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REAL INTEREST RATES, CREDIT MARKETS, AND ECONOMIC STABILIZATION

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ABSTRACT

The role of a real interest rate and a credit aggregate as intermediate monetary policy targets are investigated under the assumption of rational expectations. The analysis expands a standard aggregate model to include a credit market and a market determined interest rate on bank deposits. This allows the implications for output stabilization of real interest rate policy to be examined for a wider variety of shocks than normally considered in the literature, as well as allowing a credit aggregate policy to be studied.

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REAL INTEREST RATES, CREDIT MARKETS, AND ECONOMIC STABILIZATION

1. Introduction

During the 1970s, monetary authorities in a number of countries reoriented the conduct of policy toward setting explicit targets for monetary growth. Two principal criteria of this approach (Friedman [1975]) are that the measure of the money supply be closely related to the policy objective variable — usually nominal income growth — and that the money supply contain reliable information about the future path of this variable. However, instability in estimated money demand equations in the mid-1970s and, more recently, the extent and speed at which innovation has been occurring in financial markets in response to record high interest rates, deregulation, the computerization of the financial industry and other factors [1] have raised concern about the appropriateness of using monetary growth targets for short-run policy purposes. Indeed, two consequences of financial innovation can be identified which would suggest (or in some circumstances clearly have indicated) that the aforementioned criteria are not being met.

The first involves the spread of cash management techniques whereby transactions balances are kept at a minimum. This development results in a shift in the relationship between the money supply and the ultimate policy objective, thereby rendering monetary growth targets less useful unless the changing relationship can be monitored closely. The second involves combining transactions and savings balances, particularly those of the household sector, into an all-in-one account which earns a near-market rate of interest.[2] This development introduces an interest-rate-setting decision, or an own-rate, into the relationship between the money supply and the policy variable.[3]

Because of these changing circumstances, increasing attention is being focused on the possible role of real interest rates as intermediate targets for monetary policy.[4] In considering real interest rates for purposes of conducting policy, four important issues need to be addressed: (i) what real interest rate measure should be used (Feldstein and Summers [1978]), (ii) what ability does the monetary authority have to control the real rate (Shiller [1980]), (iii) what is an appropriate target level, if any, for the real rate, and (iv) what are the consequences of focusing on real interest rates as opposed solely to a monetary aggregate for purposes of setting policy. In this paper, the last three issues are addressed with particular attention being placed on the fourth issue.

As an alternative to both monetary aggregates and real interest rates, Friedman [1983] has suggested that the close correlation between nominal income and a credit aggregate be exploited in the design of monetary policy. By incorporating a rudimentary credit market, the model developed here can also examine the role of a credit aggregate as an intermediate target for monetary policy.

In the next section, a basic aggregate, rational expectations model is extended to incorporate a market for loans, a market determined interest rate on deposits, and a monetary policy rule which permits non-borrowed reserves to deviate from a target path in response to both real interest rate movements and movements in the aggregate quantity of loans. The model is used, in section 3, to examine the implications of such a policy rule for aggregate output and price stability. Conclusions are summarized in section 4.

2. The Model

This section extends a standard aggregate rational expectations model (McCallum [1980]) to incorporate a market for loans and bank reserves. It differs from the recent models of Parkin [1978], Turnovsky [1980] and Benavie and Froyen [1983] by considering policy rules which incorporate responses to a real interest rate and a credit aggregate.

The real side of the economy consists of two equations. The first is a very simple IS relationship determining aggregate demand. This is assumed to take the form

$$(1) \qquad y_t = \beta_o - \beta_1 r_t + \varepsilon_t$$

where y_t is the logarithm of aggregate output and r_t is the real rate of interest on bank loans, the only nonmonetary asset in the model; ε_t is a white noise disturbance term.

The second equation, which completes the specification of the goods market is an aggregate supply function given by

(2) $y_t = \bar{y} + \alpha_1(p_t - {}_{t-1}p_t) + u_t.$

Equation 2 is a Lucas-type aggregate supply equation with $\bar{y}$ and p_t denoting the logs of capacity output and the price level respectively.[5] The notation ${}_{t-1}x_t$ signifies an expectation of a variable x_t formed at time t-1. This general notation is used throughout the analysis and expectations are assumed to be rational. The disturbance term in (2), u_t, is assumed to be a white noise process.

The demand for loans is assumed to be inversely related to the real interest rate on loans and positively related to income. This latter effect reflects an assumption that both firms and households increase their demand for loans as aggregate real spending rises. The loan demand equation is then given by

(3) $l_t - p_t = \delta_o - \delta_1 r_t + \delta_2 y_t + v_t$

where l_t is the log of the nominal quantity of loans. Like u_t and ε_t, v_t is taken to be a white noise disturbance term.

Money demand is specified in equation (4) as the demand for bank deposits:

(4) $$d_t - p_t = \gamma_o + \gamma_1 i_{dt} - \gamma_2 i_t + \gamma_3 y_t + \psi_t$$

where d_t is the log of the nominal stock of deposits, i_{dt} is the nominal interest rate on deposits, i_t is the nominal loan rate and ψ_t is a white noise disturbance term.

Banks are assumed to issue loans and deposits and to hold reserves against their deposits. If banks face a downward sloping demand for loans as a function of the interest rate on loans, an upward sloping demand for deposits as a function of i_{dt}, and an upward sloping supply of federal funds as a function of the interest rate on federal funds, i_{ft}, bank supply of loans will take the form

(5) $$l_t - p_t = a_o + a_1 i_t - a_2 i_{dt} - a_3 i_{ft} + e_{it}.$$

The supply of deposits is assumed to be

(6) $$d_t - p_t = b_o + b_1 i_t - b_2 i_{dt} + b_3 i_{ft} + e_{2t}.$$

The demand for reserves by banks will be assumed equal to required reserves; excess reserves are set equal to zero. If the log of the reserve requirement ratio is ρ and the log of total reserves is tr_t,

(7) $tr_t = \rho + d_t$.

The supply of reserves has two components: non-borrowed reserves nb_t, the monetary authorities' policy instrument, and borrowed reserves. To represent bank borrowing behaviour, assume the ratio of total reserves (borrowed plus non-borrowed) to non-borrowed reserves is given by

(8) $tr_t - nb_t = c_o + c_1 i_t + c_2 i_{dt} + c_3 i_{ft} + e_{3t}$.

Equations (5)-(8) provide a very simple representation of the banking sector. For a discussion of the derivation of such relationships from a model of profit maximizing banks, see Benavie and Froyen [1982].

To link the real and nominal interest rates on loans, the Fisher equation is assumed to take the form

(9) $i_t = r_t + {}_tp_{t+1} - p_t$.

One key feature of this model is that participants in financial markets are assumed to have current-period aggregate information when forming expectations about the one-period ahead rate of inflation. In the supply function, however, ${}_{t-1}p_t$ appears. This can be rationalized in terms of one-period wage contracts in the labour market and in terms of quick processing and dissemination of information in financial markets. This feature of the model is incorporated by using $i_t - {}_tp_{t+1} + p_t$ instead of (the more common) $i_t - {}_{t-1}(p_{t+1}-p_t)$ as the real interest rate. As McCallum [1980] has demonstrated, this specification invalidates the policy ineffectiveness proposition characteristic of one class of rational expectations models developed by Sargent and Wallace [1975] and others by making the unconditional variance of the expectational error for p_t potentially dependent on policy parameters.

To complete the model, a specification of the monetary authorities' behaviour must be adopted. One formulation of policy is that used by Poole [1970] in which a fixed money stock rule is compared with a fixed nominal interest rate rule. However, Sargent and Wallace [1975] have shown that under such an interest rate rule the price level is indeterminate.[6] Accordingly, policy will be characterized by a feedback rule for nb_t that allows nb_t to deviate from a (constant) target in response to past fluctuations in the real interest rate from its expected level. In considering a potential role for real interest rates as an intermediate target, however, it is important to bear in mind that the monetary authorities cannot arbitrarily fix r_t given the model's assumption that aggregate supply equals aggregate demand. In addition, to capture the role of a credit aggregate in the design of monetary policy, the monetary authorities are assumed to adjust nb_t in response to unanticipated movements in the stock of loans. The feedback rule is assumed to take the form

$$(10) \quad nb_t = m_o + m_1(r_{t-1} - {}_{t-2}r_{t-1}) + m_2(l_{t-1} - {}_{t-2}l_{t-1})$$

where m_o denotes the logarithm of the non-borrowed reserves target.[8] If $m_1 = m_2 = 0$, the authorities act to hold non-borrowed reserves at the targeted level. If $m_1 \neq 0 (m_2 \neq 0)$, the monetary authorities allow nb_t to deviate from m_o if, in the previous period, there was an unanticipated movement in the real rate (stock of loans). At the beginning of period t, when the monetary authorities are setting nb_t, r_t and l_t are not yet observable. Any feedback rule for setting nb_t can contain only variables observable at the end of t-1.[7] If r_{t-1} or l_{t-1} differ from what had, at the beginning of period t-1, been expected, the expectational error is viewed as a signal of shocks to the system. The monetary authorities are assumed to respond to $(r_{t-1} - {}_{t-2}r_{t-1})$ and $(l_{t-1} - {}_{t-2}l_{t-1})$, rather than the underlying disturbances (u_{t-1}, v_{t-1}, etc.) directly. As the intermediate target literature has made clear, this leads to suboptimal stabilization policy (Friedman [1975]). However, it is also the case that the relevant class of policies which are likely to actually be followed by central banks, and which have recently been proposed, are more closely captured by a rule such as equation (10) than they are by an optimal feedback rule.

Obtaining the rational expectations solution to the model is straightforward and the details can be found in the appendix. It is shown there that

(11) $p_t = \pi_o + \pi_1' \theta_t + \pi_2' \theta_{t-1}$

where $\theta_t' = (\varepsilon_t, u_t, v_t, \psi_t, e_{1t}, e_{2t}, e_{3t})$ and π_1' and π_2' are 1 x 7 vectors of parameters. Using (11), (1), (2), and (3),

(12) $r_t = \beta_1^{-1}(\beta_o - \bar{y}) - \beta_1^{-1}(\alpha_1 \pi_1' \theta_t + u_t) + \beta_1^{-1} \varepsilon_t$

(13) $y_t = \bar{y} + \alpha_1 \pi_1' \theta_t + u_t$

(14) $1_t = (\pi_o + \delta_o - \delta_1 \beta_1^{-1}(\beta_o - \bar{y}) + \delta_2 \bar{y}) + (\pi_1' + (\delta_1 \beta_1^{-1} + \delta_2) \alpha_1 \pi_1') \theta_t$

$+ \pi_2' \theta_{t-1} - \delta_1 \beta_1^{-1}(\varepsilon_t - u_t) + \delta_2 u_t + v_t$

Equations (11)-(14) will be utilized in the next section to examine the role of m_1 and m_2 in stabilizing economic activity.

3. Policy Analysis

As a necessary prelude to any analysis of stabilization policy, it must be shown that the policy feedback rule (10) does allow the monetary authority to affect the behavior of the economy by its choice of m_o, m_1, and m_2.

From (12),

$$(15) \qquad r_t - {}_{t-1}r_t = -\beta_1^{-1}\left[\alpha_1 \pi_1' \theta_t - \varepsilon_t + u_t\right]$$

Denoting the elements of π_1', by π_{1i}, $i = 1, \ldots, 7$, the conditional variance of r_t can be defined as

$$(16) \qquad \sigma_r^2 = \beta_1^{-2}\left[(1-\alpha_1\pi_{11})^2\sigma_\varepsilon^2 + (1+\alpha_1\pi_{12})^2\sigma_u^2 + \alpha_1^2\pi_{13}^2\sigma_v^2 + \alpha_1^2\pi_{14}\sigma_\psi^2\right.$$

$$\left. + \alpha_1^2\pi_{15}^2\sigma_{e1}^2 + \alpha_1^2\pi_{16}\sigma_{e2}^2 + \alpha_1^2\pi_{17}\sigma_{e3}^2\right]$$

where σ_x^2 denotes the variance of the random variable x, and the elements of θ are assumed to be independently distributed. Dealing first with the case in which $m_2 = 0$ (the monetary authorities do not respond to the credit aggregate), inspection of the solution reported in the appendix reveals $\sigma_r^2 \to o$ as $m_1 \to \infty$. Thus, making the level of non-borrowed reserves respond to past unanticipated movements of the real rate of interest allows fluctuations in the current real rate to be smoothed. In the Poole [1970] analysis, the monetary authorities can arbitrarily fix the nominal interest rate. Here, the monetary authorities can fix the real rate, but only at the value

${}_{t-1}r_t = \beta_1^{-1}(\beta_o - \bar{y})$ which equates expected aggregate supply and

aggregate demand.

From (13), $\sigma_y^2 = E[y_t - {}_{t-1}y_t]^2 \to \sigma_\varepsilon^2$ as $m_1 \to \infty$. Thus, a policy of stabilizing the real rate of interest also serves to insulate real output from financial sector and aggregate supply shocks, but not from aggregate demand shocks. In addition, as

$$m_1 \to \infty,\ p_t - {}_{t-1}p_t \to (1/\alpha_1)(\varepsilon_t - u_t)$$

while ${}_{t-1}p_t$ approaches a finite limit. Note that the financial disturbances ψ_t, v_t, and the e_{it}'s, have no effect on either output or prices under a fixed real rate policy. The price level is determinate under such a policy because, from (10), expected future values of non-borrowed reserves are given by m_o and are thus finite (see McCallum [1981]).

Having demonstrated that r_t is affected by policy in the model, the consequences of targeting on the real interest rate by the monetary authorities can now be analyzed in the context of the model solution when m_1 is finite. The general solution for y_t is given in (13). Comparing (13) with (12) shows immediately that <u>only in the face of aggregate demand (ε_t) shocks is there a conflict between real</u>

<u>interest rate and real output stabilization</u>. To insulate r_t from ε_t requires that $1-\alpha_1\pi_{11} = 0$ which, in turn, requires $m_1 = \infty$. From (13), however, $m_1 = \infty$ makes the coefficient on ε_t in the equation for y_t equal to 1. The appendix shows that stabilizing output in the face of aggregate demand shocks would require that $m_1 < 0$, but insulating y_t from demand stocks makes ε_t's coefficient in (12) equal to β_1^{-1}. A clear conflict exists between stabilizing r and stabilizing y. Shifts in the IS curve cause r and y to move in the same direction. By affecting interest sensitive components of aggregate demand, the movement in r tends to work as an automatic stabilization mechanism. If policy attempts to prevent movements in r, this automatic stabilization mechanism is eliminated and larger output fluctuations result.

Under a pure non-borrowed reserve rule, $m_1=m_2=0$ and the coefficient on ε_t in (13) is less than one so that y_t responds less to ε_t than under a rule which fixes r_t. This result corresponds to that of Poole's analysis in which a money supply rule is preferred if disturbances occur to aggregate demand. The combination policy which insulates y_t from ε_t shocks requires the monetary authorities to reduce the current level of non-borrowed reserves if last period's real interest rate was unexpectedly high ($m_1 < 0$).

In the face of the seven sources of shocks modelled here, the value of m_1 which minimizes σ_y^2 will be a complicated function of the relative variances of the underlying disturbances. However, increases, for example, in the variance of the error term in the money demand equation (4) would tend to increase the σ_y^2 minimizing value of m_1. Thus, greater money demand instability calls for greater deviations of the level of non-borrowed reserves from its target path in response to real interest rate movements.

In rational expectations, equilibrium business cycle models (Barro [1981]), it is usually not optimal to attempt to stabilize output in the face of supply shocks. Barro [1976] suggests a policy criterion which, in the present framework, would call for choosing m_1 to minimize $\sigma_p^2 = E[p_t - {}_{t-1}p_t]^2$. From (11),

$$\sigma_p^2 = \pi_1' \Omega \pi_1$$

where $\Omega = E(\theta_t \theta_t')$. If the monetary authorities adjust nb_t in response to real interest rate movements in order to minimize σ_p^2, it will still be the case that real output and real interest rates are completely insulated from financial sector disturbances.

Suppose now the monetary authorities respond to unanticipated movements in bank loans but not to real interest rate movements (i.e. $m_1 = 0$, $m_2 \neq 0$). It has already been shown that a policy of stabilizing r_t insulates real output from all but aggregate demand shocks. If l_t is stabilized (around ${}_{t-1}l_t$), equations (1)-(3) can be used to derive the associated expressions for unanticipated fluctuations in y, r and p. From (1)-(3) we obtain

$$y_t - {}_{t-1}y_t = -\beta_1(r_t - {}_{t-1}r_t) + \varepsilon_t$$

$$y_t - {}_{t-1}y_t = \alpha_1(p_t - {}_{t-1}p_t) + u_t$$

$$l_t - {}_{t-1}l_t = 0 = p_t - {}_{t-1}p_t - \delta_1(r_t - {}_{t-1}r_t) + \delta_2(y_t - {}_{t-1}y_t) + v_t$$

Solving for $y_t - {}_{t-1}y_t$, $r_t - {}_{t-1}r_t$, and $p_t - {}_{t-1}p_t$ yields

$$(17) \qquad y_t - {}_{t-1}y_t = \frac{\alpha_1\delta_1\varepsilon_t + \beta_1 u_t - \alpha_1\beta_1 v_t}{\alpha_1\delta_1 + (1 + \alpha_1\delta_2)\beta_1}$$

$$(18) \qquad r_t - {}_{t-1}r_t = \frac{(1+\alpha_1\delta_2)\varepsilon_t - u_t + \alpha_1 v_t}{\alpha_1\delta_1 + (1+\alpha_1\delta_2)\beta_1}$$

$$(19) \qquad p_t - {}_{t-1}p_t = \frac{\delta_1\varepsilon_t - (\delta_1 + \delta_2\beta_1)u_t - \beta_1 v_t}{\alpha_1\delta_1 + (1+\alpha_1\delta_2)\beta_1}$$

Equations (17)-(19) show that a <u>policy which eliminates unanticipated movements in a credit aggregate such as bank loans would prevent money demand and banking sector disturbances from affecting</u>

output, the real interest rate on loans, and the price level. For these disturbances, then, a real interest rate policy and a credit aggregate policy are equally effective in stabilizing output. As indicated by equation (17), however, aggregate supply shocks, aggregate demand shocks, and disturbances to loan demand continue to produce output and price fluctuations under a credit aggregate policy.

The factors relevant for a comparison of a real rate policy and a credit aggregate policy are similar to those important in the Poole [1970] comparison of money supply and nominal interest rate policies. Under a policy which eliminates unanticipated movements in the real rate, $y_t - {}_{t-1}y_t = \varepsilon_t$. Under a credit aggregate policy, ε_t still affects output, but the coefficient on ε_t in (17) is less than one. Demand disturbances have a smaller effect on real output under a policy which prevents unanticipated fluctuations in bank loans than in real interest rates.

On the other hand, u_t and v_t influence $y_t - {}_{t-1}y_t$ under a credit policy but do not under a real rate policy[9]. Both policies succeed in preventing money demand disturbances from affecting either real output or the price level.

4. Summary and Conclusions

This paper utilizes an expanded aggregate rational expectations model which includes a credit market to investigate possible roles for real interest rates and a credit aggregate as intermediate targets for purposes of short-run stabilization policy. For this purpose policy is characterized by a feedback rule that permits non-borrowed reserves to deviate from a constant target in response to past fluctuations in either the real interest rate or the stock of loans outstanding from expected levels.

The analysis shows that stabilizing real interest rates and stabilizing output and the price level (or nominal income) in response to demand shocks is not possible. A non-borrowed reserve rule, as with the money supply rule in the original Poole analysis, is preferred in this circumstance. With pure supply or financial sector shocks, output can be stabilized by stabilizing unexpected movements in real interest rates, at the cost, for supply shocks, of increased price variance. Moreover, the monetary authorities can only stabilize the real interest rate at the value determined by equating aggregate supply with aggregate demand.

Stabilizing output and the price level in response to demand shocks is also not possible by following a credit aggregate rule. However, because interest rates must adjust to prevent any unanticipated fluctuations in bank loans with such a rule, the contributions of demand shocks to the variance in output is less than in the case of a real interest rate rule. In contrast, stabilizing credit in response to an aggregate supply shock would not prevent output fluctuations as would a real rate rule, because the resulting movements in interest rates have a proportionate impact on aggregate demand. With financial sector disturbances, other than those to loan demand, the analysis shows the equivalence of a real interest rule and a credit aggregate rule.

FOOTNOTES

[1] Financial innovation in Canada has been spurred primarily by market forces, whereas in the United States, the Depository Institutions Deregulation and Monetary Control Act of 1980 has given additional impetus to developments in financial markets.

[2] The most recent example in the United States is the Super-NOW account which was introduced in early 1983. In Canada, most chartered banks now offer daily interest chequing accounts which combine features of daily interest savings and personal chequing accounts.

[3] See, for example, Benavie and Froyen [1982] for an analysis of the relationship between policy variables and the money supply with a flexible deposit rate.

[4] Moreover, in the United States, recently proposed bills in both Houses of Congress seek to amend the Federal Reserve Act by requiring the Federal Open Market Committee to establish targets for long-term nominal or short-term real rates of interest. For discussions of real rate targeting, see Hester [1982] and Walsh [1983].

[5] See Benavie [1983] for an analysis of monetary policy when the real rate of interest enters the aggregate supply curve.

[6] McCallum [1981] has shown, however, that the nominal interest rate can be used as a policy instrument to achieve a money target without leading to problems of price level indeterminacy. Turnovsky [1980] explicitly takes the view that an indeterminate expected price level is not a problem if the conditional variance is finite.

[7] This differs from Woglom [1979] and Benavie [1983] who allow the monetary authorities to respond contemporaneously to the nominal rate of interest.

[8] Because the error terms in (1) and (2) are assumed to be serially uncorrelated, ${}_{t-2}r_{t-1} = (\beta_0 - \overline{y})/\beta_1)$ is a constant. This would not be the case if ε_t or u_t were serially correlated.

[9] If the objective is to minimize the variance of $p_t - {}_{t-1}p_t$, a comparison of (19) should be made with $(1/\alpha_1)(\varepsilon_t - u_t)$ since this is $p_t - {}_{t-1}p_t$ when $r_t - {}_{t-1}r_t = 0$. The coefficients of both ε_t and v_t in (19) are less than $1/\alpha_1$ in absolute value.

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APPENDIX

This appendix outlines the derivation of the rational expectations solution for p_t reported in section 2.

Equations (3)-(8) and (10) can be used to eliminate l_t, d_t, tr_t, and nb_t, yielding a three equation model of the financial sector which can be written as

$$\text{A.1} \quad \begin{bmatrix} a_1+\delta_1 & & -a_2 \\ b_1-\gamma_2 & -(b_2+\gamma_1) & b_3 \\ c_1+\gamma_2 & c_2-\gamma_1 & c_3 \end{bmatrix} \begin{bmatrix} i_t \\ i_{dt} \\ i_{ft} \end{bmatrix} = \begin{bmatrix} \delta_o-a_o+\delta_1({}_tp_{t+1}-p_t)+\delta_2 y_t+p_t+v_t-e_{1t} \\ \gamma_o-b_o+\gamma_3 y_t+p_t+\psi_t-e_{2t} \\ Z_t \end{bmatrix}$$

where $Z_t = \rho+\gamma_o-c_o+p_t+\gamma_3 y_t+\psi_t-e_{3t}-m_o+(m_2\delta_1+m_2\beta_1\delta_2-m_1)(r_{t-1}-{}_{t-2}r_{t-1})-$

$$m_2\delta_2\varepsilon_{t-1}-m_2(p_{t-1}-{}_{t-2}p_{t-1})-m_2 v_{t-1}.$$

A.1 can be solved for i_t to yield

$$\text{A.2} \quad i_t = h_o+\delta_1 h_1({}_tp_{t+1}-p_t)+h_2 y_t-m_2 h_3(p_{t-1}-{}_{t-2}p_{t-1})+(h_3+h_4+h_5)p_t$$

$$+ (m_2\delta_1+m_2\beta_1\delta_2-m_1)h_3(r_{t-1}-{}_{t-2}r_{t-1}) + h_4(v_t-e_{1t}) + h_5(\psi_t-e_{2t})$$

$$+ h_3(\psi_t-e_{3t})-m_2 h_3 v_{t-1} - m_2\delta_2 h_3\varepsilon_{t-1}$$

where h_i, $i=o,\ldots,5$ are functions of the parameters in A.1. Notice that the h_i's are independent of m_1 and m_2. Subtracting expected inflation from A.2 gives

A.3 $r_t = h_o+(\delta_1 h_1-1)({}_tp_{t+1}-p_t)+h_2y_t-m_2h_3(p_{t-1}-{}_{t-2}p_{t-1})+(h_3+h_4+h_5)p_t$

$+(m_2\delta_1+m_2\beta_1\delta_2-m_1)(r_{t-1}-{}_{t-2}r_{t-1})+h_4(v_t-e_{1t})+h_5(\psi_t-e_{2t})+h_3$

$(\psi_t-e_{3t}-m_2v_{t-1}-m_2\delta_2\varepsilon_{t-1})$.

A.3, together with (1), implies

A.4 $r_t-{}_{t-1}r_t = (1+\beta_1h_2)^{-1}[(\delta_1h_1-1)({}_tp_{t+1}-{}_{t-1}p_{t+1}-p_t+{}_{t-1}p_t)+h_2\varepsilon_t +$

$(h_3+h_4+h_5)(p_t-{}_{t-1}p_t) + h_4(v_t-e_{1t})+h_5(\psi_t-e_{2t})+h_3(\psi_t-e_{3t})]$

Lag A.4 one period and substitute the result, together with (1), into A.3 to produce

A.5 $(1+\beta_1h_2)r_t = h_o+(\delta_1h_1-1)({}_tp_{t+1}-p_t)+h_2\varepsilon_t-m_2h_3(p_{t-1}-{}_{t-2}p_{t-1})$

$+(h_3+h_4+h_5)p_t+(m_2\delta_1+m_2\beta_1\delta_2-m_1)(1+\beta_1h_2)^{-1}[(\delta_1h_1-1)({}_{t-1}p_t-{}_{t-2}p_t)$

$+(1-\delta_1h_1)(p_{t-1}-{}_{t-2}p_{t-1})+h_2\varepsilon_{t-1}+(h_3+h_4+h_5)(p_{t-1}-{}_{t-2}p_{t-1})+h_4$

$(v_{t-1}-e_{1t-1})+h_5(\psi_{t-1}-e_{2t-1})+h_3(\psi_{t-1}-e_{3t-1})]+h_4(v_t-e_{1t})+h_5(\psi_t-e_{2t})$

$+h_3(\psi_t-e_{3t}-m_2v_{t-1}-m_2\delta_2\varepsilon_{t-1})$

From (1) and (2),

A.6 $\beta_1r_t = \beta_o-\bar{y} - \alpha_1(p_t-{}_{t-1}p_t) + \varepsilon_t-u_t$

Using A.6 to eliminate r_t from A.5 yields the following equation in the price level and expectations of the price level.

A.7 $$[\beta_1(h_3+h_4+h_5)+\alpha_1(1+\beta_1 h_2)]p_t = n_o + \beta_1(1-\delta_1 h_1)({}_tp_{t+1}-p_t)$$

$$+ \beta_1(1-\delta_1 h_1)(1+\beta_1 h_2)^{-1}(m_2\delta_1+m_2\beta_1\delta_2-m_1)({}_{t-1}p_t-{}_{t-2}p_t) +$$

$$\beta_1[m_2h_3-(1+\beta_1 h_2)^{-1}(m_2\delta_1+m_2\beta_1\delta_2-m_1)(1-\delta_1 h_1+h_3+h_4+h_5)](p_{t-1}-{}_{t-2}p_{t-1})$$

$$+[(1+\beta_1 h_2)+\beta_1 h_2]\epsilon_t - (1+\beta_1 h_1)u_t - \beta_1 [h_4(r_t-e_{1t})+h_5$$

$$(\psi_t-e_{2t})+h_3(\psi_t-e_{3t})] - \beta_1(1+\beta_1 h_2)^{-1}(m_2\delta_1+m_2\delta_2\beta_1-m_1)[h_2\epsilon_{t-1}$$

$$+h_4(v_{t-1}-e_{1t-1})+h_5(\psi_{t-1}-e_{2t-1})+h_3(\psi_{t-1}-e_{3t-1})] + \beta_1 h_3 m_2$$

$$[v_{t-1}+\delta_2\epsilon_{t-1}]$$

where n_o is a constant term.

Equation (A.7) can be solved for p_t by use of the method of undetermined coefficients. The hypothesized trial solution is of the form

A.8 $$p_t = \pi_o + \pi_1'\theta_t + \pi_2'\theta_{t-1}$$

where $\pi_i' = (\pi_{i1}, \pi_{i2}, \pi_{i3}, .. \pi_{i7})$ and $\theta_t' = (\epsilon_t, u_t, v_t, \psi_t, e_{1t}, e_{2t}, e_{3t})$. Substituting A.8 into A.7, after using A.8 to evaluate the expectations terms appearing in A.7, and equating coefficients on each side leads to the following set of restrictions on π_o, π_1 and π_2:

$$\kappa\pi_o = n_o$$

$$\kappa\pi_{11} = \beta_1(1-\delta_1 h_1)(\pi_{21}-\pi_{11})+(1+\beta_1 h_1) - \beta_1 h_2$$

$$\kappa\pi_{12} = \beta_1(1-\delta_1 h_1)(\pi_{22}-\pi_{12}) - (1+\beta_1 h_1)$$

$$\kappa\pi_{13} = \beta_1(1-\delta_1 h_1)((\pi_{23}-\pi_{13}) - \beta_1 h_4$$

$$\kappa\pi_{14} = \beta_1(1-\delta_1 h_1)(\pi_{24}-\pi_{14}) - \beta_1(h_3+h_5)$$

$$\kappa\pi_{15} = \beta_1(1-\delta_1 h_1)(\pi_{25}-\pi_{15}) + \beta_1 h_4$$

$$\kappa\pi_{16} = \beta_1(1-\delta_1 h_1)(\pi_{26}-\pi_{16}) + \beta_1 h_5$$

$$\kappa\pi_{17} = \beta_1(1-\delta_1 h_1)(\pi_{27}-\pi_{17}) + \beta_1 h_3$$

$$\kappa\pi_{21} = - \beta_1(1-\delta_1 h_1)\pi_{21} + \beta_1(1-\delta_1 h_1)(1+\beta_1 h_2)^{-1} M\pi_{21}$$
$$+ \beta_1 Q\pi_{11} - \beta_1(1+\beta_1 h_2)^{-1} Mh_2 + \beta_1 h_3 m_2 \delta_2$$

$$\kappa\pi_{22} = - \beta_1(1-\delta_1 h_1)\pi_{22} + \beta_1(1-\delta_1 h_1)(1+\beta_1 h_2)^{-1} M\pi_{22} + \beta_1 Q\pi_{12}$$

$$\kappa\pi_{23} = - \beta_1(1-\delta_1 h_1)\pi_{23} + \beta_1(1-\delta_1 h_1)(1+\beta_1 h_2)^{-1} M\pi_{23} + \beta_1$$

$$Q\pi_{13} - \beta_1(1+\beta_1 h_2)^{-1}Mh_4 + \beta_1 h_3 m_2$$

$$\kappa\pi_{24} = - \beta_1(1-\delta_1 h_1)\pi_{24} + \beta_1(1-\delta_1 h_1)(1+\beta_1 h_2)^{-1}M\pi_{24}$$

$$+ \beta_1 Q\pi_{14} - \beta_1(1+\beta_1 h_2)^{-1}M(h_3+h_5)$$

$$\kappa\pi_{25} = - \beta_1(1-\delta_1 h_1)\pi_{25} + \beta_1(1-\delta_1 h_1)(1+\beta_1 h_2)^{-1}M\pi_{25} +$$

$$\beta_1 Q\pi_{15} + \beta_1(1+\beta_1 h_2)^{-1}Mh_4$$

$$\kappa\pi_{26} = - \beta_1(1-\delta_1 h_1)\pi_{26} + \beta_1(1-\delta_1 h_1)(1+\beta_1 h_2)^{-1}M\pi_{26} + \beta_1 Q\pi_{16}$$

$$+ \beta_1(1+\beta_1 h_2)^{-1}Mh_5$$

$$\kappa\pi_{27} = - \beta_1(1-\delta_1 h_1)\pi_{27} + \beta_1(1-\delta_1 h_1)(1+\beta_1 h_2)^{-1}M\pi_{27} +$$

$$\beta_1 Q\pi_{17} + \beta_1(1+\beta_1 h_2)^{-1}Mh_3$$

where $\kappa = \beta_1(h_3+h_4+h_5) + \alpha_1(1+\beta_1 h_2)$

$$Q = \beta_1 \left[m_2 h_3-(1+\beta_1 h_2)^{-1}M(1-\delta_1 h_1+h_3+h_4+h_5)\right]$$

and $M = m_2(\delta_1+\beta_1\delta_2)-m_1$

These equations can be solved in a pairwise fashion for π_{1i}, π_{2i}, $i = 1, \ldots, 7$. For example, the equations for π_{11} and π_{21} can be solved with $m_2 = 0$ to varify that $\lim_{m_1 \to \infty} \pi_{11} = 1/\alpha_1$. Hence, $1 - \alpha_1 \pi_{11} = 0$ as asserted in the text.

Note that $\pi_o = n_o/\kappa$ is independent of m_1 and m_2 so that the price level is well determined.