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# The Welfare Cost of Nominal Wage Contracting

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We use a dynamic general equilibrium model to obtain quantitative estimates of the welfare cost of nominal wage contracting. We find that the welfare cost of such contracts can vary quite a lot depending on the degree of indexation, the size and persistence of monetary shocks and the contract length. The size and persistence of technology shocks do not affect the welfare cost significantly. The elasticity of labour supply is important for the welfare cost. If the labour supply elasticity is small the welfare cost of nominal wage contracts can be substantial.

## 1. INTRODUCTION

According to the Panel Study on Income Dynamics, 44.4% of employed workers in the U.S. economy are salaried employees. From the viewpoint of a quarterly business cycle model these are individuals who agree to four period wage contracts. Of the remaining workers 48.6% are hourly employees and a substantial fraction of these are covered by wage contracts, either explicit or implicit, that fix wages for four periods or more. These observations suggest that nominal wage rigidity is an important feature of the economy. This, of course, is one of the reasons why wage rigidity has long been regarded as a primary mechanism for the propagation of monetary shocks through the real economy. The observation that fixed wages are so prevalent and are readily accepted suggests that there may be important welfare costs and benefits associated with these arrangements. In this paper we develop quantitative estimates of the welfare cost of nominal wage contracts and study how it varies with changes in the contracting arrangements and with changes in the economic environment.

The literature on nominal wage contracts is by now vast. Gray (1976, 1978) used nominal wage contracts to study issues related to indexation. Fischer (1977) introduced nominal wage contracts to show that monetary policy is effective even in a model with rational expectations. Taylor (1979, 1980) used contracts that are somewhat different from those used by Gray and Fischer to study their role in the propagation of shocks through the economy. More recently, nominal contracts have been introduced into dynamic general equilibrium models of the sort studied in the real business cycle literature. Benassy (1995), Cho (1993), Cho and Cooley (1995, 1993), Cho and Phaneuf (1993*a*, 1993*b*), and King (1993) have used model economies with nominal contracts to study the importance of

monetary shocks, propagated by contracts, in aggregate fluctuations. Their findings show that nominal contracts may be an important element in general equilibrium models of aggregate fluctuations. They also demonstrate that only modest amounts of rigidity are necessary for monetary shocks to have substantial real effects.

Missing from these studies of nominal contracting is an analysis of the welfare cost of nominal wage contracts. This paper quantifies the welfare cost of wage contracting in a dynamic general equilibrium model with multiperiod wage contracting. The model used is a variant of the standard models used in the real business cycle literature, adapted to incorporate nominal wage contracting and to facilitate the computation of welfare cost. We estimate the welfare cost of wage contracts relative to an economy where wages are free to adjust each period. We describe, in a dynamic setting, how the welfare cost varies with the length of contracts, the degree of indexation, with the size and persistence of real and nominal shocks and with labour supply elasticities.<sup>1</sup>

Briefly, we find that, for the range of indexation from 0 to 60%, the welfare cost of nominal wage contracts is small for one year contracts and does not increase very dramatically with contract length. When the degree of indexation of the contracts increases above 70% (so that the contracts are increasingly on the real wage), the welfare cost is much higher. The finding of small welfare costs associated with nominal wage contracts is broadly consistent with the findings of Ball and Romer (1990), which are based on a very different environment than the one studied here.<sup>2</sup> In addition, our findings are consistent with Ball and Romer's view that labour market fluctuations may be an important element in determining the size of welfare costs of business cycles. These findings complement those in Lucas (1987), where the welfare cost of business cycles is due entirely to fluctuations in consumption.

In the next section of the paper we describe the economic environment and the solution technique. The third section presents the analysis of the welfare cost of nominal wage contracts. Section 4 deals with the effects of labour supply elasticities on the welfare cost. Section 5 concludes.

## 2. THE ECONOMY

We consider an environment populated by a continuum of identical agents or households. Each agent is endowed with one unit of time per period, initial capital stock  $k_0$  and initial money holdings  $m_{-1}$ .<sup>3</sup> Agents in this economy hold money because real money balances enter the utility function. This assumption will be seen to greatly simplify the welfare calculation. Each agent maximizes his lifetime utility which is assumed to be additively time separable,

$$U = E_0 \sum_{t=0}^{\infty} \beta^t [\ln(c_t) + \psi_1 \ln(l_t) + \psi_2 \ln(m_t/P_t)], \quad (2.1)$$

where  $c_t$  is consumption,  $l_t$  is leisure ( $l_t = 1 - n_t$ ),  $m_t$  is the household's money holdings in period  $t$ , which is carried over from this period to the next period,  $P_t$  is the aggregate price level,  $\beta$  is a discount factor, and the  $\psi$ 's are preference parameters.

1. Cho and Phaneuf (1993b) study the problem of optimal indexation of wage contracts in an environment that is similar to the one used in this paper. However, their focus is on the optimal degree of indexation and the implications of indexation for business cycle fluctuations, especially on the correlations between the total hours of work and average labour productivities.

2. They study the welfare implications of nominal and real price rigidities in a static environment.

3. We use the convention throughout that lower case letters denote individual choice variables and capital letters denote their aggregate *per capita* counterparts.

Agents maximize (2.1) subject to the following sequence of budget constraints

$$P_t(c_t + k_{t+1}) + m_t \leq W_t n_t + R_t k_t + m_{t-1} + \Gamma_t. \tag{2.2}$$

The variables on the left-hand side of (2.2) are the household expenditures and those on the right-hand side are the available funds. Here,  $k_{t+1}$  is capital investment in period  $t$ , which will have productive power in the next period,  $W_t$  and  $R_t$  are the nominal wage rate and the nominal rental rate of capital, respectively, and  $\Gamma_t$  is a lump sum transfer of money from the government. We assume a 100% rate of depreciation of capital to obtain a closed form solution.<sup>4</sup>

The firm in the economy produces output,  $Y_t$ , using the Cobb–Douglas production function

$$Y_t = A_t K_t^\theta N_t^{1-\theta}, \quad 0 \leq \theta \leq 1, \tag{2.3}$$

where  $\theta$  is the share of capital in the production,  $A_t$  is a productivity shock,  $K_t$  is the *per capita* capital stock and  $N_t$  is the *per capita* hours of work. It is assumed that the technology shock follows an AR (1) process

$$\ln(A_{t+1}) = \rho \ln(A_t) + \varepsilon_{t+1}, \quad \text{where } \varepsilon_t \sim \text{i.i.d. } N(0, \sigma_\varepsilon^2). \tag{2.4}$$

The firm solves a series of static maximization problems

$$\text{Maximize}_{\{N_t, K_t\}} [P_t(A_t K_t^\theta N_t^{1-\theta}) - W_t N_t - R_t K_t]. \tag{2.5}$$

The profit maximization problem for the firm implies the following conditions equating the marginal product of inputs to their real price

$$W_t/P_t = (1 - \theta)A_t [K_t/N_t]^\theta, \tag{2.6}$$

$$R_t/P_t = \theta A_t [N_t/K_t]^{1-\theta}. \tag{2.7}$$

Newly created money is injected into the economy via lump-sum transfers to the private agents

$$\Gamma_t = (g_t - 1)M_{t-1}, \tag{2.8}$$

where  $g_t$  is the gross growth rate of money. We assume that  $\ln(g_t)$  follows an MA (1) process

$$\ln(g_t) = \omega_t + \zeta \omega_{t-1}, \quad \text{where } \omega_t \sim \text{i.i.d. } N(\ln(g)/(1 + \zeta), \sigma_\omega^2). \tag{2.9}$$

Here  $g$  is the steady state growth rate of money.

In the absence of nominal wage contracts, the equilibrium for this economy can be obtained by maximizing (2.1) subject to (2.2) and the non-negativity constraints and then by using (2.6) and (2.7) in the first-order conditions. We can solve for the rules determining  $C_t$ ,  $K_{t+1}$ ,  $N_t$  and  $P_t$  as functions of the state of the economy as

$$C_t = (1 - \beta\theta)A_t K_t^\theta N_t^{1-\theta}, \tag{2.10}$$

$$K_{t+1} = \beta\theta A_t K_t^\theta N_t^{1-\theta}, \tag{2.11}$$

$$N_t = \frac{1 - \theta}{(1 - \theta) + (1 - \beta\theta)\psi_1}, \tag{2.12}$$

$$\frac{1}{P_t} = \psi_2 C_t \sum_{j=0}^{\infty} \beta^j E_t \left[ \frac{1}{M_{t+j}} \right]. \tag{2.13}$$

4. Since we assume 100% rate of capital depreciation,  $R_t$  is the gross rate of return on capital.

Using (2.10), (2.3) and the money supply process (2.9) in (2.13),<sup>5</sup> we can determine the price level according to

$$P_t = V(\omega_t)M_t/Y_t, \quad (2.14)$$

where  $V(\omega_t)$  represents the velocity of money as a function of the monetary shock of period  $t$ .  $V(\omega_t)$  is given by the expressions<sup>6</sup>

$$V(\omega_t) = \frac{1 - \beta + \beta\theta}{\psi_2(1 - \beta)} \frac{1}{1 + \tilde{V}(\omega_t)}, \quad (2.15)$$

where

$$\tilde{V}(\omega_t) = \frac{\beta \exp(-\zeta\omega_t) \exp(-(\ln(g)/1 + \zeta) + \frac{1}{2}\sigma_\omega^2)}{1 - \beta \exp[-\ln(g) + \frac{1}{2}(1 + \zeta)^2\sigma_\omega^2]}.$$

If  $\zeta = 0$ , monetary shocks are independently and identically distributed and the velocity is a constant

$$V = \frac{1 - \beta + \beta\theta}{\psi_2(1 - \beta)} \{1 - \beta \exp[-\ln(g) + \frac{1}{2}\sigma_\omega^2]\}. \quad (2.16)$$

Thus, if money shocks are i.i.d., the Cambridge form of the quantity equation holds. To get a closed form solution, we approximate (2.15) using the first order Taylor series expansion

$$\ln[V(\omega_t)] = \phi_2 + \phi_3\omega_t, \quad (2.17)$$

where

$$\phi_2 = \ln\left(\frac{1 - \beta + \beta\theta}{\psi_2(1 - \beta)}\right) - \ln(1 + \phi_4) - \frac{\zeta\phi_4 \ln(g)}{(1 + \zeta)(1 + \phi_4)},$$

$$\phi_3 = \frac{\zeta\phi_4}{1 + \phi_4},$$

and

$$\phi_4 = \frac{\beta \exp(-\ln(g) + \frac{1}{2}\sigma_\omega^2)}{1 - \beta \exp(-\ln(g) + \frac{1}{2}(1 + \zeta)^2\sigma_\omega^2)}.$$

We will use (2.17) in the calculation of the solution rather than (2.15).

The final feature of the model is nominal wage contracting. The form of the contracts we consider follows the original ideas of Gray (1976) and Fischer (1977). Like them, we beg the important question of why workers and firms agree to these arrangements. Some

5. The solutions for consumption, capital stock and the hours of work are the same as in the economy without money. The solution for the price level is derived from the household's first-order condition for money holdings

$$\frac{1}{C_t P_t} = \beta E_t \left( \frac{1}{C_{t+1} P_{t+1}} \right) + \frac{\psi_2}{M_{t+1}}.$$

Using repeated substitution, we arrive at (2.13).

6. We assume the following in deriving the velocity:

$$\beta \exp[-\ln(g) + \frac{1}{2}(1 + \zeta)^2\sigma_\omega^2] < 1.$$

In fact, this inequality is satisfied easily in the data.

justification for contracts are discussed by Danziger (1988) and Gomme and Greenwood (1994) among others. Our goal is to evaluate the welfare consequences.

We assume that the nominal wage rate prevailing in period  $t$  has been set in period  $t-j$ . Once the contract is signed, the workers cede to firms the right to determine the number of hours of work. The wage contract may allow for indexation of the contract wage. Formally, we add the following constraint to the household's problem

$$n_t = N_t. \quad (2.18)$$

Since  $n_t$  is a choice of the household and  $N_t$  is a choice of the firm, (2.18) says that the households supply as much labour as is demanded by the firm. The nominal wage for period  $t$  is set in period  $t-j$  so that the marginal value of the quantity constraint (2.18) is set equal to zero given the information available at  $t-j$ . This way of defining the contract wage guarantees that the steady states with and without wage contracts will be the same. The contract wage is given by the expression

$$\begin{aligned} \ln(W_t) = & E\{\ln(\psi_t) + \ln(C_t) - \ln(1 - N_t) + \ln(P_t) | \Omega_{t-j}\} \\ & + \gamma_j \{\ln(P_t) - E[\ln(P_t) | \Omega_{t-j}]\}, \end{aligned} \quad (2.19)$$

where the first line represents the "nominal base wage". It is derived by equating the expected marginal rate of substitution between consumption and leisure to the expected real wage. It clearly depends on expected hours worked which is obtained by equating the expected marginal product of labour to the expected real wage.<sup>7</sup> The last term in (2.19) reflects the indexation of the contract and  $\gamma_j$  is the indexation parameter for a nominal wage contract that was set in period  $t-j$ . When  $\gamma_j=0$ , there is no indexation in the contract wage rate, and when  $\gamma_j=1$ , the contract wage rate is fully indexed. In the latter case the contract is on the real wage.<sup>8</sup>

To solve the model analytically, we approximate  $\ln(1 - N_t)$  around the steady state as follows

$$\ln(1 - N_t) \cong \phi_0 - \phi_1 \ln(N_t), \quad (2.20)$$

where  $\phi_0 = \ln(1 - N) + [N/(1 - N)] \ln(N)$ ,  $\phi_1 = N/(1 - N)$  and  $N$  is the steady state value of the aggregate hours of work.<sup>9</sup>

Workers and firms in the model can write contract wage rates for more than one period in multi-period contract cases. For example, in a two-period contract, the contract wage rates for periods  $t+1$  and  $t+2$  are determined at the end of period  $t$ . At the end of period  $t+2$  the contract wage rate in periods  $t+3$  and  $t+4$  is determined and so on. In three-period contracts, the contract wage rate for periods  $t+1$ ,  $t+2$ , and  $t+3$  is determined at the end of period  $t$ . At the end of period  $t+3$  the contract wage rates in periods  $t+4$ ,  $t+5$  and  $t+6$  are determined. They repeat this contracting practice indefinitely. This reflects the way wages are set for salaried employees and in many union wage agreements.<sup>10</sup>

7. Our contract is close in spirit to Gray's contract where the "nominal base wage" is chosen to make anticipated labour demand equal to anticipated labour supply over the course of the contract.

8. Explicitly, (2.19) is derived by setting up the Lagrangian function for the household's optimization problem and taking the derivative with respect to  $N_t$ . Setting the derivative equal to zero, adding the indexation condition, and using the condition that individual and aggregate decisions must be equal in equilibrium ( $c_t = C_t$ , etc.), yields (2.19). Equation (2.19) can also be viewed as the missing first-order condition that arises from the quantity constraint imposed by the fact that individuals cede to firms the right to determine aggregate hours.

9. This approximation is crucial for getting a closed form solution. Christiano (1990) and Tauchen (1990) have found that linear approximations as in (2.20) yield a solution very close to the exact one.

10. Here we consider only synchronized rather than staggered contracts.

If we assume that the contracts start to be written at the end of period 0 and the initial period wage rates are given, the contract wage rates for  $j$ -period nominal contracts are

$$\begin{aligned} \ln(W_t) = E\{\ln(\psi_1) - \phi_0 + \ln(C_t) + \phi_1 \ln(N_t) + \ln(P_t) | \Omega_{t-1}\} \\ + \gamma_j \{\ln(P_t) - E[\ln(P_t) | \Omega_{t-1}]\}, \quad \text{if } t=1, j+1, 2j+1, \dots \end{aligned} \quad (2.21)$$

$$\begin{aligned} \ln(W_t) = E\{\ln(\psi_1) - \phi_0 + \ln(C_t) + \phi_1 \ln(N_t) + \ln(P_t) | \Omega_{t-2}\} \\ + \gamma_j \{\ln(P_t) - E[\ln(P_t) | \Omega_{t-2}]\}, \quad \text{if } t=2, j+2, 2j+2, \dots \end{aligned} \quad (2.22)$$

⋮

$$\begin{aligned} \ln(W_t) = E\{\ln(\psi_1) - \phi_0 + \ln(C_t) + \phi_1 \ln(N_t) + \ln(P_t) | \Omega_{t-j}\} \\ + \gamma_j \{\ln(P_t) - E[\ln(P_t) | \Omega_{t-j}]\}, \quad \text{if } t=j, 2j, 3j, \dots \end{aligned} \quad (2.23)$$

The consumer-worker's problem can be written as

$$\text{Maximize } E_0 \sum_{t=0}^{\infty} \beta^t [\ln(c_t) + \psi_1 \ln(1 - N_t) + \psi_2 \ln(m_t/P_t)] \quad (2.24)$$

$\{c_t, m_t, k_{t+1}\}$

$$\text{s.t. } (2.2), (2.18), (2.21)-(2.23)$$

$$c_t \geq 0, 0 \leq N_t \leq 1, K_{t+1} \geq 0.$$

The solution is (see Cho and Phaneuf (1993b) for a derivation)

$$C_t = (1 - \beta\theta) A_t K_t^\theta N_t^{1-\theta}, \quad (2.25)$$

$$K_{t+1} = \beta\theta A_t K_t^\theta N_t^{1-\theta}. \quad (2.26)$$

The decision rules for the hours of work can be obtained from the first-order conditions for the firm's profit maximization

$$\ln(N_t) = \ln(N) + \sum_{h=1}^q [\alpha_h^j \varepsilon_{t-h+1} + \delta_h^j (\omega_{t-h+1} - \omega)], \quad t=q, j+q, 2j+q, \dots \quad (2.27)$$

where  $q=1, 2, \dots, j$ , and  $N$ ,  $\alpha_h^j$ , and  $\delta_h^j$  are defined as

$$N = \frac{1 - \theta}{(1 - \theta) + (1 - \beta\theta)\psi_1},$$

$$\alpha_1^j = \frac{\gamma_j}{\theta + (1 - \gamma_j)(1 - \theta)},$$

$$\alpha_h^j = \frac{\gamma_j [\rho^h - \theta^h]}{(\rho - \theta)[\theta + (1 - \gamma_j)(1 - \theta)]} + \sum_{s=2}^h \frac{\gamma_j (1 - \theta) \theta^{s-1}}{\theta + (1 - \gamma_j)(1 - \theta)} \cdot \alpha_{h-s+1}^j, \quad h=2, 3, \dots, j,$$

$$\delta_1^j = \frac{(1 - \gamma_j)(1 + \phi_3)}{\theta + (1 - \gamma_j)(1 - \theta)},$$

$$\delta_h^j = \frac{(1 - \gamma_j)(1 + \zeta)}{\theta + (1 - \gamma_j)(1 - \theta)} + \sum_{s=2}^h \frac{\gamma_j (1 - \theta) (\theta^{s-1})}{\theta + (1 - \gamma_j)(1 - \theta)} \delta_{h-s+1}^j, \quad h=2, 3, \dots, j.$$

For example, the decision rules for the hours of work in two period contracts turn out to be

$$\ln(N_t) = \ln(N) + \alpha_1^2 \varepsilon_t + \delta_1^2 \cdot (\omega_t - \omega) \quad \text{if } t \text{ is odd,} \quad (2.28)$$

and

$$\ln(N_t) = \ln(N) + \alpha_2^2 \varepsilon_{t-1} + \delta_2^2 (\omega_{t-1} - \omega) + \alpha_1^2 \varepsilon_t + \delta_1^2 (\omega_t - \omega) \quad \text{if } t \text{ is even.} \quad (2.29)$$

In the case of three period contracts, the decision rules are:

$$\ln(N_t) = \ln(N) + \alpha_1^3 \varepsilon_t + \delta_1^3 (\omega_t - \omega) \quad \text{if } t = 1, 4, 7, \dots, \quad (2.30)$$

$$\ln(N_t) = \ln(N) + \sum_{h=1}^2 [\alpha_h^3 \varepsilon_{t-h+1} + \delta_h^3 (\omega_{t-h+1} - \omega)] \quad \text{if } t = 2, 5, 8, \dots, \quad (2.31)$$

$$\ln(N_t) = \ln(N) + \sum_{h=1}^3 [\alpha_h^3 \varepsilon_{t-h+1} + \delta_h^3 (\omega_{t-h+1} - \omega)] \quad \text{if } t = 3, 6, 9, \dots \quad (2.32)$$

When the contract length is longer than three periods, we obtain the solution in a similar way.

Finally, we note that the price level is determined by the quantity equation (2.14). It is easy to see from the solutions above that, in general, both monetary and technology shocks affect the total hours of work, and thus output, consumption, and investment. It is also clear from the expressions for the  $\alpha$ s and  $\delta$ s that indexation is a key factor in determining the impact of the shocks. If  $\gamma_j = 0$  (contracts are not indexed), the total hours of work depend solely on the monetary shock, and if  $\gamma_j = 1$  (real wage contracts), the hours depend solely on the technology shock.<sup>11</sup>

The magnitude of effects of real and nominal shocks are also determined by the parameters  $\theta$ ,  $\rho$ ,  $\zeta$  and  $\phi_3$ . The share of capital in production,  $\theta$ , is also related to the elasticity of demand for labour which is decreasing in  $\theta$ . Employment is determined by the firms, given contract wage rates, and thus the effects of real and nominal shocks are small when  $\theta$  is large. This means that  $\alpha'_h$ s and  $\delta'_h$ s increase with  $\theta$ . The persistence of the real shocks is determined by  $\rho$ , and it turns out that the magnitude of  $\alpha'_h$ , the weight on real shocks, increases with  $\rho$ . Further, the persistence of nominal shocks increases with  $\zeta$ , and the size of  $\delta'_h$ , the weight on monetary shocks, increases with  $\zeta$ . Finally, the parameter determining the response of velocity of money to the money shocks ( $\phi_3$ ) increases the effects of nominal shocks. This is because the velocity of money increases with expansionary money shocks so that nominal income increases with  $\phi_3$  according to the quantity equation. This, in turn, means that the price level increases with  $\phi_3$  and the firm produces more. Note that any parameter determining the size of  $\phi_3$  also affects the size of  $\delta'_h$ .

11. This feature of the solution is shared by the model in Gray (1978). Although the solution for the total hours is not presented in her paper, it can be obtained (in her notation) as follows

$$\ln(L_t) = \text{constant} + \frac{\eta(1-\gamma)\beta_t + \eta\gamma\alpha_t}{1 + \eta\delta(1-\gamma)},$$

where  $L_t$ ,  $\gamma$ ,  $\alpha_t$  and  $\beta_t$  are the total hours of work, the indexation parameter, productivity and nominal shocks respectively. In addition,  $\delta$  is the labour share in production and  $\eta = 1/(1-\delta)$ . Thus, the solution in the text is the same as the one implied by Gray. However, Gray's setup is static, so her model cannot capture the dynamic features of multi-period contracts.



## 3. MEASURING WELFARE COST

Using the solutions described in the previous section and imposing that, in equilibrium, individual decisions must be consistent with aggregate outcomes, we can rewrite the lifetime utility as

$$\begin{aligned} U &= E_0 \sum_{t=0}^{\infty} \beta^t [\ln(C_t) + \psi_1 \ln(1 - N_t) + \psi_2 \ln(M_t/P_t)] \\ &= [\ln(1 - \beta\theta)] / (1 - \beta) + \psi_2 E_0 \sum_{t=0}^{\infty} \beta^t \ln[V(\omega_t)] \\ &\quad + E_0 \sum_{t=0}^{\infty} \beta^t [(1 + \psi_2) \ln(Y_t) + \psi_1 \ln(1 - N_t)]. \end{aligned} \quad (3.1)$$

Using the solution for  $K_{t+1}$ ,  $\ln(K_t)$  can be written as

$$\ln(K_t) = \sum_{s=1}^t \theta^{s-1} \{\ln(\beta\theta) + \ln(A_{t-s}) + (1 - \theta) \ln(N_{t-s})\} + \theta^t \ln(K_0), \quad (3.2)$$

and if we use (3.2),  $\ln(Y_t)$  can be written as

$$\begin{aligned} \ln(Y_t) &= \ln(A_t) + \theta \sum_{s=1}^t \theta^{s-1} \{\ln(\beta\theta) + \ln(A_{t-s}) + (1 - \theta) \ln(N_{t-s})\} \\ &\quad + \theta^{t+1} \ln(K_0) + (1 - \theta) \ln(N_t). \end{aligned} \quad (3.3)$$

If we use (3.3) and (2.17) and (3.1), we see that lifetime utility is a linear function of a constant,  $\omega_0$ ,  $\ln(K_0)$ , the expected value of  $\{\ln(A_h)\}_{h=0}^t$ ,  $\{\ln(N_h)\}_{h=0}^t$ , and  $\{\ln(1 - N_h)\}_{h=0}^t$ , conditional on the information in the initial period. However, we know that if we assume that the state in the initial period is the same as the steady state values (mean values), the expected value of  $\ln(A_h)$  conditional on the initial period information is zero and the expected value of  $\ln(N_h)$  is  $\ln(N)$ .

Let  $U^c$  denote the lifetime utility associated with a model with nominal contracts, and let  $U^m$  denote the lifetime utility associated with the non-contracting counterpart. The difference between  $U^m$  and  $U^c$  is

$$D = U^m - U^c = E_0 \sum_{t=0}^{\infty} \beta^t \psi_1 \{\ln(1 - N) - \ln(1 - N_t)\}, \quad (3.4)$$

where  $N_t$  and  $N$  are obtained in (2.27).<sup>12</sup> The costs of contracting in a period can be expressed as

$$\begin{aligned} \hat{D} &= -E_0 \psi_1 [\ln(1 - N_t) - \ln(1 - N)] \\ &\cong \frac{\psi_1}{1 - N} E_0 (N_t - N) + \frac{\psi_1}{(1 - N)^2} E_0 [(N_t - N)^2], \end{aligned} \quad (3.5)$$

where we used the second-order Taylor series expansion of  $\ln(N_t - N)$ .<sup>13</sup> What this says is that the cost of nominal contracting in a period, say  $t \geq j$ , is obtained as the expected

12. One important feature of this analysis is that the cost of nominal contracting does not depend on the utility the agent gets from money holdings. That is, the preference parameter  $\psi_2$  does not appear in the expression for welfare cost.

13. Note that we used a first-order Taylor series expansion in (2.20) but that we are using a second-order Taylor series expansion in (3.5). This practice is in accord with the numerical solution literature. It is typical to use a second-order Taylor series expansion when approximating an objective function (i.e. a utility function). However, when approximating first-order conditions, such as Euler equations from a stochastic optimization problem, it is typical to use a first-order Taylor series expansion. These different orders of approximation were originally motivated by solving the problem numerically. However, these practices yield accurate solutions in standard environments (see Taylor and Uhlig (1990)). To confirm this in our setting, we tried a third-order Taylor series expansion to approximate (3.4) and to see if it improves accuracy and found the results are not very different from those reported.

value of (3.5) and this will depend only on the solution for  $N_t$ . Since  $N_t$  has a log-normal distribution, this dictates the form of the expression for the welfare cost.

With multi-period contracts, the cost is not the same for every period. The cost of contracting in the  $s$ -th period after writing the contract is

$$\hat{D}_s = \frac{\psi_1 N}{(1-N)} [\exp(\Pi) - 1] + \frac{\psi_1 N^2}{2(1-N)^2} [\exp(4\Pi) - 2\exp(\Pi) + 1], \quad (3.6)$$

where  $\Pi$  is the variance of deviations of log hours from the steady state, i.e.  $\ln(N_t) - \ln(N)$ , which can be defined as:

$$\Pi = \frac{1}{2} \sum_{h=1}^s [(\alpha^j_h)^2 \sigma_\varepsilon^2 + (\delta^j_h)^2 \sigma_g^2]. \quad (3.7)$$

It is obvious from this expression that the cost of nominal contracting is positive. The welfare cost (3.6) is affected by many factors like the utility of leisure parameter  $\psi_1$ , steady state hours<sup>14</sup>  $N$  and the factors determining the size of  $\Pi$ . The size of  $\Pi$  is determined by the capital share in production  $\theta$ , the indexation parameter  $\gamma_j$  and uncertainties in real and nominal shocks. It is not easy to figure out the effects of changes in these parameters on the welfare cost except for a few simple cases. Accordingly, we evaluate these effects via simulation.

The costs  $\hat{D}_s$  are in utility terms and are better understood if they are expressed in terms of consumption. We follow Cooley and Hansen (1992) and define  $X_s$  as the increment to consumption that would be necessary to yield the same level of utility in the contracting environment as the agent realizes in the non-contracting environment. Let  $C$  denote the steady state consumption and  $X_s$  the welfare costs in the  $s$ -th period of  $j$  period contracts in consumption term. Then,

$$\ln(C - X_s) = \ln(C) - \hat{D}_s \Rightarrow X_s/C = [\exp(\hat{D}_s) - 1]/\exp(\hat{D}_s). \quad (3.8)$$

The cost as a function of the steady state GNP is

$$X_s/\text{GNP} = (1 - \beta\theta)[\exp(\hat{D}_s) - 1]/\exp(\hat{D}_s). \quad (3.9)$$

Note that  $X_s$  is increasing with  $s$ . Now the average cost of contracting per period of  $j$  period contracts is

$$X_j = \frac{1}{j} \left( \sum_{s=1}^j X_s/\text{GNP} \right). \quad (3.10)$$

This shows that cost is increasing with the length of contracts  $j$ .

### Calibration

Our goal is to use the theory outlined above to provide quantitative estimates of the magnitude of the welfare cost associated with contracts. It is also of interest to understand how the cost varies with changes in the environment. To achieve this we proceed as in the real business cycle literature by assigning values to the parameters of the model based on the National Income and Product Accounts (NIPA) and other features of the U.S. economy. We then simulate these model economies to generate the data necessary to estimate the welfare cost of contracting.<sup>15</sup>

14. Of course,  $\psi_1$  and  $N$  are not independent of each other.

15. For a more detailed discussion of calibration, see Cooley and Prescott (1995).

We set the parameter values as follows. We interpret a period in this model as a year<sup>16</sup> which dictates that we set  $\beta$  to be 0.96. This means that the annual interest rate in the steady state is 4%. We assume capital's share to be  $\theta = 0.36$ , which has been used in most real business cycle models (see Kydland and Prescott (1982), Hansen (1985) and Cho and Cooley (1995)) and is based on the NIPA using a somewhat narrow definition of capital. The parameter  $\psi_1$  is set to 2.28, a value that implies that total hours of work in the steady state are about 30% of the total endowment of time. If the indexation does not vary,  $\gamma_j$  is set at 30%. This rate of indexation is arbitrary, and it is probably higher than the rate for the U.S. economy. We chose it as baseline value because it is close to the rate that Cho and Phaneuf (1993b) have shown to be optimal indexation in a similar model.<sup>17</sup> For the baseline simulations the standard deviations of the shocks are set to  $\sigma_\varepsilon = \sigma_g = 0.04$ , and the persistence parameters of the shocks are zero. However, when the persistence parameters are allowed to vary, the standard deviations of the total shocks are calibrated to be 0.04. This is broadly consistent with the estimated standard deviation of technology shocks based on an analysis of Solow residuals. We present experiments that illustrate the sensitivity of our findings to this number. Since  $\psi_2$  is not involved in (3.6), the utility from money holdings do not play any role in the following analyses.

### Findings

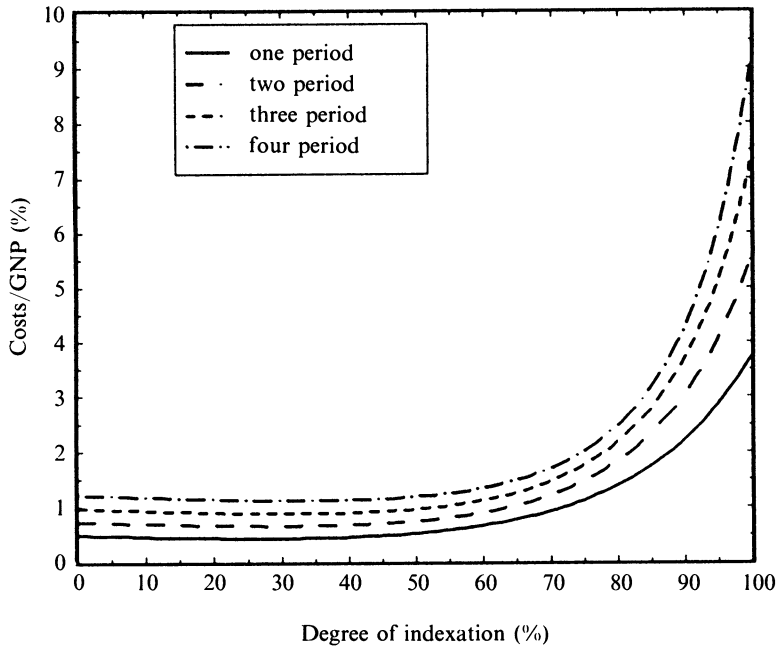
Figure 1 summarizes the findings of several experiments based on contracts of various lengths. Figure 1(A) shows the effect of indexation on welfare cost for various contract lengths. Obviously, when the contract wage rate is determined in a period which is farther apart from the period when the wage rate is actually applied, the welfare cost is greater. For the range of indexation from zero to 60%, there is little effect of the indexation on welfare cost. Over this range, the costs of contracts are about 0.07%, 0.11%, 0.15% and 0.19% of the steady state GNP in the cases of one-period, two-period, three-period, and four-period contracts respectively. However, the welfare cost begins to increase sharply as the degree of indexation increases over 70%. If the indexation is 100%, the costs are 0.57%, 0.84%, 1.12% and 1.42% in the four cases respectively. Two forces are at work as the degree of indexation increases. If there is no indexation, the contracts are purely nominal and the welfare cost is mainly associated with monetary disturbances. However, as the degree of indexation increases, the contracts become real-wage contracts and the welfare cost is due to real disturbances. In sum, if a contract is not indexed at all, the welfare cost is actually quite low. If the contract is fully indexed, then the welfare cost is much higher and it is technology shocks that drive the cost.

The intuition behind these results is the following. Looking at the solution (2.27), we see that, with i.i.d. shocks,  $\delta_1 = 1$  and  $\alpha_1 = 0$  with no indexation, and  $\delta_1 = 0$  and  $\alpha_1 = 1/\theta$  with full indexation. Hence full indexation yields much larger responses to technology shocks than no indexation does to monetary shocks. With  $\theta$  small, the marginal product of labour falls only slowly as employment rises, so employment rises substantially in

16. If we wanted to interpret a period as a quarter the calibration would be slightly different. First, the utility discount factor would be higher. Second, the variances of real and nominal shock innovations would be much smaller. Since the elasticity of labour supply depends on the equilibrium allocation, the value of  $\psi_1$  would have to be adjusted to get an appropriate quarterly labour allocation. The persistence of real and nominal shocks would have to be adjusted. Finally, the process for the nominal shocks would require additional moving average terms.

17. Bills (1991) documents rates of indexation for union wage contracts of greater than two years in the range of 50%. When we consider the economy as a whole it is surely less than this. We study the sensitivity to this parameter below and find that varying it over a reasonable range does not affect the result very much.

(A) Indexation and welfare costs



(B) The size of technology shock and welfare costs

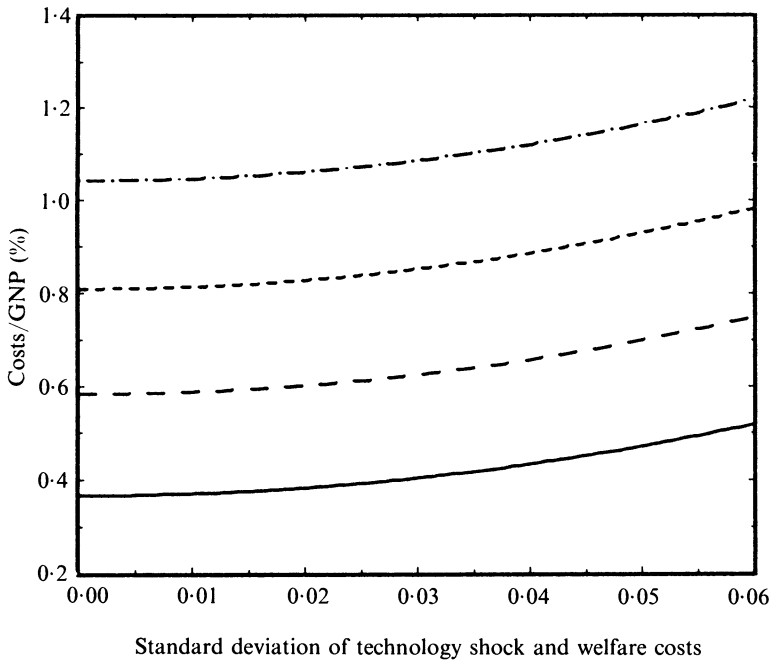
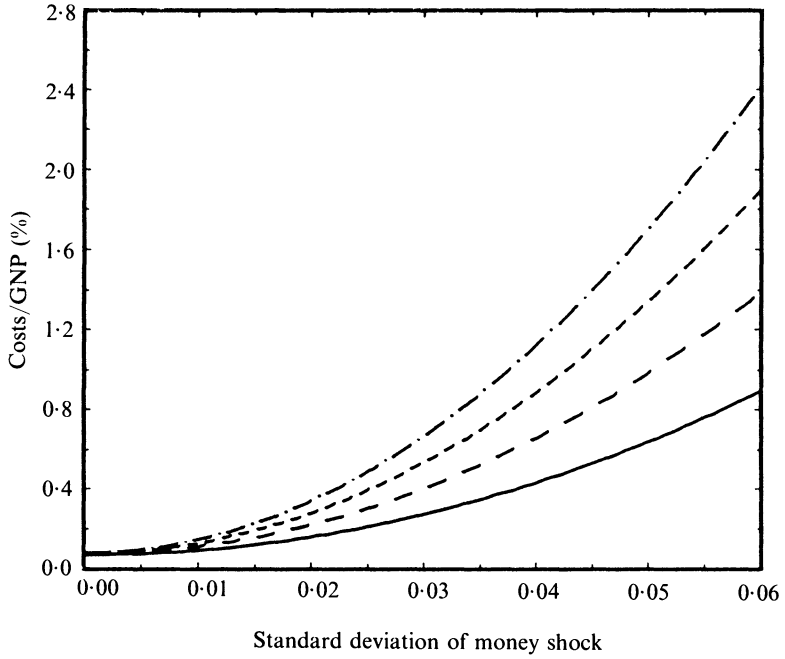


FIGURE 1

(C) The size of money shock and welfare costs



(D) Technology shock persistence and welfare cost

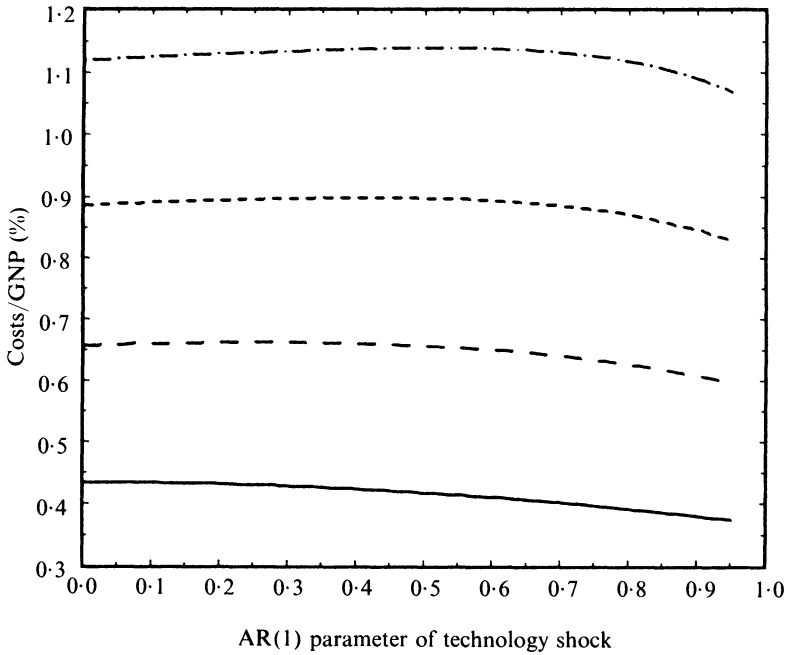


FIGURE 1—continued

(E) Money shock persistence and welfare costs

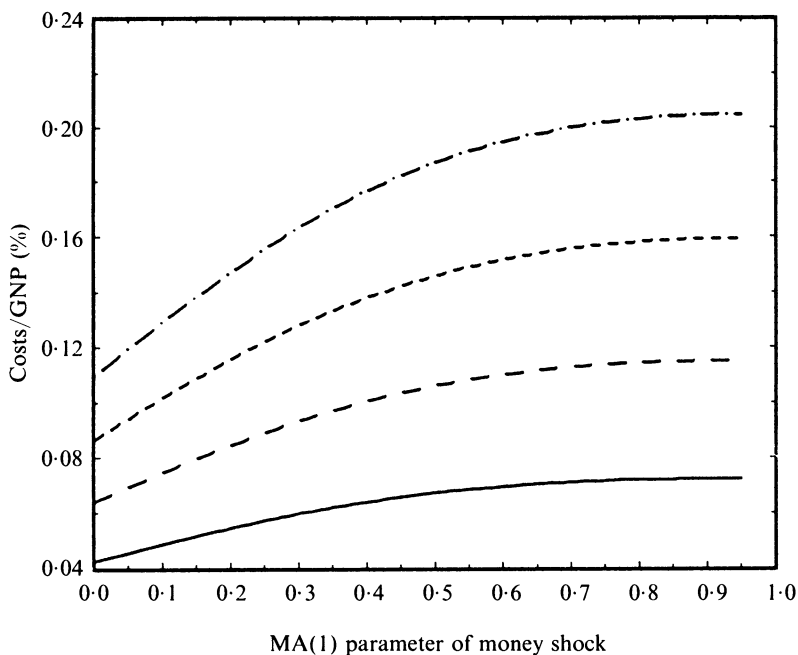


FIGURE 1—continued

response to a technology shock if the real wage is fixed. With a fixed nominal wage and a monetary shock, as employment rises above normal, not only does the marginal product of labour fall, but the price level falls (relative to what it would be if output did not change) and the real wage rises. Hence, employment changes relatively little.<sup>18</sup> Although technology shocks have significant welfare consequences with real contracts, the evidence is that the degree of indexation in most contracts is actually quite low and it surely is for the economy as a whole.

Figure 1(B) shows how the welfare cost varies with the size of the technology shock. If  $\sigma_\varepsilon = 0$ , the welfare cost is purely due to the uncertainty in money supply. In this case the costs are about 0.055, 0.088, 0.121, and 0.157% of GNP in one-, two-, three- and four-period-ahead contracts. There are two things worth noting. First, the impact of a change in the standard deviation of the technology shocks depends little on contract length. This is because of the assumption that technology shocks are i.i.d. around a deterministic trend. This means that there is no more uncertainty about technology shifts four periods ahead than one period ahead. However, a longer contract length implies persistent effects of the technology and monetary shock innovations even in the case of i.i.d. shocks. Figure 1(B) suggests that the latter effect is not large. Second, the welfare cost does not increase sharply with the standard deviation of technology shocks and the impact depends little on contract length. This is because nominal wage contracts with a low degree of indexation mainly amplify nominal shocks (see Cho and Cooley (1995)).

18. We are grateful to a referee for suggesting this intuition.

The effect of changes in the standard deviation of monetary shocks on the welfare cost of nominal wage contracts is illustrated in Figure 1(C). The response to changes in monetary uncertainty is quite different. First, if there is no monetary uncertainty (only technology shocks), there are hardly any differences among the welfare costs of different contracts. Again, this is because we are assuming i.i.d. technology shocks in the baseline case. Also, the welfare cost increases sharply with an increase in the standard deviation of the money shock and the increase is steeper with longer contracts.<sup>19</sup>

Figure 1(D) shows the effect on welfare cost of an increase in the persistence of the technology shocks. There are small changes in the welfare cost with an increase in the AR (1) parameter of the technology shock. An increase in persistence affects the economy in two ways. First, a high value of the real shock in the current period implies a high value of the shocks in future periods. Thus, a disturbance which is not expected has a more persistent and larger effect on the economy. Given the predetermined contract wage rate, labour productivity will be high (or low) for longer periods with a large AR (1) parameter than with small one and total hours will deviate from the steady state value for a longer time.<sup>20</sup> This means that the  $\alpha'_h$ s in (3.7) get larger. Second, although we vary the persistence of the technology shocks, we are keeping the variance of the total real shocks constant by changing the standard deviation of the innovation. That is, as the persistence of the real shocks increases, the standard deviation of the innovation is lowered to keep the total variance of the technology shocks constant. This means that  $\sigma_\varepsilon^2$  in (3.7) gets smaller with increased persistence. The overall effect of a change in the AR (1) parameter depends on which effect dominates. The findings suggest that these two effects are almost offsetting implying that the persistence of the technology shock is not an important factor determining the size of the welfare cost.

Finally, Figure 1(E) shows the effect of an increase in the persistence of monetary shocks on welfare cost. Once again there are two effects associated with an increase in the persistence of the nominal shock. If the persistence of the nominal shock is higher, given the contract wage rate, an unexpected increase in the nominal shock affects the price of the goods produced by the firms. Since a high price in the present period means a high price in the future (given the predetermined contract wage rate), persistent shocks affect the economy more than do temporary ones. This means that the  $\delta'_h$ s in (3.7) get larger. Second, as with the technology shocks, the variance of the monetary shocks is kept constant, which means that  $\sigma_\omega^2$  in (3.7) becomes smaller. The overall effect of a nominal disturbance on the economy depends on which effect dominates. Figure 1(E) shows that the former effect dominates the latter one and that the welfare cost increases with the persistence of nominal shocks. This result confirms again that monetary shocks have a more powerful effect on welfare than do technology shocks.

As an aside, it is interesting to contrast our estimates of the welfare cost of wage rigidity to the findings of Lucas (1987) who calculated the cost of business cycles by comparing the utility of agents in economies with and without business cycles. His finding was quite striking: the cost of business cycles is negligible. His estimated cost

19. If we look at the composition of  $\Pi$  defined in (3.7), we see that it is a weighted sum of the variances of the real and nominal shocks. The welfare cost is roughly the sum of the cost from real shocks and from nominal shocks. Our simulation results suggest that the weight on the nominal shocks is much larger than that on the real shocks because nominal wage contracts amplify monetary shocks much more than real shocks. It is not a consequence of the assumption that real shocks are i.i.d. and that money follows a random walk. Although money follows a random walk, what matters is the innovation to the money growth shock.

20. We are assuming that the agent (household) supplies as much labour as demanded by firms. This means that the responsiveness of the quantity of labour employed to the shocks does not depend on the labour supply elasticity but on labour demand elasticity. This will be made clear in Section 5.

of business cycles result simply from the consumption risk faced by agents. Our results are driven not by consumption risk but by leisure (or labour supply) risk associated with the nominal wage contracts (see (3.4)). The solutions are such that consumption risk does not play a role in the determination of the welfare cost.<sup>21</sup> There is reason to believe that the risk due to the labour market fluctuations is at least as important in the determination of the welfare cost of business cycles as is the risk in consumption. Fluctuations in the labour market, over the business cycle, are much larger than fluctuations in consumption. This means that, if the degree of risk aversion in leisure is the same as that in consumption, the welfare cost due to labour market fluctuations is larger than that due to consumption fluctuations. Once frictions are introduced in the labour market, the welfare cost of business cycle fluctuations may no longer be negligible. Although they are still fairly low, the welfare cost are much larger in this paper.<sup>22</sup> One of the key factors determining the size of the welfare costs is the labour supply elasticity. We turn to this issue in the next section.

#### 4. LABOUR SUPPLY ELASTICITY AND WELFARE COST

Our baseline estimates of the welfare cost of contracting are based on a specification of preferences that are fairly standard but embody strong restrictions, particularly on labour supply behaviour. In this section, we explore how the implied labour supply behavior affects the welfare cost of nominal wage contracting. To explore this issue, we assume the following preferences which include (2.1) as a special case

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \left[ \ln(c_t) + \frac{\hat{\psi}_1}{1-\nu} (1-n_t)^{1-\nu} + \psi_2 \ln(m_t/P_t) \right], \tag{4.1}$$

where we assume that  $\nu \geq 0$  and  $\nu \neq 1$ . If  $\nu = 0$ , the model is the indivisible labour model of Hansen (1985), and if  $\nu = 1$ , the preferences are the log separable form assumed in (2.1). In (4.1), the elasticity of intertemporal substitution of labour supply depends on the equilibrium allocation and given the allocation, it decreases with  $\nu$ .<sup>23</sup> Hence labour supply will be less sensitive to changes in wage rates as the value of  $\nu$  gets larger. The parameter

21. As we can see in (3.1)–(3.3),  $\ln(C_t)$  is a linear function of real and nominal shock innovations in our model and hence the expected value of  $\ln(C_t)$  reduces to the steady-state log consumption  $\ln(C)$ . Hence  $E_0[\ln(C_t) - \ln(C)] = 0$  in all periods under the assumption that initial shocks take the mean values.

22. It is not straightforward to compare the welfare cost in this paper to that in Lucas’s monograph. He obtained the cost relative to consumption, while we compute it relative to total output (GNP). Further, Lucas used three estimates for the standard deviation of consumption (see Table 2 on page 26 in his monograph) as the measures of consumption uncertainty, while we use estimates of the standard deviations of technology and monetary shocks. In the real business cycle literature (for instance, see Prescott (1986)), the standard deviations of the shocks used in our model imply the smallest estimate of the standard deviation of consumption in Lucas’s Table 2. Thus, when we refer to the results in Lucas’s monograph, we have in mind the first column and the first row of Table 2, which is the case of log-linear preferences and of realistic consumption risk in U.S. economy. According to his estimate, the welfare cost of consumption risk is about 0.008% of total consumption. Since the total consumption is about three quarters of GNP in the model economy, the welfare cost obtained by Lucas is about 0.006% of GNP. This number is about ten times as small as the smallest estimate of the welfare cost obtained in this paper.

23. We have also experimented with a preference specification, in which the elasticity of labour supply does not depend on the equilibrium allocation

$$E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[ \ln(c_t) - \psi_t \frac{n_t^{1-\nu}}{1-\nu} + \psi_2 \ln(m_t/P_t) \right] \right\},$$

and have obtained qualitatively the same results as those reported here.



$\nu$  also represents the attitude of the agent toward risk with respect to leisure. As  $\nu$  gets larger, the agent is more risk averse with respect to leisure (i.e. labour supply).

With this preference specification, the solutions are very similar to those obtained in the previous sections. The solutions for consumption, investment and the price level are the same. The only difference is in the solution for hours of work. With the preferences (4.1), if there are no contracts, the hours of work can be obtained from the equation

$$\hat{\psi}_1(1 - N_t)^{-\nu} = \left[ \frac{1 - \theta}{1 - \beta\theta} \right] \frac{1}{N_t}. \quad (4.2)$$

This implies the hours of work are fixed in the absence of nominal wage contracts.

To anchor the steady state values to those obtained in the previous case, we determine  $\hat{\psi}_1$  by setting the hours of work obtained from (4.2) equal to those in our earlier analysis

$$\hat{\psi}_1 = \frac{(1 - \theta)(1 - N)^\nu}{(1 - \beta\theta)N}, \quad (4.3)$$

where  $\nu$  is a free parameter and  $N$  is defined in (2.27), i.e. the steady state hours of work in the log linear model. Choosing the value of the preference parameter  $\hat{\psi}_1$  in this way, we will have the same steady state across the models.

The contract wage rate in the case of a one-period contract is determined as

$$\begin{aligned} \ln(W_t) = E\{\ln(\hat{\psi}_1) + \ln(C_t) - \nu \ln(1 - N_t) + \ln(P_t) | \Omega_{t-1}\} \\ + \gamma_1 \{\ln(P_t) - E[\ln(P_t) | \Omega_{t-1}]\}, \end{aligned} \quad (4.4)$$

and the contract wage rates for contracts with longer length can be obtained in an analogous way. Following the same steps as in the previous sections, we get the same solution for hours of work as in those sections. In other words, if we make the steady state the same across the models, the solution does not depend on the labour supply decision. This result reflects the fact that the amount of labour employed in a period is determined by the firms (labour demand). Households simply supply the amount of labour demanded by the firms at the predetermined contract wage rate.

The costs of nominal wage contracting are not the same across the models. With the preferences (4.1), the cost of nominal wage contracting is obtained as follows. First, the cost for the  $s$ -th period is

$$\hat{D}_s = \left( \frac{\psi_1}{1 - \nu} \right) [(1 - N)^{1 - \nu} - E_0[(1 - N_t)^{1 - \nu}]]. \quad (4.5)$$

Using a second-order Taylor series expansion, we obtain

$$\begin{aligned} (1 - N_t)^{1 - \nu} = (1 - N)^{1 - \nu} - (1 - \nu)(1 - N)^{1 - \nu}(N_t - N) \\ - \frac{\nu(1 - \nu)(1 - N)^{-1 - \nu}}{2} (N_t - N)^2. \end{aligned} \quad (4.6)$$

Using (4.6) in (4.5), we can rewrite the cost as

$$\hat{D}_s = \frac{\hat{\psi}_1}{(1 - N)^\nu} E_0(N_t - N) + \frac{\nu \hat{\psi}_1}{2(1 - N)^{1 + \nu}} E_0[(N_t - N)^2]. \quad (4.7)$$

Since  $N_t$  has a log-normal distribution, replacing the expectations in (4.7) yields

$$\hat{D}_s = \frac{\hat{\psi}_1 N}{(1-N)^\nu} [\exp(\Pi) - 1] + \frac{\nu \hat{\psi}_1 N^2}{2(1-N)^{1+\nu}} [\exp(4\Pi) - 2 \exp(\Pi) + 1]. \quad (4.8)$$

If we use (4.3), (4.8) can be rewritten as:

$$\hat{D}_s = \left( \frac{1-\theta}{1-\beta\theta} \right) [\exp(\Pi) - 1] + \left[ \frac{\nu(1-\theta)N}{2(1-\beta\theta)(1-N)} \right] [\exp(4\Pi) - 2 \exp(\Pi) + 1]. \quad (4.9)$$

Note that the first term in the right-hand side of (4.9) does not depend on the elasticity parameter  $\nu$ . In addition, since  $\Pi$  does not depend on  $\nu$ , the second term in the right-hand side of (4.9) is increasing with  $\nu$  and hence the costs are also an increasing linear function of  $\nu$ . This result reflects the fact that the agent is risk averse and the degree of risk aversion increases with  $\nu$ .

The average cost in a period and the cost in terms of the steady state GNP can be obtained in the same way as in the previous sections, so we will not repeat those steps here.

### Calibration

The parameter values are determined as in Section 3. Since the elasticity of labour supply depends on the equilibrium allocation as well as on the value of the preference parameter  $\nu$ , we determine the value of  $\hat{\psi}_1$  as (4.3) to keep the steady state allocations the same across the models. Once the value of  $\hat{\psi}_1$  is determined in this way, the elasticity of labour supply depends critically on the value of  $\nu$ . We look at the changes in the welfare cost that result from varying the value of  $\nu$ .<sup>24</sup>

24. If we set up a life cycle problem as in McCurdy (1981), we get an Euler equation

$$\beta \left( \frac{1-N_{t+1}}{1-N_t} \right)^{-\nu} = \frac{W_{t+1}}{W_t(1+r_t)},$$

where  $W_t$  is the wage rate in period  $t$  and  $r_t$  is the interest rate. The elasticity of intertemporal substitution of leisure is  $1/\nu$ . Now we can transform this elasticity into the elasticity of intertemporal substitution of working hours. If we take log of the Euler equation, we have

$$\ln(\beta) - \nu[\ln(1-N_{t+1}) - \ln(1-N_t)] = \ln\left(\frac{W_{t+1}}{W_t(1+r_t)}\right),$$

and if we use (2.20) in this equation, we have

$$\ln(\beta) + \nu\phi_1 \ln\left(\frac{N_{t+1}}{N_t}\right) = \ln\left(\frac{W_{t+1}}{W_t(1+r_t)}\right).$$

Thus, the elasticity of intertemporal substitution of working hours is  $1/(\nu\phi_1)$ . Because we assume that the steady state working hours is one third of total time endowment,  $\phi_1$  can be obtained as

$$\phi_1 = \frac{N}{1-N} = \frac{1/3}{1-1/3} = \frac{1}{2}$$

and thus  $1/(\nu\phi_1) = 2/\nu$ . In other words, the elasticity of intertemporal substitution of hours of work [ $1/(\nu\phi_1)$ ] is two times greater than that of leisure ( $1/\nu$ ). Using this fact, we can infer from Figure 2 the relationship between the welfare cost of nominal wage contracting and the elasticity of intertemporal substitution of labour supply.

### Results

Figure 2 shows how the welfare cost responds to changes in the elasticity parameter  $\nu$ . As the value of  $\nu$  gets larger (i.e. the elasticity of labour supply decreases), the welfare cost increases. As the value of  $\nu$  increases, the elasticity of labour supply decreases and at the same time the agents become more risk averse. According to Figure 2, the rate at which the cost gets larger with the value of  $\nu$  depends on the length of the contracts. When the value of  $\nu$  increases by 1, the welfare costs of nominal wage contracting increases by about 0.02%, 0.03%, 0.04% and 0.05% of GNP in the case of one-, two-, three- and four-period contracts respectively.

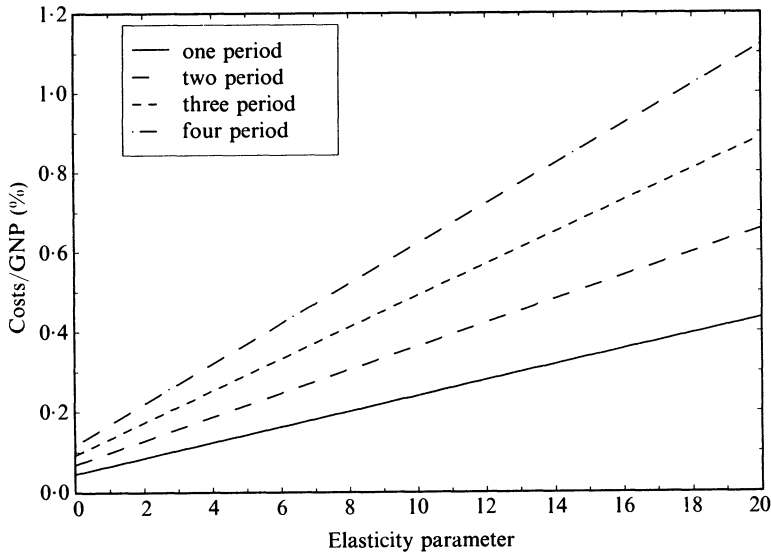


FIGURE 2  
Labor supply elasticity and welfare cost

The case  $\nu = 0$  is the indivisible labour model studied by Rogerson (1988) and Hansen (1985).<sup>25</sup> In this case, the agents are neutral toward the risk associated with the hours of work and hence the welfare costs are the smallest.<sup>26</sup> When  $\nu = 10$ , the welfare cost is about 5.28 times larger than those in the case that  $\nu = 0$ , and when  $\nu = 20$ , the cost is about 9.55 times larger. This holds true in all of the four cases.

Given a value of  $\nu$ , we have executed the same sensitivity analysis as in the previous section. We do not present the results here because they simply show the same pattern of welfare costs as the parameters are varied. The level of the welfare cost of wage contracts is approximately linear in  $\nu$ .

## 5. CONCLUSION

We have presented quantitative estimates of the welfare cost of nominal wage contracts derived in the setting of a dynamic general equilibrium model. The welfare cost can vary

25. They showed that if indivisible labour and employment lotteries are combined, preferences can be expressed as a linear function of the number of employed persons (or employment probability). To reach this result, we need a preference specification which is separable in consumption and hours of work.

26. Although the agent is risk neutral in terms of the labour supply  $N_t$ , there are still welfare costs associated with fluctuations in  $N_t$  because it has a log-normal distribution. That is,  $N_t$  is not a linear function of the shocks.

quite a bit depending on the degree of indexation, the size of money supply uncertainty, and the length of contracts. However, the size and the persistence of real shocks do not affect the welfare cost very much. For any plausible environment the welfare cost of nominal wage contracting are actually quite small. However, the results depend critically on the elasticity of labour supply. If the elasticity of labour supply (i.e. the degree of risk aversion) becomes very low, the welfare cost can be substantial.

The welfare cost in all of the cases considered in this paper are much larger than the cost of fluctuations estimated by Lucas (1987). Although the results are not directly comparable to those in Ball and Romer (1990), the findings in this paper are qualitatively consistent with the findings in Ball and Romer.

Our findings are based on a model economy which incorporates some potentially important restrictions. The assumption of 100% depreciation was made to facilitate finding a closed form solution for the economy with contracts. This assumption, combined with the log-linearity of the preferences in consumption, is what restricts the source of the welfare cost to labour market fluctuations. Hence, the welfare cost estimates we provide may be lower bounds.

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