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Optimal Wage Indexation and Monetary Policy in an Economy with Imported Raw Materials

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An economy's openness from the input side has important effects on the optimal design of its macroeconomic policies. Given the exchange rate regime, the larger the share of imported raw materials in domestic production, the smaller the optimal degree of wage indexation to unanticipated inflation. Alternatively, given the wage indexation parameter, the larger the share of imported raw materials in domestic production, the smaller the optimal degree of foreign exchange intervention by the monetary authority (the more flexible the exchange rate).

This paper analyzes the effect of imported materials on the design of optimal wage indexation and money supply rules in a small open economy. There is a voluminous literature on wage indexation which follows the analytical framework of Gray (1976) and is characterized by the existence of nominal wage contracts in the labor market. The existence of such contracts results in short-run real wage stickiness and a short-run disequilibrium in the labor market which causes welfare loss. Economists have examined various wage indexation schemes that attempt to undo the rigidity due to the labor contracts and thus reduce or eliminate the loss in welfare (see, for example, Fischer, 1977a,b; Karni, 1983; or Marston and Turnovsky, 1985b). One of the principal conclusions of this literature is that full wage indexation to the price level cannot eliminate completely the welfare loss. Full indexation has stabilizing effects when the disturbances that affect the economy are nominal, but has destabilizing effects when the disturbances that affect the economy are real. The optimal degree of wage indexation is between zero and unity and depends on the relative importance of nominal versus real shocks.

In an open economy setting, the question of optimal wage indexation has come up in the discussions of the choice between fixed or flexible exchange rates (see, for example, Sachs, 1980; Flood and Marion, 1982; or Marston, 1982). Turnovsky (1983) and Aizenman and Frenkel (1985) have emphasized that the optimal degree

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of wage indexation and the optimal choice of an exchange rate regime are interrelated. Aizenman and Frenkel show that the optimal degrees of wage indexation and foreign exchange intervention are simultaneously determined as outcomes of a joint optimization problem. Furthermore, since foreign exchange intervention is directly related to monetary policy, the optimization problem concerns the degree of wage indexation together with the parameters of the money supply rule which the monetary authority adopts in its stabilization effort.

Since the middle 1970s the OPEC oil price increase has generated another voluminous literature on the macroeconomic effects of supply shocks. The main question which macroeconomists debated was whether monetary policy should be expansionary after an adverse supply shock and avoid high rates of unemployment, or contractionary and avoid high rates of inflation (see, for example, Gordon, 1975; Findlay and Rodriguez, 1977; Phelps, 1978; Bruno and Sachs, 1981; Blinder, 1981; Bruno, 1984; or Fischer, 1985. The authors emphasized the crucial role that wage indexation plays in the appropriate response of monetary policy, but did not pursue the course of examining optimal monetary policy together with optimal wage indexation policy.

In this paper I bridge the two literatures on optimal wage indexation and the monetary policy response to supply shocks by deriving the optimal wage indexation coefficient together with the optimal money supply rule in a small open economy with imported raw materials which is subject to supply shocks. I am primarily interested in finding how openness of the economy from the input side, as measured by the share of imported raw materials in domestic production, affects both the optimal degree of wage indexation and the optimal money supply response. Aizenman (1985a,b) in two related papers has claimed that under flexible exchange rates, openness from the output side, as measured by the importance of the traded goods sector, increases the optimal wage indexation because it enhances the importance of nominal shocks; and it increases the responsiveness of the optimal money supply rule because it enhances the destabilizing role which relative output prices play in the economy. I do not expect to find similar results when considering openness from the input side. For example, in contrast to openness from the output side, openness from the input side enhances the importance of real shocks.

Section I describes the model which consists mainly of a production and a monetary sector. Section II describes the welfare criterion and derives the expected welfare loss function that will be minimized. Section III contains the main results. Section IV summarizes the principal conclusions.

I. The Model

In this section I outline the structure of the model. I begin by describing the supply side which yields real output, real income and employment as functions of real wages, the relative price of imported raw materials and shocks to productivity. Then I specify the wage indexation rule. Finally, I describe the monetary sector which provides the reduced form solution for the exchange rate, the price level, and the other variables.

The model assumes risk neutrality and incomplete information.[1] Prices and interest rates are observable, but real quantities are observed only with a lag. The government and the private sector possess the same information. Monetary policy can affect real variables in the model, not because of superior information, but because workers are locked into prenegotiated labor contracts before shocks occur, while the monetary authority has the ability to act after it observes the shocks themselves or signals of unobserved shocks.[2]

I.A. *The Supply Side*

The domestic final good, $Y_t = F(N_t, f(L_t, K_t))$, is produced using imported raw materials, N_t, and domestic value added, $Z_t = f(K_t, L_t)$. As Bruno and Sachs (1981), or Marston and Turnovsky (1985a), I assume that the production function F belongs to the constant elasticity of substitution (CES) family, while the value added function f is Cobb–Douglas in labor, L_t, and capital, K_t. Thus:

$$\langle 1' \rangle \qquad Y_t = B\{\beta N^{-\rho} + (1-\beta)(L^{1-a}K^{a})^{-\rho}\}^{-1/\rho} e^{u_t},$$

$$\rho > -1, \qquad u_t \sim N(0, \sigma_u^2),$$

where B is a multiplicative constant and u_t is a white noise productivity shock which *cannot be observed* during time period t. Let us denote by $\sigma = 1/(1+\rho) > 0$ the elasticity of substitution between N_t and Z_t.

I conduct the analysis with all variables expressed as percentage deviations from their initial equilibrium. Let lower case letters denote the percentage change in the corresponding level variable, so, for example, $x_t = (X_t - X_0)/X_0$ where X_0 is the value of X in the absence of shocks (the initial equilibrium). For small deviations from the initial equilibrium equation $\langle 1' \rangle$ can be written as follows:

$$\langle 1 \rangle \qquad y_t = c_1 n_t + c_2(1-a)l_t + u_t,$$

$$c_1 = \beta(Y_0/N_0)^{\rho}, \qquad c_2 = (1-\beta)(Y_0/Z_0)^{\rho},$$

$$0 < c_1 < 1, \qquad 0 < c_2 < 1, \qquad c_1 + c_2 = 1.$$

In the derivation of $\langle 1 \rangle$, I assume that the time period is sufficiently small so that capital remains fixed, *i.e.*, $k_t = 0$. Thus $z_t = ak_t + (1-a)l_t = (1-a)l_t$.[3] c_1 and c_2 are the shares of imported materials and domestic value added in domestic output.

Producers are assumed to be risk neutral and thus choose the short-run inputs L_t and N_t to maximize expected profits:

$$E_t\{P_t Y_t - W_t L_t - P_m N_t\},$$

where E_t denotes the expectations operator conditional on information available at the beginning of period t, P_t is the price of domestic output, W_t the nominal wage rate, and P_m the price of imported raw materials, all expressed in terms of domestic currency. The information set includes all prices and rates of interest, but does not include shocks to other variables within the period. The derived demands for labor, l_t^d, and raw materials, n_t^d, depend, therefore, on the actual relative input prices and on the producer expectations of the unobservable productivity shock. They are written in percentage deviations from equilibrium as follows:

$$\langle 2 \rangle \qquad l_t^d = -1/a)(w_t - p_t) - (c_1/ac_2)(p_{mt} - p_t) + (1/ac_2)E_t u_t$$

$$\langle 3 \rangle \qquad n_t^d = -[1-a)/a](w_t - p_t) - (1/c_2)[\sigma + c_1(1-a)/a](p_{mt} - p_t)$$
$$+ (1/c_2)[\sigma + (1-a)/a]E_t u_t.$$

The higher the real wage rate or the relative price of raw materials, the lower the producer demand for labor and raw materials. But the higher the expected value of the productivity shock, the higher the producer demand for labor and raw materials. Also, the higher the weight of raw materials in the production function, c_1, the more sensitive the demand for labor is to changes in $p_{mt}-p_t$ and $E_t u_t$. Notice that the elasticity of substitution between domestic value added and imported raw materials, σ, does not affect the demand for labor because of the assumed separability of the production function.

Due to costs of continuous renegotiation nominal wages are set by contracts at the beginning of every period before the various shocks hit the economy. Workers agree to supply the amount of labor demanded by firms at the prespecified wage rate. During the period shocks occur that were not anticipated at the beginning of period t and cause disequilibrium in the labor market. Employment is then determined by the demand for labor. This is the familiar contracting framework initiated by the work of Gray (1976). I also assume that producers are international price takers in raw materials. Thus $l=l^d$ and $n=n^d$. Substituting for l and n in ⟨1⟩ we get:

⟨4⟩
$$y_t = -[(1-a)/a](w_t-p_t)-(c_1/c_2)[\sigma+(1-a)/a](p_{mt}-p_t) + (1/c_2)[c_1\sigma+(1-a)/a]E_t u_t + u_t.$$

When raw materials are imported, domestic real income expressed in units of domestic output differs from domestic output. Let y_t^I denote (the percentage change in) real income. y_t^I equals domestic value added expressed in units of output, z_{yt}, plus the productivity shock u_t:

⟨5′⟩
$$y_t^I = z_{yt} + u_t,$$

where z_{yt} is implicitly defined from:

⟨1″⟩
$$y_t = c_1(n_t + p_{mt} - p_t) + c_2 z_{yt} + u_t.$$

Contrast equations ⟨1⟩ and ⟨1″⟩. In ⟨1⟩ value added, $z_t=(1-a)l_t$, is expressed in terms of physical inputs. In ⟨1″⟩ value added, z_{yt}, is expressed in terms of units of final good. Next, from ⟨5′⟩, ⟨1″⟩, and ⟨3⟩ we can derive real income as follows:[4]

⟨5⟩
$$y_t^I = -[(1-a)/a](w_t-p_t)-(c_1/ac_2)(p_{mt}-p_t)+[(1-a)/ac_2]E_t u_t + u_t.$$

Contrast equations ⟨4⟩ and ⟨5⟩. Real income is independent of the elasticity of substitution σ, and equals real output only when $c_1=0$.

I.B. The Wage Indexation Rule

As Aizenman and Frenkel (1985), I assume that nominal wages are set according to the following time invariant rule:

⟨6′⟩
$$\log(W_t) = \log(W_0) + b[\log(P_t) - \log(P_0)],$$

which in percentage deviations is written as follows:

⟨6⟩
$$w_t = bp_t.$$

W_0 is the nominal wage which is bargained at the beginning of the period and would have prevailed had no shocks occurred; b is the indexation parameter. When $b=1$, wages are fully indexed to the unanticipated rate of inflation. When $b=0$, nominal wages are rigid within the period. Equation ⟨6⟩ represents the typical wage indexation scheme of most countries. However, wages can potentially be indexed to other observable variables or shocks. In Section II, I discuss this issue further.

I.C. The Monetary Sector

Thus far I expressed real output, real income and employment as functions of relative prices and the expected productivity shock; and the real wage rate as a function of the domestic price level. Now I utilize international commodity arbitrage conditions to determine the remaining relative prices as functions of the domestic price level; and the equilibrium condition in the money market to determine the domestic price level and the nominal exchange rate. Thus the model's solution depends on exogenous shocks and on the expected productivity shock, which will also be expressed as a function of observable shocks through a signal extraction process that makes the expectations consistent with the model.

I assume that the domestic final good is traded internationally and that purchasing power parity holds:[5]

$$\langle 7\rangle \qquad p_t = e_t + p_t',$$

where e_t denotes the (percentage change in the) nominal exchange rate (the price of a foreign currency in terms of domestic currency), and p_t' denotes the (percentage change in the) foreign price level; p_t' is an observable exogenous stochastic shock which was not anticipated at the beginning of period t. Similarly, since raw materials are imported, the law of one price holds:

$$\langle 8\rangle \qquad p_{mt} = e_t + p_{mt}',$$

where p_{mt}' denotes the (percentage change in the) foreign price of raw materials; p_{mt}' is an observable exogenous stochastic shock which was not anticipated at the beginning of period t.

The demand for real money balances is assumed to be a positive function of domestic real income and a negative function of the domestic nominal interest rate:

$$\langle 9\rangle \qquad m_t^d - p_t = d_y y_t^I - d_i i_t + v_{dt},$$

$$d_y \geqslant 0, \qquad d_i \geqslant 0, \qquad v_{dt} \sim N(0, \sigma_d^2),$$

where m_t^d is the (percentage change in the) demand for nominal money balances, i_t is the deviation from equilibrium of the nominal interest rate level (which I denote by r_t below), and v_{dt} is a stochastic disturbance to money demand which *cannot be observed* during time period t.

Domestic bonds are assumed perfect substitutes for foreign bonds and, thus, open interest parity holds:

$$\langle 10\rangle \qquad r_t = r_t' + E_t \log(S_{t+1}) - \log(S_t),$$

where r_t and r_t' are the domestic and foreign nominal interest rate levels; and S_t and S_{t+1} are the nominal exchange rate levels that correspond to e_t and e_{t+1}. Now I invoke a central assumption for the analysis: all shocks are assumed to be not only unanticipated but also *temporary*. This implies that deviations from equilibrium are temporary. Rational expectations, therefore, imply that the nominal exchange rate is expected to revert back to its equilibrium value, *i.e.*, $E_t \log S_{t+1} = \log S_0$, where

S_0 is the nominal exchange rate in the absence of shocks. Thus, $E_t \log S_{t+1} - \log S_t = \log S_0 - \log S_t = -e_t$. Equation ⟨10⟩ reduces to:

$$\langle 10' \rangle \qquad r_t = r_t' - e_t .$$

Rewriting equation ⟨10′⟩ in terms of interest rate deviations, we get:

$$\langle 11 \rangle \qquad i_t = i_t' - e_t ,$$

where i_t' represents an exogenous shock to the foreign interest rate level (the deviation in the foreign interest rate).

Substituting equations ⟨6⟩, ⟨7⟩, and ⟨8⟩ into the real income equation ⟨5⟩, and then substituting real income and equation ⟨11⟩ into the money demand equation ⟨9⟩, and suppressing the time subscript, we may rewrite the (percentage deviation in the) demand for money as a function of the (percentage deviation in the) nominal exchange rate, actual exogenous shocks, and the expected productivity shock:

$$\langle 12 \rangle \qquad m^d = [1 + d_i + d_y(1-b)(1-a)/a]e + v_d - d_y u + d_y((1-a)/ac_2)Eu$$
$$- d_i i' - d_y(c_1/ac_2)p_n' + [1 + d_y(1-b)(1-a)/a + d_y c_1/ac_2]p'$$

Let us now specify the money supply as follows:

$$\langle 13 \rangle \qquad m^s = v_s - q_e e - q_i i' - q_n p_n' - q_p p', \qquad v_s \sim N(0, \sigma_s^2),$$

where the time subscript is again suppressed. v_{st} is a temporary unobservable control error of the monetary authority, and the parameters q_e, q_i, q_n, and q_p are time invariant and measure the strength of the response of the monetary authority to *observable* deviations from the initial equilibrium. Thus the monetary authority takes into account all the relevant information conveyed by the set of indicators: e, i', p_n', and p'.[6] Later, I will determine the optimal values of the time invariant response coefficients q. Notice that $q_e = 0$ represents a regime of flexible exchange rates, while $q_e = \infty$ represents a regime of fixed exchange rates.

Equating money supply with money demand provides the solution of the nominal exchange rate as a function of actual exogenous shocks and the expected productivity shock:

$$\langle 14' \rangle \qquad e = [1 + d_i + q_e + d_y(1-b)(1-a)/a]^{-1}$$
$$\times \{ -[d_y u - v + d_y(1-a)/ac_2 Eu]$$
$$+ (d_i - q_i)i' + (d_y c_1/ac_2 - q_n)p_n'$$
$$- [1 + q_p + d_y(1-b)(1-a)/a + d_y c_1/ac_2]p' \},$$

where, for notational convenience, v is defined to be the net monetary shock $v_s - v_d$. $v \sim N(0, \sigma_v^2)$ with $\sigma_v^2 = \sigma_s^2 + \sigma_d^2$, and is unobservable. The value of Eu which is consistent with the information set available to economic agents, and which satisfies the requirement of rational expectations, can be easily found from equation ⟨14′⟩. In ⟨14′⟩ all parameters are known. The shocks i', p_n', p' as well as e and Eu are also known. The net monetary shock v and the productivity shock u are unknown, but economic agents can use ⟨14′⟩ to find the linear combination $d_y u - v$. This linear combination summarizes all the available information on u. Thus the optimal forecast about u is a forecast based on knowledge about $d_y u - v$, and can be found by regressing u on $d_y u - v$ and using the regression fit:

$$\langle 15\rangle \qquad Eu = (g/d_y)[d_y u - v], \qquad g = d_y^2\sigma_u^2/(d_y^2\sigma_u^2 + \sigma_v^2),$$

where I assume, without any loss of generality, that u and v are independent.

Substituting $\langle 15\rangle$ into $\langle 14'\rangle$ we find the reduced form solution of e:

$$\langle 14\rangle \qquad \begin{aligned} e = {} & [1 + d_i + q_e + d_y(1-b)(1-a)/a]^{-1} \\ & \times \{-[1 + ((1-a)/ac_2)g](d_y u - v) \\ & \quad + (d_i - q_i)i' + (d_y c_1/ac_2 - q_n)p_n' \\ & \quad - [1 + q_p + d_y(1-b)(1-a)/a + d_y c_1/ac_2]p'\}. \end{aligned}$$

Next, using equations $\langle 7\rangle$ and $\langle 14\rangle$ we derive the reduced form solution of p:

$$\langle 16\rangle \qquad \begin{aligned} p = {} & [1 + d_i + q_e + d_y(1-b)(1-a)/a]^{-1} \\ & \times \{-[1 + ((1-a)/ac_2)g](d_y u - v) \\ & \quad + (d_i - q_i)i' + (d_y c_1/ac_2 - q_n)p_n' + \\ & \quad + [q_i + q_e - q_p - d_y c_1/ac_2]p'\}. \end{aligned}$$

Finally, the reduced form solutions of employment, l, real output, y, and real income, y', follow directly by applying equation $\langle 16\rangle$ together with equations $\langle 6\rangle$, $\langle 7\rangle$, $\langle 8\rangle$ on equations $\langle 2\rangle$, $\langle 4\rangle$, and $\langle 5\rangle$.

II. The Objective Function

The monetary authority's objective is to minimize, or possibly eliminate, the welfare loss due to the friction caused by prenegotiated labor contracts (see Aizenman and Frenkel, 1985). In a frictionless economy, labor supply behavior is described by the following equation:

$$\langle 17'\rangle \qquad \text{Log}(L^s)_t = \log A + b\log(W/P)_t, \qquad b \geqslant 0,$$

where A is a constant, and b is the elasticity of labor supply. Suppressing the time subscript, we may rewrite $\langle 17'\rangle$ in percentage deviations from equilibrium as follows:

$$\langle 17\rangle \qquad l^s = b(w - p).$$

Equating labor supply with labor demand (equations $\langle 2\rangle$ and $\langle 17\rangle$) and utilizing equations $\langle 7\rangle$ and $\langle 8\rangle$, we derive the (percentage deviation in the) market clearing real wage, $(w-p)^*$, and employment, l^*, as follows:

$$\langle 18\rangle \qquad (w-p)^* = [1/(1+ab)]\{-c_1/c_2(p_n' - p') + 1/c_2 Eu\},$$

$$\langle 19\rangle \qquad l^* = [b/(1+ab)]\{-c_1/c_2(p_n' - p') + 1/c_2 Eu\}.$$

Clearly, l is different from l^* and this causes welfare loss. The loss in welfare is depicted in Figure 1 by the area of the producer and consumer surplus triangles.[7] Using equations $\langle 2\rangle$, $\langle 17\rangle$, and $\langle 19\rangle$ we see that this area equals $1/2((1+ab)/b)(l-l^*)^2$. Minimizing the expected value of the welfare loss is,

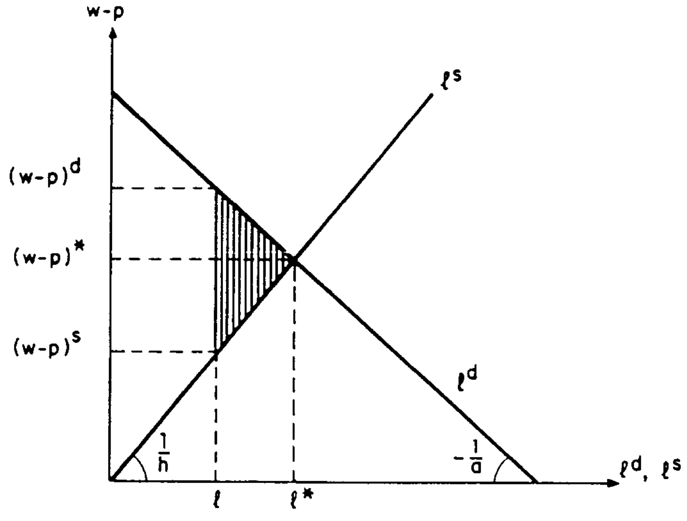

FIGURE 1. Welfare loss from labor market friction.

therefore, equivalent to minimizing H:

$$\langle 20 \rangle \qquad H = E\{-(w-p)-(1/(1+ah))(c_1/c_2)(p_n'-p') \\ +(1/(1+ah))(1/c_2)Eu\}^2.$$

Equation ⟨20⟩ shows that the wage indexation formula that would completely eliminate welfare loss is:

$$\langle 21 \rangle \qquad w|_{H=0} = p-(1/(1+ah))(c_1/c_2)(p_n'-p')+(1/(1+ah))(1/c_2)Eu.$$

Not surprisingly, equation ⟨20⟩ is identical to equation ⟨18⟩, the market clearing real wage rate. The optimal wage indexation formula should be such that it attains the market clearing real wage rate, $(w-p)^*$. According to the optimal wage indexation formula ⟨21⟩, the larger the weight of labor in domestic value added, $1-a$, the smaller the elasticity of labor supply, h, and the larger the weight of imported raw materials in the production of the domestic good, c_1, the larger the optimal response of real wages to exogenous shocks. Observe also that when $h=\infty$, the optimal wage indexation rule is $w=p$ (full indexation), and when $h=0$, the optimal wage indexation rule is the one which stabilizes employment (sets l to zero).[8]

In the following section, I utilize the model of Section I and perform the minimization of H. That is, I assume that instead of equation ⟨21⟩, the wage indexation rule is restricted to the family of rules $w=bp$; and I attempt to find the parameter b and the parameters q of the money supply response which will replicate the market clearing real wage of equation ⟨21⟩.

III. The Results

In this section I find the optimal indexation parameter b and the optimal parameters q of the money supply rule. I also describe the optimal (market clearing) percentage deviations in price, real income and real output. Substituting the wage indexation rule ⟨6⟩ and the price level equation ⟨16⟩ in equation ⟨20⟩, we write the expected welfare loss, H, as follows:

$$\langle 22\rangle \qquad H = E_t\{-H_u(d_y u - v) + H_i i' - H_n p'_n + H_p p'\}^2,$$

$$H_u = (1-b)(1+g(1-a)/ac_2)/[1+d_i+q_e+(1-b)d_y(1-a)/a] - [g/(1+ab)d_y c_2]$$

$$H_i = (1-b)(d_i - q_i)/[1+d_i+q_e+(1-b)d_y(1-a)/a]$$

$$H_n = (1-b)(q_n - d_y c_1/ac_2)/[1+d_i+q_e+(1-b)d_y(1-a)/a] + c_1/(1+ab)c_2$$

$$H_p = (1-b)(d_i + q_e - q_p - d_y c_1/ac_2)/[1+d_i+q_e+(1-b)d_y(1-a)/a] + c_1/(1+ab)c_2$$

Since i', p'_n, and p' are observable, H_i, H_n, and H_p can be set to zero by choosing the parameters q_i, q_n, and q_p as follows:

$$\langle 23\rangle \qquad q_i^* = d_i,$$

$$\langle 24\rangle \qquad q_n^* = (c_1/c_2)[(1-b)(1+b)d_y - (1+d_i+q_e)]/(1-b)(1+ab) = (c_1/c_2)(1-c_2/g)d_y,$$

$$\langle 25\rangle \qquad q_p^* = d_i + q_e + (c_1/c_2)\{-d_y/a + [1+d_i+q_e+(1-b)d_y(1-a)/a]1(1-b)(1+ab)\} = d_i + q_e - q_n^*.$$

Equation ⟨23⟩ shows that the response to foreign interest rate shocks is straightforward: the money supply should contract by the same amount as money demand. This is because, in the model, interest rates affect only the demand for money. The second equality in equations ⟨24⟩ and ⟨25⟩ is found after substituting for the optimal b or q_e, which are derived below. Equation ⟨24⟩ shows that the parameter q_n^* is negative (m' responds positively to p'_n) if $c_2 > g$. q_n^* is, of course, zero when $c_1 = 0$. And equation ⟨25⟩ shows that q_p^* is negatively related to q_n^*. This is because the prices p and p_n enter the real income equation with opposite signs.

Two free parameters are left to minimize H_u, b and q_e. Either b or q_e can be chosen to eliminate H_u. Let us begin by assuming that the degree of foreign exchange intervention, q_e, is predetermined outside the model.

III.A. Optimal Wage Indexation

For a given q_e, H_u is set to zero by choosing the wage indexation parameter b as follows:

$$\langle 26\rangle \qquad b^* = 1 - (g/d_y)(1+d_i+q_e)/[(1+ab)c_2 + (1-a)bg].$$

Let us examine the properties of the optimal degree of wage indexation, b^*. Recall that $c_2 \equiv 1 - c_1$. Equation ⟨26⟩ shows that for a given q_e, the larger the weight of imported raw materials in the production of the domestic good, c_1, the lower the optimal degree of wage indexation. This is a key result of the paper and contrasts with the result of Aizenman (1985b) that a higher degree of openness from the output side increases the optimal degree of wage indexation. Openness from the input side decreases the optimal degree of wage indexation. This is because, as we showed in Section II, a higher c_1 causes a larger change in the market clearing real wage after an expected productivity shock (the H_u term corresponds to the expected productivity shock, Eu); and the real wage can change by a larger amount the lower the degree of indexation. When openness from the input side is completely eliminated, *i.e.*, when $c_1 = 0$, the wage indexation coefficient reaches its highest value:

$$b^*|_{c_1=0} = 1-(g/d_r)(1+d_r+q_r)/[1+ah+(1-a)hg] > b^*$$

Equation ⟨26⟩ also implies that the higher the degree of foreign exchange intervention, q_r, the higher the interest elasticity of the demand for money, d_r, the higher the variance of the productivity shock, σ_u^2 (recall the definition of g in equation ⟨15⟩), the lower the variance of the net monetary shock, σ_v^2, and the lower the elasticity of labor supply, h, the lower the optimal degree of wage indexation. The effect of $1-a$, the weight of labor in domestic value added, on b^* is positive only when $c_2 > g$. Notice that in the absence of productivity shocks, $g=0$ and, consistent with the finding of the previous literature, $b^*=1$, *i.e.*, complete indexation is optimal when the only unobservable shocks are nominal shocks. Complete indexation is also optimal when labor supply is infinitely elastic, *i.e.*, when $h = \infty$.[9]

III.B. *Optimal Foreign Exchange Intervention*

Suppose now that the wage indexation parameter is predetermined outside the model. For a given b, the degree of foreign exchange intervention, q_r, which sets H_u to zero is as follows:

$$\langle 27\rangle \qquad q_r^* = -(1+d_r)+(d_r/g)(1-b)[(1+ah)c_2+(1-a)hg].$$

Clearly, equation ⟨27⟩ is a transformation of equation ⟨26⟩. It implies that for a given b, the larger the weight of imported raw materials in domestic production, c_1, the smaller the optimal degree of foreign exchange intervention. Thus the more open the economy from the input side, the more flexible exchange rates should be. This is because:

1. A smaller q_r implies more flexible prices and thus real wages.
2. A larger c_1 implies a larger change in the optimal real wage.

Equation ⟨27⟩ also shows that the larger the indexation parameter b, the lower the optimal degree of foreign exchange intervention; and for a given b, the larger the interest elasticity of money demand, d_r, the larger the variance of the productivity shock, σ_u^2, the lower the variance of the net monetary shock, σ_v^2, and the lower the elasticity of the labor supply, h, the lower the optimal degree of foreign exchange intervention (and thus the more flexible the exchange rates).

III.C. *Optimal Money Supply*

To gain further intuition let us write the optimal response of the monetary authority in terms of the exogenous shocks and the expected productivity shock. Substituting the optimal values of the parameters from equations ⟨23⟩, ⟨24⟩, ⟨25⟩, and ⟨26⟩ or ⟨27⟩ into the money supply rule ⟨13⟩, and utilizing equations ⟨14⟩ and ⟨15⟩, we get:

⟨28⟩
$$\begin{aligned} m^s - v_s &= -d_i(i' + p') + m_u Eu + m_n(p'_n - p'), \\ m_u &= [q_e/(1 + d_i + q_e)][1/g + b(1-a)/(1+ab)c_2]d_y \\ &= [1 - (1+d_i)/\{(1-b)((1+ab)c_2 + (1-a)bg\}] \\ &\quad \times [1/g + b(1-a)/(1+ab)c_2]d_y \\ m_n &= c_1[-m_u + (1/g - 1/c_2)d_y]. \end{aligned}$$

Notice that the response coefficient m_u is written in two equivalent ways. When q_e appears in the definition of m_u, b was chosen optimally according to ⟨26⟩; and when b appears in the definition of m_u, q_e was chosen optimally according to ⟨27⟩. $m^s - v_s$ represents the voluntary change in the money supply by the monetary authority. The term $-d_i(i' + p')$ neutralizes the effect that domestic interest rate shocks have on money demand and, therefore, on the rest of the economy. The remaining two terms represent the response of the money supply to perceived real shocks which affect money demand by affecting real income. Indeed, if the elasticity of money demand with respect to real income, d_y, were zero, m_u and m_n would be zero, *i.e.*, the monetary authority would have been incapable of reacting to perceived real shocks. Notice that m_u becomes larger with larger values of q_e, c_1, $1-a$, and b.

The oil price shocks of the 1970s generated a hot debate on whether monetary policy should accommodate or counteract external supply shocks. In the framework of our model, the debate centered on the algebraic sign of parameter m_n in equation ⟨28⟩. Observe that the optimal monetary response to external supply shocks, m_n, has an ambiguous algebraic sign. Thus, the answer to the debate is specific to the economy under consideration, since it depends on the size of structural parameters that describe a particular economy. Small values of the parameter g make it more likely that m_n is positive (the derivative of m_n with respect to g is negative). Therefore, accommodation is more likely to be the optimal monetary response, when the elasticity of money demand, d_y, is smaller, when the variance of the productivity shock, σ_u^2, is smaller, or when the variance of the net monetary shock, σ_v^2, is larger (recall the definition of g, equation ⟨15⟩). The degree of openness from the input side, c_1, also has an effect on the algebraic sign of the optimal monetary response, m_n. However, the derivative of m_n with respect to c_1 has an ambiguous sign.

III.D. Optimal Price Level

Substituting the optimal parameters from equations ⟨26⟩ and ⟨27⟩ into the price level reduced form equation ⟨16⟩, we get:

⟨30⟩
$$\begin{aligned} p^* &= \{[1/g + (1-a)b/(1+ab)c_2]d_y/(1 + d_i + q_e)\} \\ &\quad \times [-Eu + c_1(p'_n - p')] \\ &= \{1/(1-b)(1+ab)c_2\}[-Eu + c_1(p'_n - p')]. \end{aligned}$$

The market clearing price level decreases after expected positive productivity shocks, and increases after positive foreign relative price shocks. From equation

⟨30⟩ together with the definition of Eu from equation ⟨15⟩, we conclude that the market clearing price level becomes more responsive to shocks (more volatile), with larger values of c_1, b, $1-a$, d_y, σ_u^2, and with smaller values of σ_r^2. Also when the wage indexation parameter is chosen optimally, the volatility of the optimal price level increases as exchange rates become more flexible (as q decreases).

III.E. Optimal Real Output and Real Income

Substituting the wage indexation rule ⟨6⟩ and the price equation ⟨30⟩ into the real output and income equations ⟨4⟩ and ⟨5⟩, and utilizing equations ⟨7⟩ and ⟨8⟩, we get:

⟨31⟩
$$y^* = u + (1/c_2)[c_1\sigma + (1-a)b/(1+ab)]Eu - (c_1/c_2)[\sigma + (1-a)b/(1+ab)](p_n' - p')$$

⟨32⟩
$$y^{I*} = u + (1/c_2)[(1-a)b/((1+ab)]Eu - (c_1/c_2)[(1+b)/(1+ab)](p_n' - p')$$

The optimal real output and real income increase after expected and actual positive productivity shocks, and decrease after an increase in the foreign relative price of raw materials. From equations ⟨31⟩, ⟨32⟩, and ⟨15⟩ we also conclude that the responsiveness of y^* and y^{I*} to shocks increases with larger values of c_1, b, $1-a$, d_y, σ_u^2, and with smaller values of σ_r^2.

IV. Conclusions

The degree of openness of an economy is very important in establishing appropriate macroeconomic policies. This paper examined how openness from the input side, as measured by the weight of imported raw materials in domestic production, affects the optimal wage indexation and money supply policies. The criterion for determining optimal policies is the minimization of the welfare loss which is caused by disequilibrium in the labor market due to pre-arranged labor contracts. As in Aizenman and Frenkel (1985), the parameter of wage indexation and the parameter which describes the degree of foreign exchange intervention by the monetary authority are dual, *i.e.*, they can alternately be used to attain the same objective.

When the degree of foreign exchange intervention is given, a larger share of imported raw materials in domestic production implies a smaller optimal degree of wage indexation to unanticipated inflation. This is because a larger share of imported raw materials implies that the real wage rate which is consistent with the allocation of resources under market clearing should be more responsive to real shocks; and a more responsive market clearing real wage rate can be accomplished through a lower wage indexation coefficient. Alternatively, when the wage indexation parameter is given, a larger share of imported raw materials in domestic production implies a smaller optimal degree of foreign exchange intervention, that is, more flexible exchange rates. This is because the market clearing real wage rate becomes more responsive to real shocks, as required, when domestic prices become more flexible; and domestic prices become more flexible with a lower degree of foreign exchange intervention.

It is not clear that accommodation of external supply shocks is the optimal monetary response. This depends on the magnitude of many structural parameters that describe the economy, one of which is the degree of openness from the input side. In general, the case for monetary accommodation (instead of counteraction) is strengthened when the income elasticity of money demand becomes smaller, the variance of productivity shocks smaller and the variance of monetary shocks larger.

Notes

1. Aizenman and Frenkel (1986) have also examined optimal wage indexation rules and optimal money supply rules in an economy which is subject to supply shocks, but in a model which assumes complete current information and which does not emphasize the aspects of openness. Also, similar in spirit, but different in emphasis, is a contemporaneous paper by Turnovsky (1986a) on supply shocks and optimal monetary policy.
2. Turnovsky (1986b) analyzes the effects of different information structures on optimal monetary and wage indexation rules.
3. To derive $\langle 1 \rangle$ from $\langle 1' \rangle$ write the Taylor series expansion of $\log(Y)$ around $\log(N)$, $\log(Z)$, and $\log(e^u) = u$, and utilize the first-order terms.
4. This derivation is a short cut. In general, the price index of the domestic value added has to be defined. See Arrow (1974), Bruno (1978), or Marston and Turnovsky (1985).
5. We may allow stochastic deviations from purchasing power parity in the model, but the results remain qualitatively the same.
6. The deviation in the domestic prices level p is also an indicator, but does not contain any extra information because $p = e + p'$.
7. The assumption of risk neutrality justifies this welfare criterion. As Karni (1983) mentioned, in the absence of risk neutrality a policy scheme designed to replicate the auction economy is not optimal. Azariadis (1978) has shown that auction markets do not as a general rule allocate risks efficiently.
8. Karni (1983) and Aizenman and Frenkel (1986) have proposed wage indexation rules similar to $\langle 21 \rangle$. These authors assume complete current information, and thus they depart from the main assumption of the optimal wage indexation literature that economic agents cannot distinguish nominal from real shocks. Their indexation rules contain the actual productivity shock, u, instead of its expected value. Since they endow the government with the ability to observe u (as well as all other real shocks), they reach the conclusion that if the nominal wage rule responds properly to all real shocks, then nominal wages should also be *fully* indexed to the price level p. This is not surprising because in this case the price level carries the influence of nominal shocks only; and can also be seen from equation $\langle 21 \rangle$ by setting $Eu = u$.
9. By setting $c_1 \equiv 1 - c_2 = 0$ and $d_y = 1$, this model and, therefore, its results reduce to the results of Aizenman and Frenkel (1985).

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