16 years of age and older), the Temporary Employment Rate (h) = Temporary Employment/L, the Permanent Employment Rate (n) = Permanent Employment/L, the Employment Rate ($N = n + h$), Real Per Capita GDP (y) = Gross Domestic Product/$(f \cdot L)$, Real Per Capita Consumption (c) = (Personal Consumption Expenditures on Services + Personal Consumption Expenditures on Nondurable Goods)/$(f \cdot L)$, and Real Per Capita Investment (I) = Fixed Private Investment/$(f \cdot L)$. All of the variables are in log form and de-trended by the HP-filter, in which the smoothing parameter is set to 1600.

ments based on our model. Table 4 displays a summary of the simulated coefficients of correlation between employment and output.

As reported in Panel B of Table 2, the point estimate of the parameter σ is 0.960, which implies that the elasticity of substitution between permanent and temporary labor equals 25.[14] The intensity parameter of labor adjustment costs ϕ is estimated to be around 9 and the standard deviation of the technology shock σ_ε is estimated to be 0.802. Since the chi-square statistic at the 95% level is $\chi^2_{0.05}(1) = 3.84$, the test statistic $J = 0.30$ implies that the model cannot be rejected by the data.

Tables 3 and 4 confirm that the benchmark model well characterizes the four stylized facts that we have previously documented. First, temporary employment is more volatile than permanent employment. Specifically, the model generates the simulated standard deviation of temporary employment $std(\hat{h}_t) = 6.11$, which is much higher than that of permanent employment $std(\hat{n}_t) = 0.49$. Second, the model also generates a strong pro-cyclicality of the share of temporary employment, which is exhibited by the simulated coefficient of correlation between the share of temporary employment and output $corr(e_t, \hat{y}_t) = 0.77$. Third, the coefficient of correlation between temporary employment and output $corr(\hat{h}_t, \hat{y}_t) = 0.81$ is much higher than that between permanent employment and output $corr(\hat{n}_t, \hat{y}_t) = 0.69$. Fourth, Table 4 shows that our model can generate the two-quarter lagged behavior of permanent employment, since the value $corr(\hat{n}_{t+2}, \hat{y}_t) = 0.82$ is the largest in column 8.

4.3 Impulse response analysis

In this subsection, we show how the relevant variables will adjust in response to an unanticipated rise in total factor productivity. Figure 6 depicts their impulse responses to the technology shock in the benchmark economy. Assume that the economy starts at its stationary equilibrium in period 0. In period 1, a 1-percent persistent increase in total factor productivity leads to changes in the relevant macro variables.

First, we restrict our attention to the impulse responses of permanent employment and aggregate employment. Figure 6 shows that permanent employment is increased moder-

[14] The value is much larger than the elasticity of substitution estimated by Cappellari et al. (2012), since their estimate based on Italy's firm-level data is between 1.06–1.07.

ately upon the arrival of the positive shock at the beginning (in period 1), and then permanent employment keeps on rising but at a decreasing rate after period 1. This result can be explained intuitively as follows. When the positive shock occurs, the firm raises its expected future profits and in turn increases its demand for permanent workers because of its forward-looking decisions. Since training permanent workers takes time and incurs additional adjustment costs, this channel causes the rises in permanent employment to be lagged and also relatively smooth. In addition, given that permanent employment accounts for approximately 98% of aggregate employment, it is reasonable for the dynamics of the aggregate employment to be similar to that for permanent employment.

Second, we examine the impulse response of temporary employment to the positive shock. As exhibited in Figure 6, temporary employment rises by more than 5% upon the arrival of the shock and then it continues to decline afterwards. In addition, it is noteworthy that in period 1 the increase in temporary employment is considerably larger than that in the permanent counterpart. Here a question arises because of the result displayed in Figure 6. Why does the firm tend to hire temporary rather than permanent workers in the short run in response to the shock? To answer this question, we need to pay special attention to the following two points. First, the adjustment of permanent workers is time-consuming since it takes a few periods for the new recruits to accumulate experiences and skills and to become permanent workers. Second, there exists a high degree of substitutability between temporary and permanent labor since the estimated elasticity of substitution is at a high level, i.e., $1/(1-\sigma) = 25$. Based on these two reasons, when the positive shock arrives, the firm is motivated to hire more temporary workers to substitute for the permanent counterparts even though the former ones are less productive. On the other hand, when the time horizon is getting longer, the firm will accumulate the stock of permanent workers because their higher productivity is taken into account in the long run. This leads to the decline in temporary employment after its initial rises.

Third, the last panel in Figure 6 depicts the impulse response of the share of temporary employment, which is similar to that of temporary employment. Because the share equals the ratio of temporary employment to aggregate employment, the changes in the share of temporary employment can be explained by the changes in both temporary and permanent employment. Given that permanent employment adjusts slowly, the immediate rise in the share of temporary employment upon the arrival of the positive shock mostly results from the increase in temporary employment (over 5%). Thereafter, the share of temporary employment continues to rise at a decreasing rate. This result is derived from the fact that temporary employment keeps on rising at a diminishing rate and meanwhile permanent employment keeps on rising at an increasing rate.

Finally, Figure 6 also indicates that, in response to the increase in TFP, the household tends to have a higher expected life-time income and this increase stimulates its consumption. Moreover, the rise in aggregate employment in response to the positive shock further stimulates the investment in physical capital. As a result, this shock leads to persistent rises in output.

4.4 Implications of applying sensitivity analysis

In this subsection, we would like to intuitively explain why our benchmark model can successfully capture the cyclical behavior of temporary and permanent employment in the US economy. To this end, compared with the benchmark economy, we perform sensitivity analysis in the following three cases: (i) where there is a low degree of substitution between temporary and permanent labor (i.e., $\sigma = 0.01$), (ii) in the absence of job training (i.e., $b = 0$), and (iii) in the absence of the labor adjustment cost (i.e., $\phi = 0$). Figures 7-9 respectively depict the impulse responses of variables $\{\hat{y}_t, \hat{h}_t, \hat{n}_t, e_t\}$ to a 1-percent persistent increase in TFP in the three cases, and Table 5 reports the simulated moments in association with these three cases. For the purpose of comparing the results of the benchmark economy, in each sensitivity analysis we solely turn off one mechanism without re-estimating the parameters. More precisely, except for σ in (i), b in (ii), and ϕ in (iii), the remaining parameters that we use in doing the sensitivity analysis are the same as those calibrated in Section 4.1 and estimated in Section 4.2.

In the first case, when we set $\sigma = 0.01$, the elasticity of substitution between temporary and permanent labor $1/(1-\sigma)$ is reduced to around unity (compared with $\sigma = 0.960$ and $e = 25$ in the benchmark economy). Figure 7 depicts that, in response to a positive persistent TFP shock, the fall in the degree of substitution reduces the possibility of hiring temporary alternatives as a substitute for permanent workers during the training periods. Put differently, given the same wage ratio between the two types of workers, the share of temporary employment is consequently decreased compared to the benchmark case (see the bottom right panel of Figure 7).

The simulated moments in association with the first case (i.e., $\sigma = 0.01$) are depicted in column 4 of Panel A in Table 5, which shows that the following three moments are too low to match the data: the standard deviation of temporary employment $std(\hat{h}_t)$, the standard deviation of the share of temporary employment $std(\hat{e}_t)$, and the correlation coefficient between the share of temporary employment and output $corr(\hat{e}_t, \hat{y}_t)$. We can explain this result by focusing on the impulse response displayed in Figure 7. Compared to the benchmark economy, a lowered σ induces the firm to hire more permanent workers and to lower its current demand for temporary ones. This change leads to the reductions in the volatilities of temporary employment and the share of temporary employment. Moreover, since the possibility of hiring temporary alternatives as a substitute for permanent workers is reduced, the decrease in σ leads the share of temporary employment to be less pro-cyclical.

In the second case, we discuss the scenario in which the time-to-build mechanism for job training is absent, i.e., $b = 0$. It should be noted that $b = 0$ implies that each new recruit immediately becomes a skilled and trained permanent worker once he is hired. Consequently, the law of motion of new recruits v_t in equation (11) and the law of motion of the stock of permanent employment x_t in equation (12) are shut down, and the model degenerates to a standard RBC model.[15] In such a case, we show the transitional dynamics of the relevant variables $\{\hat{y}_t, \hat{h}_t, \hat{n}_t, e_t\}$ in response to a positive TFP shock in Figure 8. As exhibited in Figure 8, both permanent and temporary employment rises in response to the positive TFP shock because now the new recruits can directly participate in production. Compared to the benchmark case, the absence of the time-to-build mechanism leads to more direct and rapid responses of the variables $\hat{y}_t$, $\hat{h}_t$, $\hat{n}_t$ and e_t to the TFP shock, thereby causing their lagged behavior to vanish.

[15]In the case of $b = 0$, the law of motion of new recruits h_t (11) and the law of motion of the stock of permanent employment x_t (12) will degenerate, and the model is reduced to a standard real business cycle model. Then, the profit is negative and equal to the labor adjustment cost in negative value terms. To avoid this potential problem, in line with Kydland and Prescott (1991) and Burnside et al. (1993), we deal with the model with a representative household-producer optimization problem.

The simulated moments in association with the absence of job training (i.e., $b = 0$) are reported in column 5 of Panel A in Table 5. They indicate the nearly perfect positive correlations between output and the variables: temporary employment, permanent employment, and the share of temporary employment. Moreover, as reported in Panel B in Table 5, in association with $b = 0$, permanent employment is no longer characterized by lagged behavior. This result can be grasped by referring to Figure 8, i.e., in a standard RBC model, both types of employment and output display a high synchronization in response to the TFP shock.

We then discuss the third case where labor adjustment costs are absent, i.e., $\phi = 0$. The result in Figure 9 reveals that the fluctuations in $\hat{y}_t$, $\hat{h}_t$, $\hat{n}_t$, and e_t are amplified because of the reduction in labor adjustment costs. The interpretation is straightforward. Since a sharp increase in permanent workers now becomes less costly, the firm will immediately adjust its stock of permanent workers by creating more new recruits. Accordingly, the moderate decline in the share of temporary employment during the first four periods is largely explained by this immediate adjustment. Moreover, the significant increase in $\hat{y}_t$ and falls in $\hat{h}_t$ and e_t at $t = 5$ are derived from the fact that a number of recruits are becoming permanently workers.

Finally, the simulated moments in association with the absence of labor adjustment (i.e., $\phi = 0$) are reported in column 6 of Panel A in Table 5. In contrast to the smooth adjustment of permanent employment in the benchmark economy, the absence of labor adjustment costs leads to increases in the volatility and pro-cyclicality of permanent labor. As a consequence, the adjustment of permanent labor is more elastic, thereby causing permanent employment to not lag within the cycle.

4.5 Labor hoarding behavior

Figure 6 also displays how the firm reduces its demand for temporary workers but maintains a certain number of skilled and permanent workers during the recession. Since the firm shrinks its stock of permanent workers only slowly, the labor hoarding effect leads to a moderate variation of output in the short run. Specifically, the calibrated model predicts that a 1 percent decline in TFP brings about a 3.39-percent decrease in temporary employment as well as a 0.18 percent decrease in the permanent counterpart. Meanwhile, output drops by 1% upon the arrival of the negative shock and the figure is around 50% lower than the decline in output as the economy reaches another steady state (i.e., -1.5%). This result suggests that the loss of the stock of permanent workers has a persistent impact on the output in the long run.

5 Conclusion

The data for the US labor market reveal the following stylized facts involving temporary workers: (i) a higher volatility of temporary employment than of permanent employment; (ii) a strong pro-cyclicality of the share of temporary employment; (iii) the lagged behavior of aggregate employment; and (iv) a stronger correlation between temporary employment and output than in the case of the permanent counterpart. Given that the standard RBC model does not draw a distinction between temporary and permanent employment, it is unable to provide a plausible explanation for these observed facts.

This paper proposes three channels related to distinguishing temporary employment from permanent employment. The first channel has to do with the substitutability between temporary and permanent workers. The second channel is concerned with the time-to-build mechanism for job training, which leads new recruits to become productive permanent workers. The third channel relates to the costs of training permanent workers. By incorporating these three channels into into the standard RBC model, this paper finds that the modified model is able to explain the above stylized facts in the US labor market. Moreover, this paper also finds that the modified model provides a plausible explanation for the firms' decision to hoard labor when the economy experiences a recession.

Table 1: Cyclical behavior of temporary and permanent employment in the US economy

Moments		
Standard deviation of output	$std(\hat{y}_t)$	1.10
Standard deviation of share of temporary employment	$std(e_t)$	0.10
Standard deviation of temporary employment	$std(\hat{h}_t)$	6.66
Standard deviation of permanent employment	$std(\hat{n}_t)$	1.10
Correlation of coefficient between the share of temporary employment and output	$corr(e_t, \hat{y}_t)$	0.90
Correlation of coefficient between temporary employment and output	$corr(\hat{h}_t, \hat{y}_t)$	0.91
Correlation of coefficient between		
permanent employment and 3-period lagged output	$corr(\hat{n}_{t+3}, \hat{y}_t)$	0.81
permanent employment and 2-period lagged output	$corr(\hat{n}_{t+2}, \hat{y}_t)$	0.87
permanent employment and 1-period lagged output	$corr(\hat{n}_{t+1}, \hat{y}_t)$	0.84
permanent employment and output (contemporaneous)	$corr(\hat{n}_t, \hat{y}_t)$	0.75
permanent employment and 1-period lead output	$corr(\hat{n}_{t-1}, \hat{y}_t)$	0.56
permanent employment and 2-period lead output	$corr(\hat{n}_{t-2}, \hat{y}_t)$	0.34
permanent employment and 3-period lead output	$corr(\hat{n}_{t-3}, \hat{y}_t)$	0.12

Note: The sampling period is 1990:Q1–2014:Q4. Except for e_t, all of the other variables (for $\hat{y}_t, \hat{h}_t, \hat{n}_t$) are expressed in log form before being de-trended by the HP-filter, in which the smoothing parameter is set to 1600.

Table 2: Parametrization of the benchmark model

Panel A: Calibrated parameters

Category	Parameter	value
Preference	Intertemporal elasticity of substitution in consumption ($1/\theta$)	1
	Subjective discount rate (β)	0.9966
	Inverse of the Frisch elasticity of labor supply (χ)	0.0700 (varied)
	Disutility of temporary labor supply (ψ)	8.9000 (varied)
Technology	Share of physical capital (α)	0.3600
	The productivity of temporary relative to permanent workers (γ)	0.4610 (varied)
	Capital depreciation rate (δ)	0.0120
	Job separation rate (μ)	0.0849
	Persistence parameter of the auto-regressive process (ρ)	0.9790

Panel B: Estimated parameters by SMM

σ	ϕ	σ_ε^2	J	$\chi^2_{0.05}(1)$
0.960	8.903	0.673	0.30	3.84
(0.002)	(0.561)	(0.039)		

Note: Based on the statistics for the targeted moments in Panel A of Table 2, the reported values of the SMM parameters with the standard deviations in the parentheses are computed by using the 500 replications of the estimation procedure. The variance of the technology shock is reported in percentage terms.

Table 3: Calibration of the parameters

	Moments	Data	Model
Targeted			
	$std(\hat{y}_t)$	1.10	1.05
	$std(\hat{h}_t)$	6.66 (6.05)	6.11 (5.82)
	$corr(\hat{h}_t, \hat{y}_t)$	0.91	0.81
	$corr(\hat{n}_t, \hat{y}_t)$	0.75	0.69
Non-targeted (selected)			
	$std(\hat{c}_t)$	0.79 (0.72)	0.38 (0.35)
	$std(\hat{i}_t)$	4.15 (3.77)	2.77 (2.64)
	$std(\hat{n}_t)$	1.10 (1.00)	0.49 (0.47)
	$std(\hat{N}_t)$	1.17 (1.06)	0.52 (0.50)
	$std(e_t)$	0.10	0.10
	$corr(\hat{N}_t, \hat{y}_t)$	0.78	0.81
	$corr(e_t, \hat{y}_t)$	0.90	0.77

Note: The sampling period is 1990:Q1–2014:Q4. All of the variables (for $g_t = \hat{N}_t, \hat{h}_t, \hat{n}_t, e_t$) are de-trended by the HP-filter and the smoothing parameter is set to 1600. The standard deviations of output, temporary employment, consumption, investment, permanent employment, aggregate employment, and the share of temporary employment are displayed in order. In addition, the values in the parentheses are the ratios of the standard deviations of the variables to the standard deviations of output. The simulated moments are averages of variables across 1000 replications and over 100 periods.

Table 4: Coefficients of correlation between de-trended output and employment variables

Source	Data				Model			
Coef. of Corr.	$\hat{N}_t$	$\hat{h}_t$	$\hat{n}_t$	e_t	$\hat{N}_t$	$\hat{h}_t$	$\hat{n}_t$	e_t
$corr(g_{t+3}, \hat{y}_t)$	0.80	0.52	0.81	0.47	0.70	-0.08	0.77	-0.14
$corr(g_{t+2}, \hat{y}_t)$	0.87	0.73	0.87	0.69	0.80	0.16	0.82	0.10
$corr(g_{t+1}, \hat{y}_t)$	0.86	0.88	0.84	0.85	0.84	0.46	0.80	0.40
$corr(g_t, \hat{y}_t)$	0.78	0.91	0.75	0.90	0.81	0.81	0.69	0.77
$corr(g_{t-1}, \hat{y}_t)$	0.60	0.83	0.56	0.85	0.55	0.60	0.46	0.57
$corr(g_{t-2}, \hat{y}_t)$	0.38	0.68	0.34	0.72	0.36	0.44	0.29	0.43
$corr(g_{t-3}, \hat{y}_t)$	0.16	0.48	0.12	0.54	0.22	0.35	0.17	0.34

Note: All the variables are expressed in quarterly frequencies. Then, the HP-filter is applied with respect to all variables to remove the effects of the trend components. Each amount represents the coefficient of correlation between a de-trended (lagged or lead) variable and output. For example, the correlation between the one-quarter lead aggregate employment and output of the data equals 0.87.

Table 5: Sensitivity analysis

Panel A: simulated moments

Moments	Data	Benchmark.	$\sigma = 0.01$	$b = 0$	$\phi = 0$
$std(\hat{h}_t)$	6.66	6.10	0.78	4.12	6.21
$std(\hat{n}_t)$	1.10	0.49	0.82	0.44	1.05
$std(e_t)$	0.10	0.10	0.01	0.06	0.09
$corr(\hat{h}_t, \hat{y}_t)$	0.91	0.81	0.98	1.00	0.34
$corr(\hat{n}_t, \hat{y}_t)$	0.75	0.69	0.89	1.00	0.87
$corr(e_t, \hat{y}_t)$	0.90	0.77	0.08	1.00	0.21

Panel B: Coefficients of correlation between de-trended output and employment variables

Source	Data		Benchmark		$\sigma = 0.01$		$b = 0$		$\phi = 0$	
Coef. of Corr.	$\hat{h}_t$	$\hat{n}_t$	$\hat{h}_t$	$\hat{n}_t$	$\hat{h}_t$	$\hat{n}_t$	$\hat{h}_t$	$\hat{n}_t$	$\hat{h}_t$	$\hat{n}_t$
$corr(g_{t+3}, \hat{y}_t)$	0.52	0.81	-0.08	0.77	0.49	0.51	0.20	0.20	-0.34	0.16
$corr(g_{t+2}, \hat{y}_t)$	0.73	0.87	0.16	0.82	0.58	0.70	0.41	0.41	-0.13	0.36
$corr(g_{t+1}, \hat{y}_t)$	0.88	0.84	0.46	0.80	0.75	0.85	0.67	0.67	0.09	0.59
$corr(g_t, \hat{y}_t)$	0.91	0.75	0.81	0.69	0.98	0.89	1.00	1.00	0.34	0.87
$corr(g_{t-1}, \hat{y}_t)$	0.83	0.56	0.60	0.46	0.75	0.73	0.71	0.71	0.36	0.73
$corr(g_{t-2}, \hat{y}_t)$	0.68	0.34	0.44	0.29	0.55	0.62	0.47	0.47	0.42	0.65
$corr(g_{t-3}, \hat{y}_t)$	0.48	0.12	0.35	0.17	0.42	0.54	0.28	0.28	0.50	0.61

Note: See the note to Table 3.

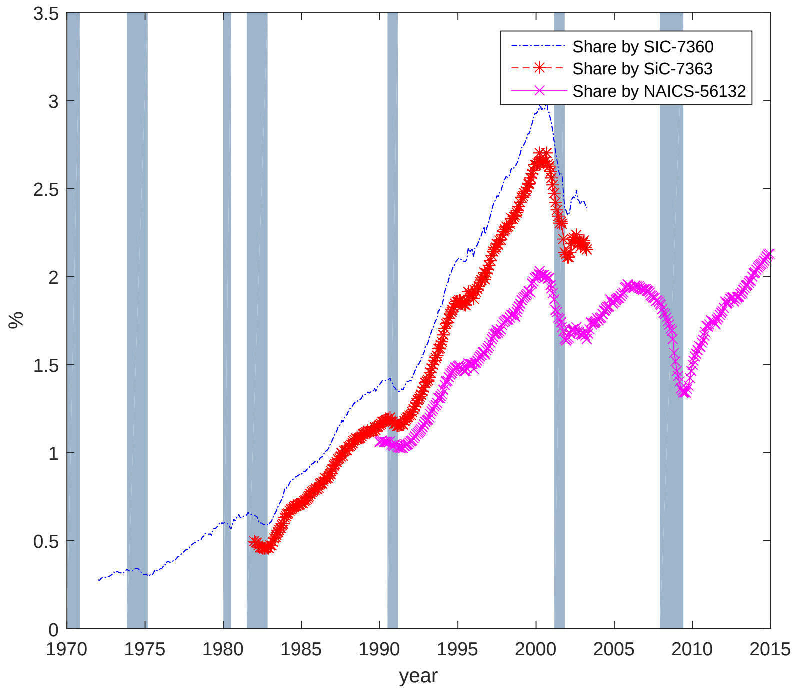

Figure 1: The share of temporary employment measured by different industry classifications (source: BLS)

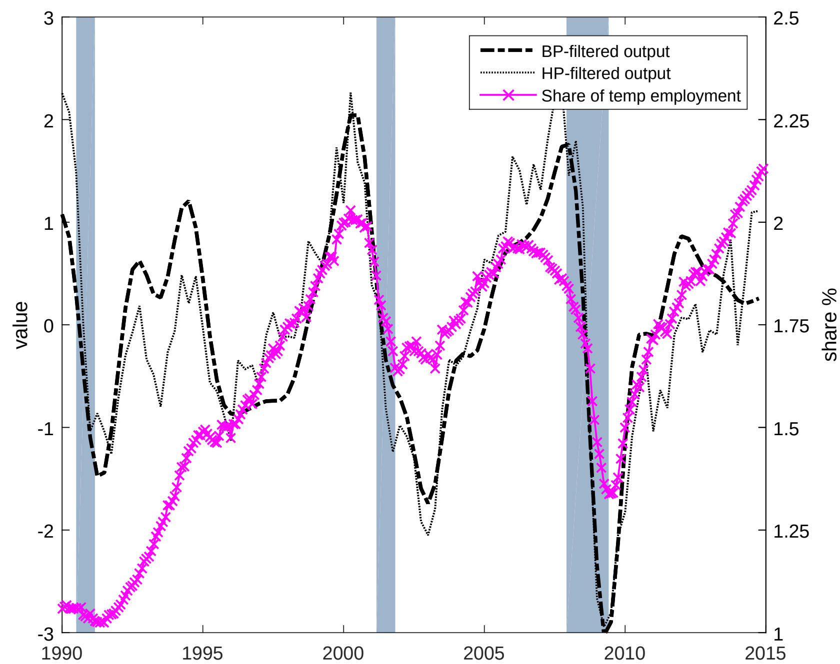

Figure 2: The cyclical component of output on right scale and the share of temporary employment on left scale (sources: BLS and FRED)

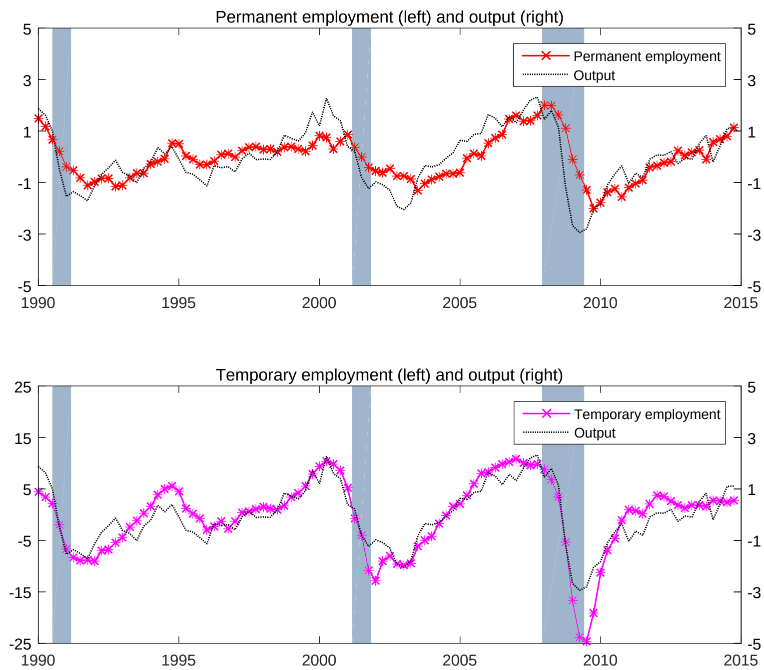

Figure 3: The HP-filtered cyclical components of permanent and temporary employment along with output (sources: BLS and FRED)

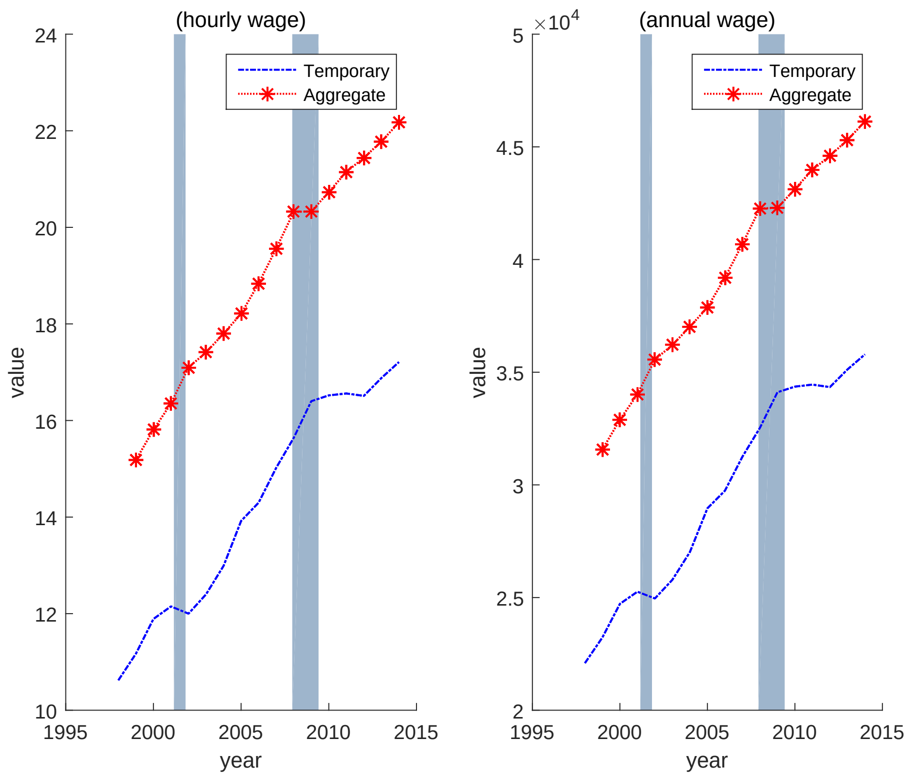

Figure 4: The wage rates of temporary and total non-farm workers in US dollars (source: OES)

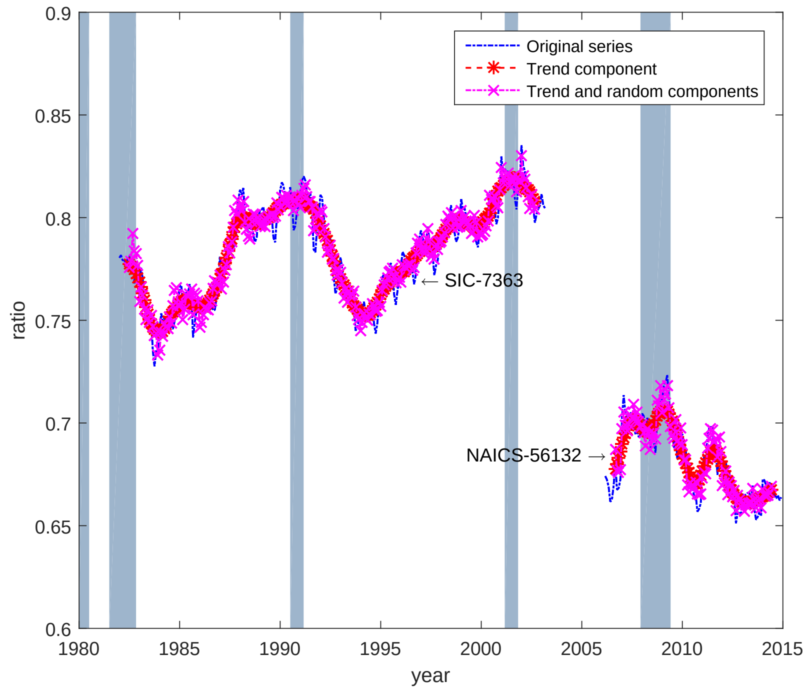

Figure 5: The ratio of hourly wages of temporary to total non-farm workers (source: BLS)

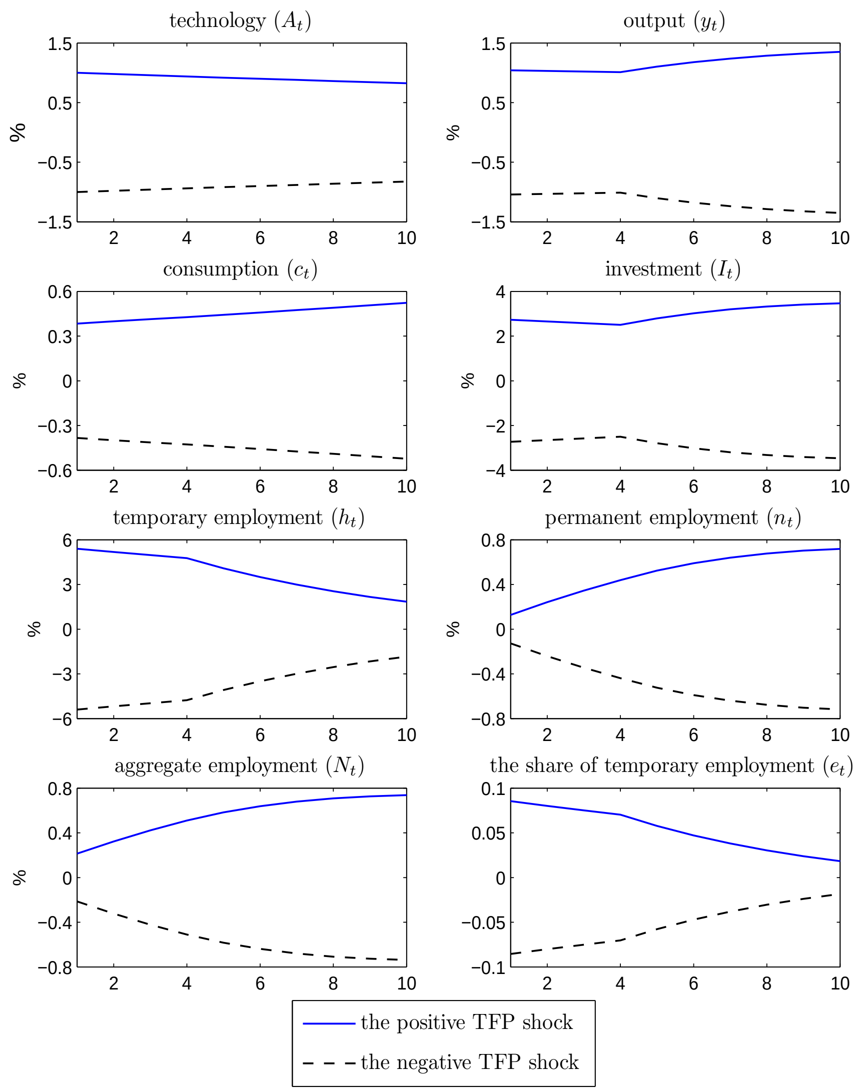

Figure 6: The impulse responses of the main variables to 1% positive (negative) TFP shock

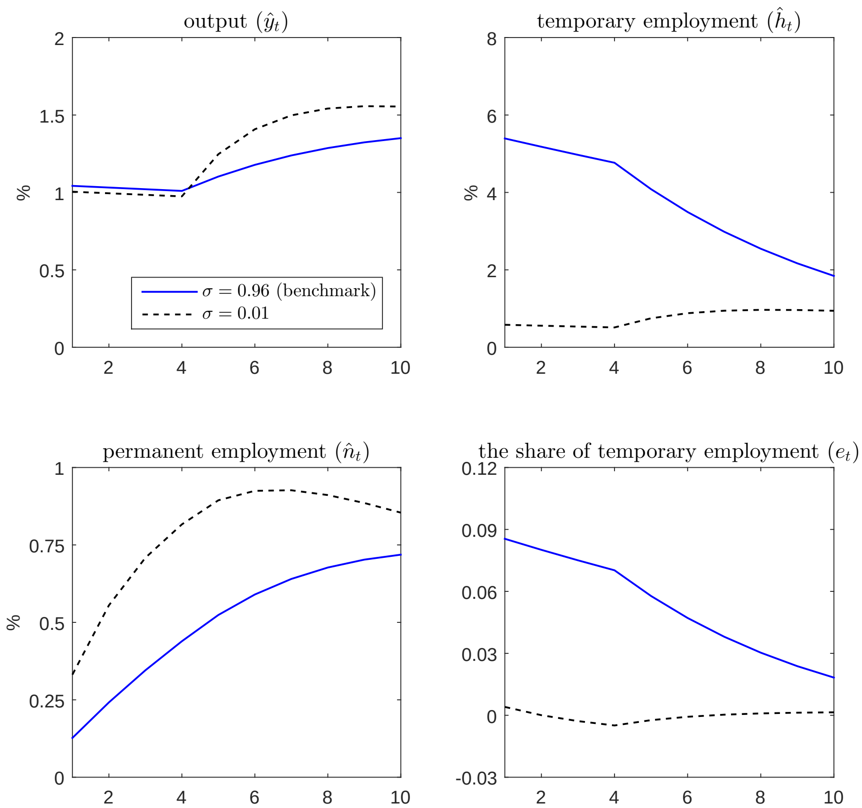

Figure 7: The impulse responses to an 1% positive TFP shock given σ = 0.96 (benchmark) and σ = 0.01

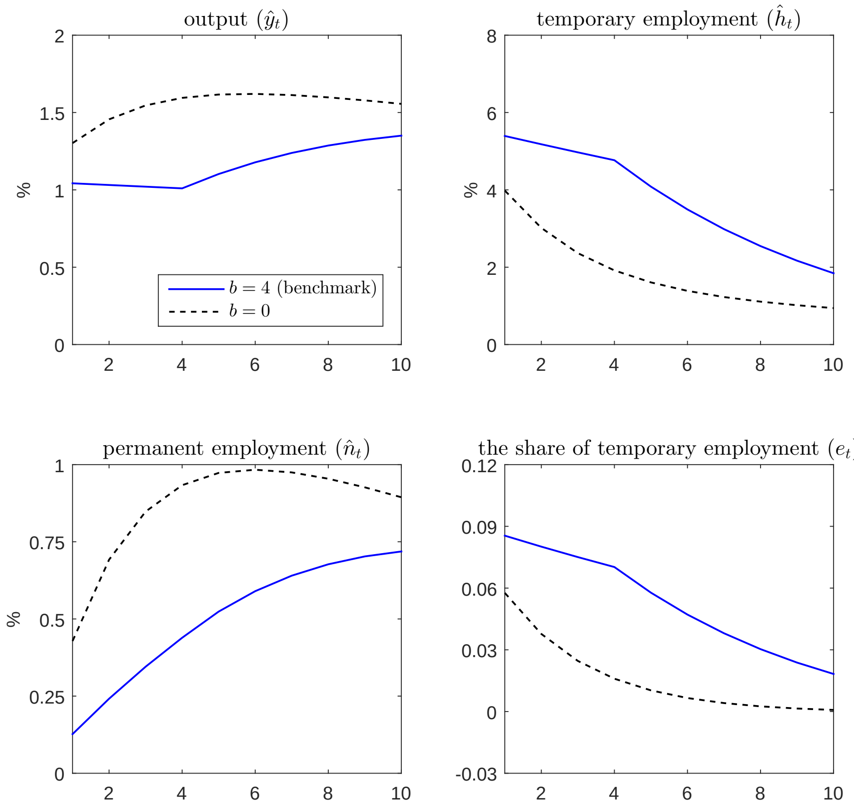

Figure 8: The impulse responses to an 1% positive TFP shock given $b = 4$ (benchmark) and $b = 0$

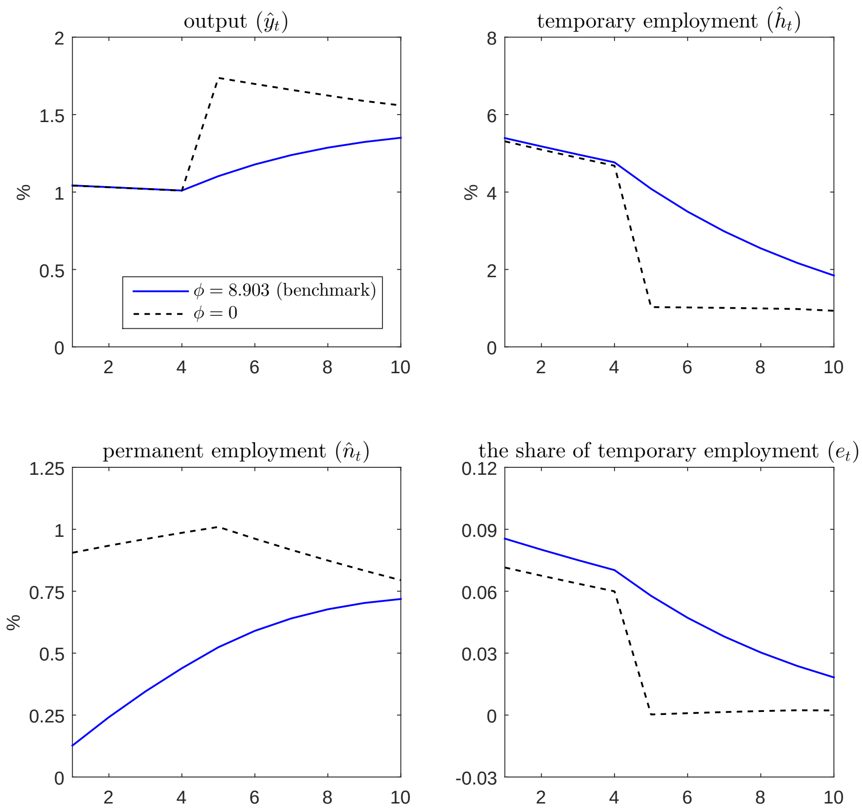

Figure 9: The impulse responses to an 1% positive TFP shock given $\phi = 8.908$ (benchmark) and $\phi = 0$

Appendix A

This appendix provides a brief derivation of the equilibrium conditions from the non-linear form to the linearized version in terms of percentage deviations from the steady state. The competitive equilibrium for the economy is composed of 16 conditions (A1)–(A16). The endogenous variables are the sequences of quantities $\{y_t, c_t, h_t, n_t, x_t, v_t, l_{1,t}, I_t, k_t, z_t, d_t\}$ and prices $\{w_{h,t}, w_{n,t}, \eta_t, \lambda_t, p_t\}$. Given $A = 1$ at the steady state, the stationary relationship at the competitive equilibrium can be stated as:

$$z = 1, \tag{A1}$$

$$w_h = \frac{(1-\alpha)\gamma^\sigma \left(\frac{h}{x}\right)^{\sigma-1}}{\gamma^\sigma \left(\frac{h}{x}\right)^{\sigma} + 1} \frac{\frac{1}{\beta} - 1 + \delta}{\alpha} \frac{k}{x}, \tag{A2}$$

$$w_n = w_h (1 + b\mu)^\chi \left(\frac{h}{x}\right)^{-\chi}, \tag{A3}$$

$$\eta = \frac{\beta}{1-\beta} \frac{1-\beta^b}{\beta^b} w_n, \tag{A4}$$

$$h = \left(\frac{w_h \left(\frac{h}{x}\right)^\theta}{\psi \left(\frac{c}{k}\right)^\theta \left(\frac{k}{x}\right)^\theta} \right)^{\frac{1}{\theta+\chi}}, \tag{A5}$$

$$\gamma = \left[\left(\frac{h}{x}\right)^{\sigma-1} \frac{w_h}{w_n} \frac{[1-\beta(1-\mu)](1-\beta^b) + (1-\beta)\beta^b}{(1-\beta)\beta^b} \right]^{\frac{-1}{\sigma}}, \tag{A6}$$

$$\frac{k}{x} = \left(\frac{\frac{1}{\beta} - 1 + \delta}{\alpha A \left[\gamma^\sigma \left(\frac{h}{x}\right)^\sigma + 1\right]^{\frac{1-\alpha}{\sigma}}} \right)^{\frac{1}{\alpha-1}}, \tag{A7}$$

$$\frac{c}{k} = \frac{\frac{1}{\beta} - 1 + \delta}{\alpha} - \delta, \tag{A8}$$

$$y = Ak^\alpha \left[x^\sigma + (\gamma h)^\sigma\right]^{\frac{1-\alpha}{\sigma}}, \tag{A9}$$

$$I = \delta k, \tag{A10}$$

$$l_1 = \mu x, \tag{A11}$$

$$v = bl_1, \tag{A12}$$

$$n = x + v, \tag{A13}$$

$$d = (1-\alpha)\, y - w_h h - w_n n, \tag{A14}$$

$$p = \beta\,(p + d)\,, \tag{A15}$$

$$\lambda = c^{-\theta}. \tag{A16}$$

Let $\hat{B}_t = (B_t - B)/B$, where $\hat{B}_t$ can be any endogenous variable in the model. By log-linearizing the conditions around B_t's steady state, we can derive the first-order log-linear approximations in terms of percentage deviations:

$$-\theta \hat{c}_t = \hat{\lambda}_t, \tag{A17}$$

$$\theta \hat{c}_t + \chi \hat{h}_t = \hat{w}_{h,t}, \tag{A18}$$

$$\theta \hat{c}_t + \chi \hat{n}_t = \hat{w}_{n,t}, \tag{A19}$$

$$0 = \hat{\lambda}_{t+1} - \hat{\lambda}_t + \beta\alpha \frac{y}{k}\left(\hat{y}_{t+1} - \hat{k}_{t+1}\right), \tag{A20}$$

$$\hat{p}_t = \hat{\lambda}_{t+1} - \hat{\lambda}_t + \beta\left(\hat{p}_{t+1} + \frac{d}{p}\hat{d}_{t+1}\right), \tag{A21}$$

$$\hat{k}_{t+1} = (1-\delta)\,\hat{k}_t + \delta \hat{I}_t, \tag{A22}$$

$$n\hat{n}_t = x\hat{x}_t + v\hat{v}_t, \tag{A23}$$

$$\hat{w}_{h,t} = (\sigma - 1)\,\hat{h}_t + \hat{y}_t - \sigma \frac{(\gamma h)^{\sigma}\,\hat{h}_t + x^{\sigma}\hat{x}_t}{(\gamma h)^{\sigma} + x^{\sigma}}, \tag{A24}$$

$$\hat{v}_t = \frac{1}{b}\sum_{a=1}^{b} \hat{l}_{1,t+a-1}, \tag{A25}$$

$$-\hat{\lambda}_{t+b-1} + \frac{1}{\beta^{b-1}}\frac{w_n}{\eta}\sum_{a=1}^{b}\beta^{a-1}\left(\hat{\lambda}_{t+a-1} + \hat{w}_{n,t+a-1}\right) = \hat{\eta}_{t+b-1} - \frac{\phi\mu}{\eta}\left(\hat{l}_{1,t+b-1} - \hat{x}_{t+b-1}\right), \tag{A26}$$

$$\hat{\eta}_t = \hat{\lambda}_{t+1} - \hat{\lambda}_t + \frac{\beta}{\eta}\left\{\frac{(1-\alpha)\,x^{\sigma-1}y}{(\gamma h)^{\sigma}+x^{\sigma}}\left[(\sigma-1)\,\hat{x}_{t+1} + \hat{y}_{t+1} - \sigma\frac{(\gamma h)^{\sigma}\,\hat{h}_{t+1} + x^{\sigma}\hat{x}_{t+1}}{(\gamma h)^{\sigma}+x^{\sigma}}\right]\right\}$$
$$+\frac{\beta}{\eta}\left[-w_n\hat{w}_{n,t+1} - \phi\mu\left(\hat{l}_{1,t+1} - \hat{x}_{t+1}\right) + (1-\mu)\,\eta\hat{\eta}_{t+1}\right], \tag{A27}$$

$$\hat{x}_{t+1} = (1-\mu)\,\hat{x}_t + \mu\hat{l}_{1,t}, \tag{A28}$$

$$d\hat{d}_t = (1-\alpha)\,y\hat{y}_t - w_h h\left(\hat{w}_{h,t} + \hat{h}_t\right) - w_n n\left(\hat{w}_{n,t} + \hat{n}_t\right), \tag{A29}$$

$$\hat{y}_t = \hat{A}_t + \alpha\hat{k}_t + (1-\alpha)\,\frac{(\gamma h)^{\sigma}\,\hat{h}_t + x^{\sigma}\hat{x}_t}{(\gamma h)^{\sigma}+x^{\sigma}}, \tag{A30}$$

$$\hat{z}_t = 0, \tag{A31}$$

$$y\hat{y}_t = c\hat{c}_t + I\hat{I}_t. \tag{A32}$$

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