A discusión

DOWNWARD NOMINAL WAGE RIGIDITY: THE IMPLICATIONS FROM A NEW-KEYNESIAN MODEL*

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ABSTRACT

We study the determinants of Downward Nominal Wage Rigidity (DNWR) in the context of a new-Keynesian heterogeneous-agent model. Labor productivity of agents is subject to perfectly insurable idiosyncratic shocks. Wage contracts are signed one period ahead and specify the minimum wage that the firm should pay to each worker conditional on her future expected marginal product. The model predicts a simple structural equation: the degrees of DNWR are entirely determined by unexpected shocks to technology and money supply. We test this model's implication with data on the U.S. economy, and we find that the above two shocks can account for about 60% of variation in the aggregate measures of DNWR.

JEL Classification: E12, E24, J31

Keywords: Downward Nominal Wage Rigidity, New-Keynesian model

1 Introduction

The hypothesis of Downward Nominal Wage Rigidity (DNWR) states that degrees of rigidity are higher when nominal wages are adjusted downward than upward. There is robust statistical evidence in support of this hypothesis: the wage-change distribution in actual economies is found to be skewed to the right due to a relative shortage of nominal wage cuts (see, e.g., McLaughlin, 1994, Akerlof, Dickens and Perry, 1996, Kahn, 1997). A possible reason for the existence of DNWR is behavioral specificities of the real-world agents: employers are reluctant to cut nominal wages because they believe that this damages workers morale (see, e.g., Bewley 1998 and Howitt 2002) and employees are reluctant to accept the nominal wage cuts because they perceive them as unfair (see, e.g., Kahneman, Knetsch and Thaler 1986, and Shafir, Diamond and Tversky 1997).

A large body of the empirical literature studies the issue of DNWR in the context of the traditional Keynesian model, see Kramarz (2001) for a survey. According to this model, inflation facilitates labor-market adjustment by speeding the downward nominal wage changes, so that there is a Phillips-curve trade-off between inflation and unemployment. As a consequence, the asymmetry in the wage-change distribution should become more (less) pronounced when inflation declines (increases). This is precisely the implication that is tested in the empirical studies, see, e.g., Card and Hyslop (1997), Groshen and Schweitzer (1997), Fehr and Goette (1999), Smith (2000).

A potential shortcoming of the above literature is that it relies mainly on statistical models postulated from general considerations rather then on structural models derived from micro foundations.[1] In particular, the postulated inverse relation between the extent of DNWR and inflation is subject to Lucas (1972) type of critique. That is, if agents have rational expectations, they will forecast inflation and will take it into account when signing the wage contracts. For instance, if an economy experiences systematic inflation of 10%, the next period contractual wage will be adjusted by 10% upward, so that the extent of DNWR will be exactly the same as in the economy with zero inflation. This implies that expected inflation should not have any effect on the extent of wage rigidities but only unexpected one. Thus,

[1] The theoretical literature on asymmetric (downward) wage rigidities is relatively scarce (see Elsby, 2004). The papers that develop dynamic general-equilibrium models of wage rigidity focus exclusively on the symmetric case, i.e., when wages are equally rigid upward and downward (see, e.g., Benassy, 1995, Cooley and Hansen, 1995, Shimer, 2003).

rather than looking at degrees of DNWR in low and high inflation periods, it would be more reasonable to look at how degrees of DNWR vary with unexpected changes in inflation. However, even unexpected inflation may be not the right explanatory variable for DNWR. What is an appropriate set of explanatory variables should be determined by a structural model. For example, in a general-equilibrium context, the explanatory variables will be the state variables, whereas inflation will be determined endogenously.

In this paper, we derive a structural model of DNWR on the basis of a new-Keynesian dynamic general equilibrium setup with heterogeneous agents. We assume two sources of heterogeneity: initial endowments of wealth and idiosyncratic labor-productivity shocks. Apart from idiosyncratic shocks, there are also shocks to the aggregate level of technology and to money supply. Markets are complete, so that agents can insure themselves against all kinds of uncertainty. The production side of our economy consists of a representative firm that produces output from two production inputs, capital and labor. Wage contracts are signed one period ahead and specify the minimum wage that the firm should pay to each worker conditional on her future expected marginal product. To ensure that the firm does not make systematic losses due to DNWR, we assume that contractual wages of all workers are rescaled down such that the expected profit is zero, which is consistent with a competitive environment. Our analysis relies essentially on two assumptions: first, the original growing economy follows a balanced growth path and, second, the associated stationary economy has a unique recursive Markov equilibrium with the aggregate state space which includes the aggregate level of wealth but not the wealth distribution.

We show analytically that a fraction of the population affected by DNWR in our model is fully determined by unexpected shocks to money supply and technology. There is a simple intuition behind this result. In a competitive environment, the firm sets wages to ensure expected zero profit. If a money-supply shock and a technology shock happen to be equal to their expectations, an exactly half of agents will experience DNWR. (This is because idiosyncratic innovations are assumed to be Normally distributed, so that a half of agents will have marginal products which are lower than the expected ones). However, if technology or money supply grows more than expected, the market clearing wages increase relative to the contractual ones, so that the extent of DNWR reduces.

We test the implications of the model with U.S. data. First, we construct several unexpected technology innovations and money-supply innovations from Solow residuals and money supply. Second, we construct two aggregate measures of DNWR such as the skewness coefficient and the mean-median difference of the wage-change distribution by using the Panel Study of Income Dynamics (PSID) data. Finally, we regress the aggregate measures of DNWR on unexpected changes in technology and money supply. We find that the results of the regression depend significantly on the measure of money supply used. The model has virtually no explanatory power under money supply given by M1, it can explain about 30% of variation in the aggregate measures of DNWR under M2 and it can account for about 60% of the variation in the aggregate measures of DNWR under M3. In the last case, we have a very good fit of the model, which is surprising given the finding of the previous literature that macro evidence of DNWR is fragile (see, e.g., Elsby, 2004, for a discussion).

An important question to be answered is how one can explain an inverse relation between degrees of DNWR and inflation documented by the empirical literature (Card and Hyslop, 1997, Groshen and Schweitzer, 1997, etc.) in the context of our model To answer this question, we extend our baseline regression equation to include ad hoc an additional explanatory variable, inflation rate. We find that, in the absence of unexpected shocks to technology and money supply, the inflation rate is statistically significant for explaining the DNWR , however, once such shocks are introduced, the inflation rate becomes statistically insignificant. Our results indicate that an inverse empirical relation between degrees of DNWR and inflation, documented by the previous literature, arises because the relevant explanatory variables, such as the unexpected shocks to technology and money supply, were omitted.

The rest of the paper is organized as follows: Section 2 formulates the theoretical model and derives the structural equation to be estimated. Section 3 describes the empirical results. Finally, Section 5 concludes.

2 The theoretical framework

Time is discrete and the horizon is infinite, $t \in T$, where $T = \{0, 1, 2, ...\}$. The economy consists of the government, a continuum of infinitely-lived heterogeneous consumers and a representative firm. The consumers' names are in the set I, which is normalized to one by $\int_I di = 1$, so that average and aggregate quantities coincide. We denote variables of agent i by superscript "i", and we use variables without superscript to denote aggregate quantities.

There are three types of shocks in the economy, the aggregate money-supply shock, m_t, the aggregate labor-productivity shock, z_t, and the idiosyncratic labor-productivity shock, b_t^i. We model the aggregate shocks in the way which is standard for the real business cycle literature, namely, by postulating two properties, deterministic growth and stochastic cycles. To be specific, we assume that the money-supply shock m_t follows

$$\begin{aligned} \log(m_t) &= \log(m_{-1}) + t\log(\gamma^m) + \log(\mu_t), \\ \log(\mu_t) &= \rho^\mu \log\left(\mu_{t-1}\right) + \varepsilon_t^\mu, \end{aligned} \tag{1}$$

where $\gamma^m > 1$ is the rate of money growth; $0 < \rho^\mu < 1$ is the persistence parameter; and $\varepsilon_t^\mu \sim N\left(0, (\sigma^\mu)^2\right)$ is a Normally distributed error term. Similarly, we assume that the aggregate labor-productivity shock z_t follows

$$\begin{aligned} \log(z_t) &= \log(z_{-1}) + t\log(\gamma^z) + \log(\theta_t), \\ \log(\theta_t) &= \rho^\theta \log(\theta_{t-1}) + \varepsilon_t^\theta, \end{aligned} \tag{2}$$

where $\gamma^z > 1$ is the rate of aggregate labor productivity growth; $0 < \rho^\theta < 1$ is the persistence parameter; and $\varepsilon_t^\theta \sim N\left(0, \left(\sigma^\theta\right)^2\right)$ is a Normally distributed error term. Concerning the idiosyncratic shocks, we assume that labor productivity of each agent follows an identical process

$$\log\left(b_t^i\right) = \rho^b \log\left(b_{t-1}^i\right) + \epsilon_t^i \tag{3}$$

where $0 < \rho^b < 1$ is the persistence parameter and $\epsilon_t^i \sim N\left(0, \left(\sigma^b\right)^2\right)$ is a Normally distributed error term. Initial conditions, m_{-1}, μ_{-1}, z_{-1}, θ_{-1} and $\left\{b_{-1}^i\right\}^{i\in I}$, are given.

A representative firm owns a technology for producing a single output commodity from two production inputs, capital, k_{t-1}, and labor, h_t. The technology is described by a production function $f : R_+^2 \to R_+$, which has constant returns to scale, is strictly increasing in both arguments, continuously differentiable, strictly concave, and satisfies the appropriate Inada conditions. The output level depends also on the current aggregate labor productivity z_t, according to $f\left(k_{t-1}, z_t h_t\right)$. Under the assumption (2), z_t can be interpreted as a stochastic labor-augmenting technological progress.

Wage contracts between the firm and workers are signed in period $t-1$. The firm commits to pay each agent nominal wage, which is at least as high as her expected t-period nominal wage. Thus, nominal wages are rigid downwards. To avoid systematic losses from wage rigidities, the firm rescales down the nominal wages of all agents by a factor of $\xi_{t-1} \geq 1$.[2] In a competitive environment, the profit of the firm, expected in period $t-1$, should be equal to zero, $E_{t-1}\left[\left(\pi_t\left(\xi_{t-1}\right)\right)\right] = 0$, which identifies the value of ξ_{t-1}.[3] Therefore, the problem of the firm is

$$\pi_t\left(\xi_{t-1}\right) = \max_{k_{t-1},\,\left\{n_t^i\right\}^{i\in I}} \left\{p_t f\left(k_{t-1}, z_t h_t\right) - r_t k_{t-1} - \xi_{t-1}\int_I n_t^i w_t^i di\right\} \tag{4}$$

subject to

$$\log\left(w_t^i\right) \geq E_{t-1}\left[\log\left(w_t^i\right)\right], \tag{5}$$

$$E_{t-1}\left[\left(\pi_t\left(\xi_{t-1}\right)\right)\right] = 0, \tag{6}$$

where p_t, r_t and w_t^i are the t-period nominal price of output, nominal interest rate and nominal wage of agent i, respectively; and $k_{t-1} = \int_I k_{t-1}^i di$ and $h_t = \int_I n_t^i b_t^i di$ with k_{t-1}^i and n_t^i being capital and labor of agent i.

Consumers are heterogeneous in two dimensions, namely, initial endowments of wealth and labor productivity. The consumers save in the form of capital and money, and they supply their labor to production. Our subsequent analysis is not directly linked to any specific model of the consumer's behavior, for example, we can consider a variant of Sidrovski's model where money enters the utility function (see, e.g., Benassy, 1995), or we can consider a variant of the cash-in-advance model where money are needed for purchasing consumption goods (see, e.g., Lucas and Stockey, 1983, 1987). Therefore, we do not elaborate a description of the consumer's side here but rather state the assumptions that should be satisfied for our economy.

A1. *In equilibrium, the economy follows a balanced growth path, where real variables grow at the rate γ^z, nominal variables grow at the rate γ^m, and labor grows at a zero rate.*

[2] In the absence of DNWR, wages of all agents are equal to their marginal products of labor, so that the equilibrium profit is equal to zero under $\xi_{t-1} = 1$. However, with DNWR, the value of $\xi_{t-1} = 1$ leads to negative profits: agents who are not affected by wage rigidities are paid their marginal products of labor while those who are affected by wage rigidities are paid more than their marginal products.

[3] While the expected profit is equal to zero by construction, the effective profit can be either positive or negative or zero depending on the realization of aggregate shocks in period t. If the effective profit is non-zero, it is distributed among the firm's shareholders in the form of dividends.

A2. *The associated stationary economy has a unique recursive Markov equilibrium with the aggregate t-period state space* $\left(\mu_t, \theta_t, \mathbf{x}_{t-1}, \left\{b^i_{t-1}, b^i_t\right\}^{i\in I}\right)$, *where* $\mathbf{x}_{t-1}$ *is a vector of t-period aggregate state variables whose values are known in period* $t-1$.

To ensure that real variables grow at the same rate and labor exposes no long-run growth, as implied by **A1**, we are to impose sufficient restrictions on preferences and technology, see King, Plosser and Rebelo (1988). A balanced growth of nominal variables can be achieved under general assumptions (see, e.g., Cooley and Hansen, 1995). The assumption that t-period state space does not include the wealth distribution, as postulated in **A2**, requires to assume that markets are complete, i.e., that consumers can fully insure themselves against uncertainty by trading state contingent claims (Arrow securities). With this assumption, we can formulate the associated planner's problem and characterize the aggregate equilibrium allocation without keeping track of the wealth distribution. The set $\mathbf{x}_{t-1}$ includes k_{t-1} and m_{t-1} (which are adjusted to growth, see Appendix) and possibly, such past variables as μ_{t-1} and θ_{t-1}, because they determine the $t-1$-period expectations of wages.[4] In Appendix, we describe an example of the heterogeneous-agent economy which satisfies our assumptions **A1** and **A2**.

The problem (4) $-$ (6) implies that if agent i is not affected by wage rigidities, her nominal wage is

$$w^i_t = \frac{p_t z_t}{\xi_{t-1}} \frac{\partial f\left(k_{t-1}, z_t h_t\right)}{\partial\left(z_t h_t\right)} b^i_t. \tag{7}$$

The corresponding nominal wage in the stationary version of the model is

$$\frac{w^i_t}{\left(\gamma^m\right)^t\left(\gamma^z\right)^t} \equiv W\left(\mu_t, \theta_t, \mathbf{x}_{t-1}, \left\{b^i_{t-1}, b^i_t\right\}^{i\in I}\right) b^i_t. \tag{8}$$

Under the assumption of stationarity, we can log-linearize the wage function $W\left(\mu_t, \theta_t, \mathbf{x}_{t-1}, \left\{b^i_{t-1}, b^i_t\right\}^{i\in I}\right)$ around a steady state level. Specifically, w^i_t can

[4]The presence of the past variables like μ_{t-1} and θ_{t-1} in the state space of period t is standard for models with nominal rigidities, see Cooley and Hansen (1995) for another example of such a model.

be approximated by

$$\log\left(w_t^i\right) \simeq \left[\log\left(\gamma^z\right)+\log\left(\gamma^m\right)\right]t+\log W|_{ss}+\left.\frac{\partial \log W}{\partial \log \mu_t}\right|_{ss}\widehat{\mu}_t+\left.\frac{\partial \log W}{\partial \log \theta_t}\right|_{ss}\widehat{\theta}_t$$
$$+\left.\frac{\partial \log W}{\partial \log \mathbf{x}_{t-1}}\right|_{ss}\widehat{\mathbf{x}}_{t-1}+\int_I \left.\frac{\partial \log W}{\partial \log b_{t-1}^i}\right|_{ss}\widehat{b}_{t-1}^i di+\int_I \left.\frac{\partial \log W}{\partial \log b_t^i}\right|_{ss}\widehat{b}_t^i di+\widehat{b}_t^i, \qquad (9)$$

where $\log W|_{ss}$ is a logarithm of the function W, evaluated in the steady state; $\left.\frac{\partial \log W}{\partial \log x_t}\right|_{ss}$ is the first-order partial derivative of $\log W$ with respect to the variable $\log x_t$ evaluated in the steady state; and $\widehat{x}_t \equiv \frac{x_t - x}{x}$ is the percentage deviation of the corresponding variable from the steady state.

Let us next compute the difference between the individual wage (9) and its expected value at $t-1$, i.e., $\Delta w_t^i \equiv \log\left(w_t^i\right) - E_{t-1}\left[\log\left(w_t^i\right)\right]$,

$$\Delta w_t^i = \left.\frac{\partial \log W}{\partial \log \mu_t}\right|_{ss}\left(\widehat{\mu}_t - E_{t-1}\left(\widehat{\mu}_t\right)\right)+\left.\frac{\partial \log W}{\partial \log \theta_t}\right|_{ss}\left(\widehat{\theta}_t - E_{t-1}\left(\widehat{\theta}_t\right)\right)$$
$$+\int_I \left.\frac{\partial \log W}{\partial \log b_t^i}\right|_{ss}\left(\widehat{b}_t^i - E_{t-1}\left(\widehat{b}_t^i\right)\right)di+\widehat{b}_t^i - E_{t-1}\left(\widehat{b}_t^i\right). \qquad (10)$$

If Δw_t^i is negative, an agent experiences DNWR because for such an agent we have $\log\left(w_t^i\right) < E_{t-1}\left[\log\left(w_t^i\right)\right]$. A log-linear approximation of a first-order autoregressive process of the form $\log\left(x_t\right) = \rho^x \log\left(x_{t-1}\right) + \varepsilon_t^x$ yields $\widehat{x}_t = \rho^x \widehat{x}_{t-1} + \varepsilon_t^x$ and $E_{t-1}\left(\widehat{x}_t\right) = \rho^x \widehat{x}_{t-1}$. Furthermore, with a continuum of agents, the law of large numbers together with the fact that $\left.\frac{\partial \log W}{\partial \log b_t^i}\right|_{ss}$ and ϵ_t^i are uncorrelated implies $\int_I \left.\frac{\partial \log W}{\partial \log b_t^i}\right|_{ss}\epsilon_t^i di = 0$. Hence, under the assumptions (1), (2) and (3), we can re-write (10) as follows:

$$\Delta w_t^i = \left.\frac{\partial \log W}{\partial \log \mu_t}\right|_{ss}\varepsilon_t^\mu+\left.\frac{\partial \log W}{\partial \log \theta_t}\right|_{ss}\varepsilon_t^\theta+\epsilon_t^i. \qquad (11)$$

We now define a simple aggregate measure of DNWR, which is a fraction of the total population affected by DNWR,

$$\phi_t = \phi\left(\varepsilon_t^{\theta}, \varepsilon_t^{\mu}\right) \equiv \int_I \Gamma\left(\Delta w_t^i\right) di =$$
$$\frac{1}{\sigma^b\sqrt{2\pi}} \int_{-\infty}^{-\left[\left.\frac{\partial \log W}{\partial \log \mu_t}\right|_{ss}\varepsilon_t^{\mu} + \left.\frac{\partial \log W}{\partial \log \theta_t}\right|_{ss}\varepsilon_t^{\theta}\right]} \exp\left(-\frac{\left(\epsilon_t^i\right)^2}{\sigma_b^2}\right) d\epsilon_t^i =$$
$$F\left(-\left[\left.\frac{\partial \log W}{\partial \log \mu_t}\right|_{ss}\varepsilon_t^{\mu} + \left.\frac{\partial \log W}{\partial \log \theta_t}\right|_{ss}\varepsilon_t^{\theta}\right]\right), \quad (12)$$

where $\Gamma\left(\Delta w_t^i\right) = \begin{cases} 1 & if\ \Delta w_t^i < 0 \\ 0 & if\ \Delta w_t^i \geq 0 \end{cases}$ is an indicator function; and F is the cumulative density function of a Normally distributed variable with a zero mean and a unit variance.

Let us consider a linear approximation of the constructed measure of wage rigidities $\phi\left(\varepsilon_t^{\mu}, \varepsilon_t^{\theta}\right)$ near the steady state,

$$\phi\left(\varepsilon_t^{\mu}, \varepsilon_t^{\theta}\right) \simeq \frac{1}{2} - \left.\frac{\partial \log W}{\partial \log \mu_t}\right|_{ss}\varepsilon_t^{\mu} - \left.\frac{\partial \log W}{\partial \log \theta_t}\right|_{ss}\varepsilon_t^{\theta}, \quad (13)$$

where we use the fact that $F(0) = \frac{1}{2}$ and $F'(0) = 1$. Assuming that the average nominal wage rises with positive shocks to money supply and technology, i.e., $\left.\frac{\partial \log W}{\partial \log \mu_t}\right|_{ss} > 0$ and $\left.\frac{\partial \log W}{\partial \log \theta_t}\right|_{ss} > 0$, from (13), we have:

$$\frac{\partial \phi}{\partial \varepsilon_t^{\mu}} = -\left.\frac{\partial \log W}{\partial \log \mu_t}\right|_{ss} < 0, \qquad \frac{\partial \phi}{\partial \varepsilon_t^{\theta}} = -\left.\frac{\partial \log W}{\partial \log \theta_t}\right|_{ss} < 0. \quad (14)$$

Thus, we conclude that $\phi\left(\varepsilon_t^{\mu}, \varepsilon_t^{\theta}\right)$ decreases monotonically with positive innovations to money supply and technology.

There is a simple economic intuition behind the results (13) and (14). Formula (13) implies that in the absence of aggregate innovations (i.e., $\varepsilon_t^{\mu} = 0$ and $\varepsilon_t^{\theta} = 0$), exactly a half of population is affected by DNWR. We have one half because the error term, ϵ_t^i, in the process of idiosyncratic shocks (3) is drawn from a Normal distribution with a zero mean: after the realization of shock in t, a half of agents has labor productivity which is higher (lower) than was expected in $t-1$, when the wage contracts were set. If there is a positive technological innovation, $\varepsilon_t^{\theta} > 0$, then the t-period distribution of labor productivity shifts to the right, as compared to one expected in $t-1$, so that the fraction of population affected by DNWR goes down. In a similar way, if there is a positive money-supply innovation (unexpected inflation), $\varepsilon_t^\theta > 0$, then the t-period distribution of market-clearing nominal wages shifts to the right, as compared to one expected in $t-1$, so that again, the fraction of population affected by DNWR reduces. Clearly, the largest reduction in the fraction of population affected by DNWR should be observed if positive innovations to money-supply and technology happen simultaneously.

3 Empirical analysis

In this section, we use the data on the U.S. economy to test the model's predictions concerning the time-series behavior of aggregate measures of DNWR. According to our model, the degree of such wage rigidity should increase whenever the economy faces negative innovations to money supply or technology. We therefore attempt to establish whether this prediction is in agreement with the data and which of the above two innovations is more important for explaining fluctuations in aggregate measures of DNWR.

Our empirical analysis is based on result (13) which implies a simple regression equation for the constructed aggregate measure of DNWR

$$\phi_t = \beta_0 + \beta_1 \varepsilon_t^\mu + \beta_2 \varepsilon_t^\theta + \epsilon_t, \tag{15}$$

where β_0, β_1, β_2 are the regression coefficients and $\epsilon_t \sim N\left(0, \sigma_\epsilon^2\right)$ is an error term.

Information on whether each given agent is affected by wage rigidity is not provided in household data, so that we cannot compute the aggregate measure (12), which is a fraction of population affected by DNWR. We consider two alternative aggregate measures, which are standardly used in the literature, namely, the skewness coefficient and the difference between the mean and median of the wage-change distribution. Concerning the first measure, one would expect the skewness coefficient to be zero, if the distribution of wage changes is symmetric. For a distribution where negative wage changes happen less frequently than positive ones (i.e., skewed to the right) this coefficient should be positive. One serious problem with the skewness statistic is that it is extremely sensitive to observations in the tails of the distribution (see Lebow, Stockton, Washer, 1995, for a discussion). Our second measure, the difference between the mean and median, is less sensitive to outliers because the effect of extreme observations is limited to the mean (see, McLaughlin, 1994). The difference between mean and median constitutes the sign-test statistic: the higher is its value, the more likely is the wage-change distribution to be skewed to the right.

To construct the above aggregate measures of DNWR in the U.S. economy, we use the Panel Study of Income Dynamics (PSID) which provides the relevant information about 53,000 individuals over the 1968-1992 period. We restrict our attention to a sub-sample of agents who receive labor income only. Furthermore, we exclude from the sample agents for whom the data on labor income or hours worked were missing. As a result, the initial sample was reduced to about 5,000 individuals per year. For each agent in the obtained sample, we compute the wage as a ratio of labor income to the total hours worked. We provide the two constructed aggregate measures of DNWR in Table 1.

We next compute the series for money-supply and technology innovations, $\{\varepsilon_t^{\mu}\}_{t=1}^{T}$ and $\{\varepsilon_t^{\theta}\}_{t=1}^{T}$, respectively. To do so, we re-write the processes for money-supply shocks (1) and technology shocks (2) in a way convenient for estimation,

$$\log(m_t) = \eta_0 + \eta_1 \log(m_{t-1}) + \eta_2 t + \varepsilon_t^{\mu}, \tag{16}$$

$$\log(z_t) = v_0 + v_1 \log(z_{t-1}) + v_2 t + \varepsilon_t^{z}, \tag{17}$$

where $\eta_0 \equiv \log(m_{-1})(1-\rho^m)+\rho^m \log(\gamma^m)$; $\eta_1 \equiv \rho^m$, $\eta_2 \equiv (1-\rho^m)\log(\gamma^m)$; and $v_0 \equiv \log(z_{-1})(1-\rho^z)+\rho^z\log(\gamma^z)$, $v_1 \equiv \rho^z$, $v_2 \equiv (1-\rho^z)\log(\gamma^z)$.

To compute the series for innovations in money-supply equation (16), we consider three alternative measures of money supply, such as M1, M2 and M3. We take the data on money supply from the web-site of the Federal Reserve Bank of Saint Louis at *http://research.stlouisfed.org/fred2/*. To compute the series for technological innovations in process (17), we use four alternative measures of Solow residuals constructed in Zimmermann (1994) and provided at *http://ideas.repec.org/zimm/data/voldata.html*. The four measures are constructed from output, employment and capital (SRoec), from output, total hours and capital (SRohc), from output and employment (SRoe) and from output and total hours (SRoh). We estimate equations (16) and (17) by Ordinary Least Squares (OLS) under the heteroskedasticity-robust residuals option. The regression results are provided in Tables 2 and 3. The large R^2-coefficients show a high explanatory power of all the regressions.

We subsequently use constructed series $\{\phi_t, \varepsilon_t^{\mu}, \varepsilon_t^{\theta}\}_{t=1968}^{T=1992}$ to estimate regression equation (15). Since both heteroskedasticity and serial correlation

Table 1. Mean-median difference of log wage changes in PSID dataset

Period	Skewness	Mean-median difference
1968-69	0.4461	0.0344
1969-70	0.7267	0.0299
1970-71	0.6160	0.0722
0971-72	-0.5190	-0.0079
1972-73	0.2806	0.0230
1973-74	0.0662	0.0102
1974-75	-0.0515	0.0082
1975-76	0.1342	0.0093
1976-77	0.0713	0.0117
1977-78	-0.0276	0.0099
1978-79	0.1777	0.0150
1979-80	0.1258	0.0247
1980-81	-0.1012	-0.0042
1981-82	0.0451	0.0048
1982-83	-0.0887	-0.0021
1983-84	0.1029	0.0046
1984-85	-0.0040	0.0058
1985-86	0.0114	0.0060
1986-87	-0.0628	0.0035
1987-88	0.1048	0.0133
1988-89	0.0631	0.0104
1989-90	0.0329	0.0033
1990-91	0.0796	0.0053
1991-92	0.2927	0.0298

Table 2. Parameters of the process for monetary shocks

	$\log(M_{t-1})$	t
MS1	0.677*** (0.105)	0.023*** (0.007)
	R^2=0.9975 $R^2_{adj.}$=0.9973	
MS2	1.085*** (0.132)	-0.009 (0.011)
	R^2=0.9985 $R^2_{adj.}$=0.9983	
MS3	1.198*** (0.106)	-0.021** (0.010)
	R^2=0.9985 $R^2_{adj.}$=0.9983	

Notes: Standard errors are reported in parentheses. ***, **, * indicate significance at the 1-, 5-, and 10-percent levels, respectively. Number of observations is 24.

Table 3. Parameters of the process for technology shocks

	$\log(Z_{t-1})$	t
SRoec	0.623*** (0.158)	0.001** (0.0004)
	R^2=0.8692 $R^2_{adj.}$=0.8567	
SRoeh	0.662*** (0.158)	0.001** (0.0003)
	R^2=0.9171 $R^2_{adj.}$=0.9092	
SRoc	0.529*** (0.181)	0.003*** (0.001)
	R^2=0.9873 $R^2_{adj.}$=0.9861	
SRoh	0.523*** (0.187)	0.004*** (0.001)
	R^2=0. 0.9937 $R^2_{adj.}$=0.9931	

Notes: Standard errors are reported in parentheses. ***, **, * indicate significance at the 1-, 5-, and 10-percent levels, respectively. Number of observations is 24. SRoec is Solow residuals from output, employment and capital; SRoeh is Solow residuals from output, total hours and capital; SRoc is Solow residuals from output and employment; SRoh is Solow residuals from output and total hours.

were present in the OLS regressions, we also provide standard errors computed by Feasible Generalized Least Squares (FGLS). By construction, FGLS delivers the same coefficients as OLS does, however, it yields lower standard errors. The results for the skewness coefficient and the mean-median difference of the wage-change distribution are provided in Table 4 and Table 5, respectively. In each table, column 1 specifies the estimation method (OLS, FGLS); column 2 states the measure of money supply (M1, M2, M3); and columns 3-10 provide the estimated coefficients β_1 and β_2 as well as R^2 and adjusted R^2 (denoted by R^2_{adj}) under four alternative measures of Solow residuals (SRoec, SRohc, SRoe, SRoh). For each measure of Solow residuals considered, we run three alternative regressions, one with technology shocks only (i.e., under the restriction $\beta_1 = 0$), another with money-supply shocks only (i.e., under the restriction $\beta_2 = 0$) and the other with both technology and money-supply shocks (i.e., under no restrictions).

We now discuss the estimation results obtained with the skewness coefficient as a dependent variable. As follows from Table 4, all the estimated coefficients are negative, which is consistent with the model's prediction that negative money-supply and technology innovations increase the aggregate amount of DNWR. As we see from the upper row of the table, technology innovations alone cannot explain variation in the aggregate measure of wage rigidities considered: under restriction $\beta_1 = 0$, the coefficient β_2 is statistically insignificant, R^2 is extremely low, and R^2_{adj} is negative.

When money-supply shocks are introduced (i.e., $\beta_1 \neq 0$), the results depend crucially on the measure of money-supply used. To be specific, the explanatory power of M1 innovations is again very low: under the restriction $\beta_2 = 0$, the coefficient β_1 is statistically insignificant, R^2 is low, and R^2_{adj} is negative. Furthermore, allowing for both technology and M1 innovations does not almost increase the explanatory power of the regression.

Considering M2, as a measure of money supply, improves the results considerably: the coefficient on M1 is significant at a 1% level, and innovations to M2 can account for about $R^2 \approx 30\%$ of variation in our aggregate measure of wage rigidities. Adding technology innovations to the regression does not improve the results compared to M2 innovations alone: the adjusted R^2_{adj} actually decreases, and the coefficient on technology innovations is not significant.

M3 is the measure of money supply that proved to have the highest explanatory power: the innovations to M3 account for $R^2 \approx 53\%$ of variation in our aggregate measure of wage rigidities. Surprisingly, technology inno-

Table 4. Regression results: the skewness coefficient is a dependent variable

1	2	3	4	5	6	7	8	9	10
		SRoec		SRohc		SRoe		SRoh	
		β_1	β_2	β_1	β_2	β_1	β_2	β_1	β_2
OLS	M1	-	-3.727 (7.592)	-	-4.860 (7.004)	-	-4.667 (8.598)	-	- 12.400 (12.669)
OLS	M1	R^2=0.0108 $R^2_{adj.}$=-0.0341		R^2= 0.0214 $R^2_{adj.}$= -0.0231		R^2=0.0132 $R^2_{adj.}$=-0.0316		R^2=0.0417 $R^2_{adj.}$= -0.0018	
OLS	M1	-0.474 (2.139)	-	-0.474 (2.139)	-	-0.474 (2.139)	-	-0.474 (2.139)	-
OLS	M1	R^2= 0.0022 $R^2_{adj.}$=-0.0431		R^2= 0.0022 $R^2_{adj.}$=-0.0431		R^2= 0.0022 $R^2_{adj.}$=-0.0431		R^2= 0.0022 $R^2_{adj.}$=-0.0431	
OLS	M1	-0.196 (2.271)	-3.530 (8.095)	-0.002 (2.292)	-4.863 (7.578)	-0.177 (2.259)	-4.475 (9.133)	0.492 (2.371)	-13.671 (14.328)
OLS	M1	R^2=0.0112 $R^2_{adj.}$=-0.0830		R^2= 0.0214 $R^2_{adj.}$=-0.0718		R^2= 0.0135 $R^2_{adj.}$=-0.0804		R^2= 0.0437 $R^2_{adj.}$=-0.0474	
FGLS	M1	-0.196 (2.124)	-3.530 (7.572)	-0.002 (2.144)	-4.863 (7.089)	-0.177 (2.092)	-4.475 (8.223)	0.492 (2.218)	-13.671 (13.403)
OLS	M2	-5.701*** (1.890)	-	-5.701*** (1.890)	-	-5.701*** (1.890)	-	-5.701*** (1.890)	-
OLS	M2	R^2= 0.2925 $R^2_{adj.}$=0.2603		R^2= 0.2925 $R^2_{adj.}$=0.2603		R^2= 0.2925 $R^2_{adj.}$=0.2603		R^2= 0.2925 $R^2_{adj.}$=0.2603	
OLS	M2	-5.747*** (1.915)	-4.421 (6.505)	-5.660*** (1.912)	-4.335 (6.025)	-5.665*** (1.923)	-3.905 (7.408)	-5.507*** (1.931)	-7.946 (11.119)
OLS	M2	R^2= 0.3077 $R^2_{adj.}$=0.2417		R^2=0.3095 $R^2_{adj.}$=0.2437		R^2=0.3017 $R^2_{adj.}$=0.2352		R^2= 0.3093 $R^2_{adj.}$=0.2435	
FGLS	M2	-5.747*** (1.791)	-4.421 (6.085)	-5.654*** (1.788)	-4.335 (5.636)	-5.665*** (1.799)	-3.905 (6.929)	-5.507*** (1.810)	-7.946 (10.321)
OLS	M3	-6.913*** (1.387)	-	-6.913*** (1.387)	-	-6.913*** (1.387)	-	-6.913*** (1.387)	-
OLS	M3	R^2=0.5303 $R^2_{adj.}$=0.5089		R^2=0. 5303 $R^2_{adj.}$=0.5089		R^2=0.5303 $R^2_{adj.}$=0.5089		R^2=0.5303 $R^2_{adj.}$=0.5089	
OLS	M3	-7.348*** (1.350)	-8.862* (5.094)	-7.376*** (1.318)	-9.335** (4.613)	-7.141*** (1.366)	-8.2646` (5.842)	-7.038*** (1.328)	-14.826* (8.496)
OLS	M3	R^2= 0.5895 $R^2_{adj.}$=0.5504		R^2= 0.5650 $R^2_{adj.}$= 0.5695		R^2=0.5712 $R^2_{adj.}$=0.5303		R^2=0.5898 $R^2_{adj.}$=0.5507	
FGLS	M3	-7.348*** (1.263)	-8.862** (4.765)	-7.376*** (1.233)	-9.335** (4.315)	-7.141*** (1.277)	-8.264* (5.165)	-7.038*** (1.243)	-14.826** (7.947)

Notes: Standard errors are reported in parentheses. ***, **, * and ` indicate significance at the 1-, 5-, 10-and 15-percent levels, respectively. Number of observations is 24. The years considered are from 1969 to 1992.

Table 5. Regression results: the mean-median difference is a dependent variable

1	2	3	4	5	6	7	8	9	10
		SRoec		SRohc		SRoe		SRoh	
		β_1	β_2	β_1	β_2	β_1	β_2	B_1	β_2
OLS	M1	-	-0.188 (0.507)	-	-0.249 (0.469)	-	-.277 (0.571)	-	0.284 (0.860)
		R^2=0.0000 $R^2_{adj.}$=-0.0454		R^2= 0.0127 $R^2_{adj.}$= -0.0322		R^2= 0.0106 $R^2_{adj.}$=-0.0343		R^2=0.0049 $R^2_{adj.}$= -0.0403	
		-0.036 (0.142)	-	-0.036 (0.142)	-	-0.036 (0.142)	-	-0.036 (0.142)	-
		R^2= 0.0030 $R^2_{adj.}$=-0.0423		R^2= 0.0030 $R^2_{adj.}$=-0.0423		R^2= 0.0030 $R^2_{adj.}$=-0.0423		R^2= 0.0030 $R^2_{adj.}$=-0.0423	
		-0.045 (0.147)	-0.213 (0.524)	-0.056 (0.148)	-0.292 (0.491)	-0.050 (0.147)	-0.313 (0.592)	-0.067 (0.145)	0.895 (0.887)
		R^2=0.0108 $R^2_{adj.}$=-0.0834		R^2= 0.0195 $R^2_{adj.}$=-0.0738		R^2= 0.0161 $R^2_{adj.}$=-0.0776		R^2= 0.0490 $R^2_{adj.}$=-0.0415	
FGLS		-0.045 (0.137)	-0.213 (0.490)	-0.056 (0.139)	-0.266 (0.459)	-0.050 (0.137)	-0.313 (0.554)	-0.067 (0.136)	0.895 (0.830)
OLS	M2	-0.368*** (0.109)	-	-0.368*** (0.109)	-	-0.368*** (0.109)	-	-0.368*** (0.109)	-
		R^2= 0.3200 $R^2_{adj.}$= 0.2891		R^2= 0.3200 $R^2_{adj.}$= 0.2891		R^2= 0.3200 $R^2_{adj.}$= 0.2891		R^2= 0.3200 $R^2_{adj.}$= 0.2891	
		-0.368*** (0.111)	-0.169 (0.421)	-0.365*** (0.112)	-0.163 (0.392)	-0.372*** (0.110)	-0.354 (0.472)	-0.370*** (0.108)	-0.842 (0.699)
		R^2= 0.3441 $R^2_{adj.}$=0.2816		R^2= 0.3445 $R^2_{adj.}$= 0.2821		R^2=0.3528 $R^2_{adj.}$=0.2911		R^2=0.3817 $R^2_{adj.}$=0.3228	
FGLS		-0.368*** (0.104)	-0.169 (0.394)	-0.365*** (0.103)	-0.163 (0.442)	-0.372*** (0.103)	-0.354 (0.442)	-0.370*** (0.101)	-0.842 (0.654)
OLS	M3	-0.397*** (0.123)	-	-0.397*** (0.123)	-	-0.397*** (0.123)	-	-0.397*** (0.123)	-
		R^2=0.3391 $R^2_{adj.}$=0.3090		R^2=0.3391 $R^2_{adj.}$=0.3090		R^2=0.3391 $R^2_{adj.}$=0.3090		R^2=0.3391 $R^2_{adj.}$=0.3090	
		-0.449*** (0.125)	-0.623\` (0.426)	-0.429*** (0.123)	-0.514 (0.390)	-0.456*** (0.127)	-0.781* (0.476)	-0.431*** (0.119)	-1.210* (0.694)
		R^2= 0.3827 $R^2_{adj.}$= 0.3239		R^2=0.3720 $R^2_{adj.}$= 0.3122		R^2=0.3971 $R^2_{adj.}$=0.3397		R^2= 0.4059 $R^2_{adj.}$=0.3493	
FGLS		-0.449*** (0.117)	-0.623* (0.329)	-0.429*** (0.115)	-0.514\` (0.365)	-0.456*** (0.116)	-0.781* (0.446)	-0.397*** (0.112)	-1.210** (0.650)

Notes: Standard errors are reported in parentheses. ***, **, * and \` indicate significance at the 1-, 5-, 10-and 15-percent levels, respectively. Number of observations is 24. The years considered are from 1969 to 1992.

vations become also important if introduced together with M3 innovations: under three measures of Solow residuals out of four considered, the coefficient on technology innovations is significant at a 5% level, and R^2 increases to 59% (R^2_{adj} increases from 51% up to 57%).

As is seen from Table 5, the estimation results with the mean-median difference as a dependent variable, are similar to those with the skewness coefficient, although the fit of the model is generally lower. Again, the model with both M3 and technology innovations has the highest explanatory power: it yields $R^2 \approx 37\% - 41\%$ ($R^2_{adj} \approx 31\% - 35\%$). The coefficient on M3 innovations is significant at a 1% level, while that on technology innovations is significant at $5 - 15\%$, depending on the measure of Solow residuals considered.

There is an important issue related to our discussion. Recall that empirical literature (Card and Hyslop, 1997, Groshen and Schweitzer, 1997, etc.) provides evidence of an inverse relation between degrees of DNWR and inflation, while our model predicts that the only determinants of the degrees of DNWR are unexpected shocks to technology and money supply. To investigate this issue, we extend our baseline regression equation (15) to include ad hoc an additional explanatory variable, inflation rate. To compute the inflation rate, we use the Consumer's Price Index for all urban consumers, which we download from the web-site of the Federal Reserve Bank of Saint Louis. The regression results for the skewness coefficient and the mean-median difference are provided in Tables 6 and 7, respectively. In the tables, β_3 denotes the coefficient on the inflation rate. We first consider regressions of our two aggregate measures of DNWR on a constant and the inflation rate. Similar to the previous literature, we observe some evidence of an inverse relation between degrees of DNWR and inflation: when the DNWR is measured by the skewness coefficient, the inflation rate coefficient, β_3, is significant at a 15% level, and when the DNWR is measured by the mean-median difference, β_3 is significant at a 10% level (see the upper rows of Tables 6 and 7, respectively). We subsequently re-run the regressions reported in Tables 4 and 5 by adding the explanatory variable, inflation rate. We find that in the presence of unexpected shocks to technology and money supply, the inflation rate coefficient is highly insignificant. The above results suggest that an inverse relation between degrees of DNWR and inflation, found by the empirical literature, could be a consequence of omitting relevant explanatory variables, namely, the unexpected shocks to technology and money supply.

Table 6. Regression results with inflation rate: the skewness coefficient is a dependent variable.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Sroec			SRohc			Sroe			Sroh		
		β_1	β_2	β_3	B_1	β_2	β_3	β_1	B_2	β_3	β_1	β_2	β_3
OLS	M1	-	-	0.0028` (0.0017)	-	-	0.0028` (0.0017)	-	-	0.0028` (0.0017)	-	-	0.0028` (0.0017)
OLS	M1	R^2 = 0.1065 $R^2_{adj.}$ = 0.0659			R^2 = 0.1065 $R^2_{adj.}$ = 0.0659			R^2 = 0.1065 $R^2_{adj.}$ = 0.0659			R^2 = 0.1065 $R^2_{adj.}$ = 0.0659		
OLS	M1	-.614 (2.285)	-2.966 (7.804)	0.002 (0.017)	-0.738 (2.243)	-5.819 (7.071)	0.002 (0.017)	-0.625 (2.307)	-3.005 (9.069)	0.001 (0.017)	-0.428 (2.259)	-1.768 (13.656)	0.002 (0.018)
OLS	M1	R^2 = 0.1107 $R^2_{adj.}$ = 0.0253			R^2 = 0.1089 $R^2_{adj.}$ = 0.0249			R^2 = 0.1083 $R^2_{adj.}$ = 0.0251			R^2 = 0.1145 $R^2_{adj.}$ = 0.0264		
FGLS	M1	-0.614 (2.086)	-2.966 (7.124)	0.002 (0.016)	-0.738 (2.047)	-5.819 (6.455)	0.002 (0.015)	-0.625 (2.106)	-3.005 (8.279)	0.001 (0.016)	-0.428 (2.062)	-1.768 (12.466)	0.002 (0.016)
OLS	M2	-6.221*** (1.981)	-7.255 (6.459)	0.001 (0.014)	-5.661*** (0.113)	-4.977 (5.880)	0.001 (0.014)	-5.969*** (1.981)	-6.069 (7.434)	0.002 (0.014)	-5.703*** (1.989)	-1.564 (1.482)	0.001 (0.015)
OLS	M2	R^2 = 0.3345 $R^2_{adj.}$ =0.2347			R^2 = 0.3170 $R^2_{adj.}$ = 0.2145			R^2 = 0.3153 $R^2_{adj.}$ =0.2126			R^2 =0.2926 $R^2_{adj.}$ =0.1865		
FGLS	M2	-6.221*** (1.808)	-7.255 (5.896)	0.001 (0.013)	-5.661*** (1.783)	-4.977 (5.368)	0.001 (0.013)	-5.969*** (1.808)	-6.069 (6.786)	0.002 (0.013)	-5.703*** (1.815)	-1.564* (0.481)	0.001 (0.013)
OLS	M3	-7.752*** (1.370)	-8.040* (4.858)	0.001 (0.011)	-7.339*** (1.373)	-5.957 (4.495)	0.001 (0.015)	-7.674*** (1.385)	-8.230` (5.654)	0.001 (0.014)	-7.493*** (1.437)	-6.598 (9.022)	0.001 (0.014)
OLS	M3	R^2 = 0.6179 $R^2_{adj.}$ = 0.5606			R^2 =0.6007 $R^2_{adj.}$ = 0.5408			R^2 =0.6073 $R^2_{adj.}$ =0.5483			R^2 = 0.5769 $R^2_{adj.}$ =0.5135		
FGLS	M3	-7.752*** (1.250)	-8.040** (4.435)	0.001 (0.010)	-7.339*** (1.253)	-5.957` (4.103)	0.001 (0.010)	-7.674*** (1.264)	-8.230* (5.161)	0.001 (0.010)	-7.493*** (1.311)	-6.598 (8.236)	0.001 (0.011)

Notes: Standard errors are reported in parentheses. ***, **, * and ` indicate significance at the 1-, 5-, 10-and 15-percent levels, respectively. Number of observations is 24. The years considered are from 1969 to 1992.

Table 7. Regression results with inflation rate: the mean-median difference is a dependent variable.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Sroec			SRohc			Sroe			Sroh		
		β_1	β_2	β_3	β_1	β_2	β_3	β_1	β_2	β_3	β_1	β_2	β_3
OLS	M1	-	-	-0.00017* (0.00012)	-	-	-0.00017* (0.00012)	-	-	-0.00017* (0.00012)	-	-	-0.00017* (0.00012)
		R^2 = 0.1318 $R^2_{adj.}$ = 0.0923			R^2 = 0.1318 $R^2_{adj.}$ = 0.0923			R^2 = 0.1318 $R^2_{adj.}$ = 0.0923			R^2 = 0.1318 $R^2_{adj.}$ = 0.0923		
		-0.045 (0.150)	-0.340 (0.632)	-0.001 (0.001)	-0.058 (0.151)	-0.431 (0.581)	-0.001 (0.001)	-0.049 (0.150)	-0.427 (0.676)	-0.001 (0.001)	-0.065 (0.149)	-1.001 (0.943)	-0.001 (0.001)
		R^2 = 0.1478 $R^2_{adj.}$ = 0.0354			R^2 = 0.1602 $R^2_{adj.}$ = 0.0368			R^2 = 0.1531 $R^2_{adj.}$ = 0.0332			R^2 = 0.1866 $R^2_{adj.}$ = 0.0396		
FGLS		-0.045 (0.137)	-0.340 (0.577)	-0.001 (0.001)	-0.056 (0.138)	-0.430 (0.530)	-0.001 (0.001)	-0.049 (0.137)	-0.427 (0.617)	-0.001 (0.001)	-0.065 (0.135)	-1.001 (0.861)	-0.001 (0.001)
OLS	M2	-0.405*** (0.113)	-0.533 (0.494)	-0.0015 (0.001)	-0.396*** (0.113)	-0.463 (0.449)	-0.001 (0.001)	-0.416*** (0.112)	-0.718 (0.524)	-0.0015 (0.001)	-0.404*** (0.109)	-1.138` (0.719)	-0.001 (0.001)
		R^2 = 0.4046 $R^2_{adj.}$ =0.3153			R^2 = 0.3445 $R^2_{adj.}$ = 0.2821			R^2 =0.4139 $R^2_{adj.}$ =0.3259			R^2 =0.4116 $R^2_{adj.}$ =0.3234		
FGLS		-0.405*** (0.103)	-0.533* (0.452)	-0.0015 (0.001)	-0.396*** (0.103)	-0.463 (0.410)	-0.001 (0.001)	-0.416*** (0.102)	-0.718 (0.478)	-0.0015 (0.001)	-0.404*** (0.100)	-1.138* (0.656)	-0.001 (0.001)
OLS	M3	-0.461*** (0.127)	-0.861* (0.511)	-0.001 (0.001)	-0.433*** (0.126)	-0.680' (0.460)	-0.001 (0.001)	-0.463*** (0.126)	-0.967* (0.541)	-0.001 (0.001)	-0.429*** (0.122)	-1.304* (0.739)	-0.0004 (0.001)
		R^2 = 0.3984 $R^2_{adj.}$ = 0.3081			R^2 =0.3955 $R^2_{adj.}$ = 0.3048			R^2 =0.4180 $R^2_{adj.}$ =0.3307			R^2 = 0.4341 $R^2_{adj.}$ =0.3493		
FGLS		-0.461*** (0.116)	-0.861* (0.466)	-0.001 (0.001)	-0.433*** (0.115)	-0.680` (0.420)	-0.001 (0.001)	-0.463*** (0.115)	-0.967* (0.493)	-0.001 (0.001)	-0.429*** (0.111)	-1.304* (0.675)	-0.0004 (0.001)

Notes: Standard errors are reported in parentheses. ***, **, * and ` indicate significance at the 1-, 5-, 10-and 15-percent levels, respectively. Number of observations is 24. The years considered are from 1969 to 1992.

4 Conclusion

In this paper, we investigate the determinants of DNWR in the context of a new-Keynesian dynamic general equilibrium model with heterogeneous agents. According to our model, the time-series behavior of the aggregate measures of DNWR can be fully described by unexpected changes in money supply and in technology. We find that this implication of the model accords well with U.S. data under the M3 measure of money-supply shocks. In particular, our simple regression model with only two explanatory variables can account for about 60% of variation in the skewness coefficient of the wage-change distribution. The so-high fit of our model is surprising given that the previous literature, testing the Phillips curve implications of DNWR, does not find strong macroeconomic evidence of DNWR.

We should finally mention shortcomings and possible extensions of our analysis. First, in order to derive a structural model, we use a log-linear approximation. This would be an accurate procedure if all shocks were relatively small, like the aggregate money-supply and technology shocks. However, we also have idiosyncratic labor-productivity shocks which are potentially large, and thus, non-linearities are potentially important. Unfortunately, there is no easy way of extending our analysis to higher-order approximations. Second, our empirical analysis is limited to econometric estimation of the structural model. It would be also of interest to study the implications of a calibrated version of the model, especially, those concerning labor market. Finally, our model does not provide an economic justification for DNWR but only a psychological one, namely, the loss-aversion of both managers and workers which makes it impossible to renegotiate wages down, even though DNWR is distortionary and welfare-reducing. Thus, the next step should be to develop a testable micro-macro model, where DNWR arises endogenously, as an optimal choice of rational economic agents.

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5 Appendix

In this section, we present an example of the heterogeneous-agent economy which satisfies the assumptions **A1** and **A2** in the main text.

The government increases money supply according to

$$m_t = m_{t-1}\left(\frac{\gamma^m \mu_t}{\mu_{t-1}}\right), \tag{18}$$

where $\frac{\gamma^m \mu_t}{\mu_{t-1}}$ denotes the t-period growth rate of money supply, as implied by (1). The government distributes the newly printed money among agents proportionally to their previous-period money holdings, so that a consumer with m_{t-1}^i units of money at the end of period $t-1$ will start period t with $m_{t-1}^i \frac{\gamma^m \mu_t}{\mu_{t-1}}$ units of money.

We assume that consumers hold money because they derive utility from the real money holdings, as in, e.g., Benassy (1995). A consumer i solves the following intertemporal utility-maximization problem:

$$\max_{\left\{c_t^i, n_t^i, m_t^i, k_t^i, a_t^i(s)\right\}_{t\in T}^{s\in S}} E_0 \sum_{t=0}^{\infty} \delta^t u\left(c_t^i, 1-n_t^i, \frac{m_t^i}{p_t}\right), \tag{19}$$

subject to

$$\begin{aligned} & c_t^i + \frac{m_t^i}{p_t} + k_t^i + \int_{s\in S} q_t(s)\, a_t^i(s)\, ds \\ & = \frac{w_t^i n_t^i}{p_t} + \frac{\pi_t^i\left(\xi_{t-1}\right)}{p_t} + \left(1 - d + \frac{r_t}{p_t}\right) k_{t-1}^i + \frac{m_{t-1}^i \gamma^m \mu_t}{p_t \mu_{t-1}} + a_{t-1}^i(s_t), \end{aligned} \tag{20}$$

where c_t^i, m_t^i, $k_t^i \geq 0$, $n_t^i \in [0,1]$ and initial condition $\left\{k_{-1}^i, m_{-1}^i, a_{-1}^i(s_0), b_{-1}^i\right\}$ is given. Here, c_t^i and m_t^i are the agent's i consumption and stock of money, respectively; the total time endowment is normalized to one, so that n_t^i and $1-n_t^i$ represent the individual labor and leisure, respectively; $\pi_t^i\left(\xi_{t-1}\right)$ is nominal profit paid to the agent;[5] $\{a_t^i(s)\}_{s\in S}$ is the agent's portfolio of state contingent claims, where S denotes the set of all possible states of the world; the claim of type $s \in S$ costs $q_t(s)$ in period t and pays one unit of consumption good in period $t+1$ if the state $s \in S$ occurs and zero otherwise. The utility function u is continuously differentiable, strictly increasing in each argument and concave; $\delta \in (0,1)$ is the discount factor; $d \in (0,1]$ is the depreciation rate of capital.

Definition: A competitive equilibrium in the economy (1) − (6), (18) − (20) is defined as a stochastic processes for the prices $\{r_t, w_t^i, p_t, q_t(s)\}_{t\in T}^{s\in S, i\in I}$, for the consumers' allocation $\{c_t^i, n_t^i, m_t^i, k_t^i, a_t^i(s)\}_{t\in T}^{s\in S, i\in I}$ and for production inputs $\{k_{t-1}, n_t^i\}_{t\in T}^{i\in I}$ such that given the prices:

[5] We do not specify how profits are distributed across agents since we do not solve the model. We can assume that profits are split equally, i.e., $\pi_t^i\left(\xi_{t-1}\right) = \pi_t\left(\xi_{t-1}\right)$ for all i. However, any other splitting satisfying the market clearing condition $\pi_t\left(\xi_{t-1}\right) = \int_I \pi_t^i\left(\xi_{t-1}\right) di$ is also consistent with our analysis.

(i) $\{c_t^i, n_t^i, m_t^i, k_t^i, a_t^i(s)\}_{t\in T}^{s\in S, i\in I}$ solves the utility maximization problem (19), (20);

(ii) $\{k_{t-1}, n_t^i\}_{t\in T}^{i\in I}$ solves the profit-maximization problem $(4)-(6)$;

(iii) all markets clear and the economy's resource constraint is satisfied.

The First-Order Conditions (FOCs) with respect to state contingent claims, capital, money, labor and consumption are as follows:

$$\lambda_t^i q_t(s) = \delta \lambda_{t+1}^i \Pi \{s_{t+1} = s' \mid s_t = s\}_{s,s'\in S}, \tag{21}$$

$$\lambda_t^i = \delta E_t \left[\lambda_{t+1}^i \left(1 - d + \frac{r_{t+1}}{p_{t+1}} \right) \right], \tag{22}$$

$$\lambda_t^i + u_3 \left(c_t^i, 1 - n_t^i, \frac{m_t^i}{p_t} \right) = \delta E_t \left[\lambda_{t+1}^i \frac{\mu_{t+1}}{\mu_t} \frac{p_t}{p_{t+1}} \right], \tag{23}$$

$$u_2 \left(c_t^i, 1 - n_t^i, \frac{m_t^i}{p_t} \right) = \lambda_t^i \frac{w_t^i}{p_t}, \tag{24}$$

$$u_1 \left(c_t^i, 1 - n_t^i, \frac{m_t^i}{p_t} \right) = \lambda_t^i, \tag{25}$$

where λ_t^i is the Lagrange multiplier associated with budget constraint (20); and $\Pi \{s_{t+1} = s' \mid s_t = s\}_{s,s'\in S}$ is the transitional probability function.

By summing the individual budget constraints (20) across agents, by imposing the market clearing condition for state contingent claims, $\int_I a_t^i(s)\, di = 0$ for all s, and by taking into account that $\int_I \left(\frac{w_t^i}{p_t} + \frac{\pi_t^i}{p_t} + \frac{r_t}{p_t} k_{t-1}^i \right) di$ is equal to output produced, we obtain the economy's resource constraint,

$$c_t + \frac{m_t}{p_t} + k_t = (1-d)\, k_{t-1} + f(k_{t-1}, z_t h_t) + \frac{m_{t-1}\gamma^m \mu_t}{p_t \mu_{t-1}}. \tag{26}$$

Consider now the following social planner's problem:

$$\max_{\left\{c_t^i, n_t^i, m_t^i, k_t\right\}_{t\in T}} E_0 \sum_{t=0}^{\infty} \delta^t \int_I \lambda^i u \left(c_t^i, 1 - n_t^i, \frac{m_t^i}{p_t} \right) di, \tag{27}$$

subject to (26), (5) and (6), where $\left\{\lambda^i\right\}^{i\in I}$ is a set of the welfare weights assigned by the planner to the individual utilities.

Proposition 1 *There exists a set of welfare weights* $\left\{\lambda^i\right\}^{i\in I}$ *such that the equilibrium in the heterogeneous-agent economy* $(1)-(6)$, $(18)-(20)$ *is described by the planner's problem* (27), (26), (5) *and* (6).

Proof. FOC (21) implies that the marginal utilities of any two agents $i, i' \in I$ are constant across time and states of nature. With this result, we can define the welfare weights of agents by $\frac{\lambda^i}{\lambda^{i'}} \equiv \frac{\lambda_t^{i'}}{\lambda_t^i} = \frac{\lambda_{t+1}^{i'}}{\lambda_{t+1}^i} = ...$, and we can represent the agent's Lagrange multipliers as $\lambda_t^i = \lambda_t / \lambda^i$ for all $i \in I$. By substituting the last formula into FOCs (22) – (25), we obtain the FOCs of the planner's problem with λ_t being the Lagrange multiplier associated with resource constraint (26). The above equivalence of the FOCs proves the statement of the proposition. ■

We now show a particular set of restrictions on preferences and technology, under which the planner's economy (27), (26), (5) and (6) is consistent with balanced growth of both real and nominal variables. Let us assume that the utility function is Constant Relative Risk Aversion (CRRA), $u\left(c_t^i, 1-n_t^i, \frac{m_t^i}{p_t}\right) = \frac{\left[\left(c_t^i\right)^{\phi}\left(1-n_t^i\right)^{\psi}\left(\frac{m_t^i}{p_t}\right)^{1-\phi-\psi}\right]^{1-\tau}}{1-\tau}$ with $\tau > 0$, $\tau \neq 1$, $\phi > 0$, $\psi > 0$, $\phi + \psi < 1$, and that the production function is Cobb-Douglas $f\left(k_{t-1}, z_t h_t\right) = k_{t-1}^{\alpha}\left(z_t \int_I n_t^i b_t^i di\right)^{1-\alpha}$ with $\alpha \in (0,1)$. These assumptions insure the existence of the balanced growth path.

In order to remove growth in the nominal and real quantities, we use the following change of variables: $\widetilde{c}_t^i = \frac{c_t^i}{(\gamma^z)^t}$, $\widetilde{m}_{t-1}^i = \frac{m_{t-1}^i}{(\gamma^m)^t (\gamma^z)^t}$, $\widetilde{k}_{t-1}^i = \frac{k_{t-1}^i}{(\gamma^z)^t}$, $\widetilde{a}_{t-1}^i = \frac{a_{t-1}^i}{(\gamma^z)^t}$, $\widetilde{w}_t^i = \frac{w_t^i}{(\gamma^m)^t (\gamma^z)^t}$, $\widetilde{\pi}_t = \frac{\pi_t}{(\gamma^m)^t (\gamma^z)^t}$, $\widetilde{p}_t = \frac{p_t}{(\gamma^m)^t}$ and $\widetilde{r}_t = \frac{r_t}{(\gamma^m)^t}$. Then, the problem (27), (26), (5) and (6) can be re-written as

$$\max_{\left\{\widetilde{c}_t^i, \widetilde{n}_t^i, \widetilde{m}_t^i, \widetilde{k}_t\right\}_{t\in T}^{i\in I}} E_0 \sum_{t=0}^{\infty} \widetilde{\delta}^t \int_I \lambda^i \frac{\left[\left(\widetilde{c}_t^i\right)^{\phi}\left(1-n_t^i\right)^{\psi}\left(\frac{\widetilde{m}_t^i}{\widetilde{p}_t}\right)^{1-\phi-\psi}\right]^{1-\tau}}{1-\tau} di, \tag{28}$$

subject to

$$\widetilde{c}_t + \frac{\gamma^z \gamma^m \widetilde{m}_t}{\widetilde{p}_t} + \gamma^z \widetilde{k}_t = (1-d)\,\widetilde{k}_{t-1}^i + z_{-1}^{1-\alpha}\theta_t^{1-\alpha}\widetilde{k}_{t-1}^{\alpha}\left(\int_I n_t^i b_t^i di\right)^{1-\alpha} + \frac{\widetilde{m}_{t-1}\gamma^m \mu_t}{\widetilde{p}_t \mu_{t-1}} \tag{29}$$

$$\log\left(\widetilde{w}_t^i\right) \geq E_{t-1}\left[\log\left(\widetilde{w}_t^i\right)\right], \tag{30}$$

$$E_{t-1}\left[\left(\widetilde{\pi}_t\left(\xi_{t-1}\right)\right)\right] = 0, \tag{31}$$

where $\widetilde{\delta} \equiv \delta\left(\gamma^z\right)^{\phi+\psi}$ and $\widetilde{w}_t^i = \frac{\widetilde{p}_t z_{-1}^{1-\alpha}\theta_t^{1-\alpha}}{\xi_{t-1}}(1-\alpha)\,\widetilde{k}_{t-1}^{\alpha}\left(\int_I n_t^i b_t^i di\right)^{-\alpha} b_t^i$.

Note that the resulting economy $(28)-(31)$ is stationary. The state space of the above economy includes $\left(\mu_t, \theta_t, \widetilde{k}_{t-1}, \widetilde{m}_{t-1}, \mu_{t-1}, \theta_{t-1}, \left\{b_{t-1}^i, b_t^i\right\}^{i\in I}\right)$. The past variables μ_{t-1}, θ_{t-1} and $\left\{b_{t-1}^i\right\}^{i\in I}$ appear because they determine the $t-1$-period expectations of wages and profit in the constraints (30) and (31), respectively. Therefore, the constructed planner's economy satisfies our assumptions **A1** and **A2**.[6]

[6] Under the above assumptions, there is a one-consumer model that can be constructed analytically, see Maliar and Maliar (2003).