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OPTIMAL WEIGHTS IN A CHECK-LIST OF MONETARY INDICATORS

Peter J. Stemp
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OPTIMAL WEIGHTS IN A CHECK-LIST OF MONETARY INDICATORS

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# Executive Summary

From January 1985 onwards the Reserve Bank abandoned targeting of monetary aggregates and, instead, adopted a "check-list" approach to monetary policy. In this paper the check-list is interpreted as a money supply rule that can depend not only on interest rates and the money stock but also on any other information that is available to the monetary authority. Under this interpretation the coefficients given to particular variables in the money supply rule can be interpreted as weights in the check-list. Given an appropriate objective criterion determined by the monetary authority, optimal weights in the check-list (optimal coefficients in the money supply rule) can then be derived.

A linear stochastic model of a small open economy is presented. The model embodies the familiar features of the Dornbusch (1976) model. A check-list is formally defined as a linear money supply response function dependent on various endogenous variables in the model. Optimal weights in the check-list are derived by minimising expected deviations of output and the CPI from some pre-planned path.

The implications of the analysis for policy are examined. The suitability of the modeling framework is canvassed. The appropriate definition of the money stock and robustness of results under different lag structures are discussed. It is shown that the same analysis is applicable if the interest rate rather than the money supply is chosen as the policy instrument.

A series of principles concerning the check-list are presented:

- While the weights in the check-list will differ depending on the source of shocks in the economy, the monetary authority can make its own assessment of the source of economic shocks. The monetary authority does not need to make these known to the private sector, provided the private sector is informed about policy objectives and the structure of the economy.
When the monetary authority believes the economy is subject only to financial sector shocks some form of targeting is appropriate. In other cases the money supply will respond gradually to available information.

The check-list is generally not able to completely eliminate the effects of unexpected shocks on the economy. Variables not contained in the objective criterion may even become more volatile. In principle, it is possible to choose a check-list consistent with any pre-planned path for the economy that is feasible in the absence of shocks.

The paper concludes with a brief survey of related literature. Typically, a policy role of the form represented by the check-list is obtained when there is an asymmetry of information between the public and private sectors. Definition and targeting of an appropriate monetary aggregate is another approach that could be adopted in Australia, although uncertainties evolving from financial deregulation make such an approach unlikely to be successful in the near term.

1. INTRODUCTION

In Australia, the removal of nearly all direct regulation of the financial system has been achieved over the course of the 1980s. The major changes along the way include: the removal of official restriction on almost all bank interest rates and on bank lending (December 1980, August 1984, April 1985, April 1986); the emergence of a tender system for the sale of new issues of Commonwealth securities (August 1982); the floating of the Australian dollar and the removal of most exchange controls (December 1983); the entry of new banks and other financial intermediaries (from early 1985).

Interpretation of the economic consequences of financial deregulation has been made more difficult by the impact of an unexpected terms of trade shock leading to a balance of payments crisis. In addition, financial deregulation has been accompanied by changes in financial practices. Increasing re-intermediation from non-bank financial intermediaries to the banks has made interpretation of growth figures for the traditional monetary aggregates, such as M3, increasingly difficult. Continuing change in the financial sector\(^1\) has meant that interpretation of these traditional monetary aggregates continues to be clouded by uncertainty. As a consequence, from January 1985 onwards the Reserve Bank abandoned targeting of monetary aggregates and, instead, adopted a "check-list" approach to monetary policy.

In the words of the Governor (Governor of the Reserve Bank, 1987a): "This approach uses all major economic and financial factors - present and prospective. These include the state of the economy, the balance of payments, prices, other policies and the monetary factors namely interest rates, the exchange rate and the monetary aggregates."

\(^1\) The Governor of the Reserve Bank (1987a) describes other factors such as the off-balance sheet activities of the banking system, the changing focus of bank management from assets to joint asset-liability management, and the removal of foreign exchange controls, which has added new channels for expanding funds by borrowing abroad.
Subsequent work from the Reserve Bank using the RBII model (Edye, Kerrison and Menzie, 1987; Jonson, 1987; Edye and Kerrison, 1987) has examined the effects on the economy of different monetary policy reaction functions. Several cases have been considered. In the first case, market operations were assumed to react so as to hold the money supply unchanged in response to shocks (a "money rule"); in the second case, the exchange rate was held constant (an "exchange rate rule"); in the third case, the reaction was specified in terms of several indicator variables (a "multiple objective rule"). The optimal choice of money reaction function was shown to depend on the source of shocks in the economy. In some cases the "multiple objective rule" was clearly superior. In other cases it was intermediate between the other two rules, suggesting that reacting to a range of variables may be a reasonable "default setting" for monetary policy. This conclusion tends to support the general conclusions of the Poole analysis.

Of particular interest to the study presented in this paper are results using the AMPS model of the Australian economy (Murphy, 1986). The AMPS model has a much more elaborate modelling framework than that presented here, but it does share three key features: uncovered interest parity, rational exchange rate expectations and sticky prices. Murphy's simulation results suggest that for a domestic financial (LM) shock or a shock to the level of foreign interest rates, some form of exchange rate targeting may be optimal. For a shock to foreign prices, some form of money targeting would better stabilise domestic output. In general, the optimal choice of money supply reaction would depend on the source of shocks in the economy. These results thus also add support to the conclusions of the Poole analysis.

In an empirical study of monetary policy in Australia using the Reserve Bank’s RBA79 model of the Australia economy, Jonson and Trevor (1981) examined the effects of three simple rules for monetary policy under a range of exogenous shocks to the economy. Their results support the conclusions of the Poole analysis, at least in the short-run.

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The Treasury model of the Australian economy, NIF88 (Sim, 1988; Sim, Horn and Kouparitsas, 1988), may also provide some insights into the generality of the conclusions of the Poole analysis for the Australian economy. While appropriate simulation results are not available at this time, NIF88 typically assumes backward-looking expectations formation. Such an assumption is generally consistent with the Poole conclusions. The last section of this paper contains a discussion of related literature.
In this paper, the check-list of monetary indicators is interpreted as an extended Poole-type combination policy that can potentially depend not only on interest rates and the money stock but also on any other information that is available to the monetary authority. The check-list is then similar to the Reserve Bank "multiple objective rule" discussed above. Under this interpretation the coefficients given to particular variables in the extended combination policy can be interpreted as weights in the check-list. Given an appropriate objective criterion determined by the monetary authority, optimal weights in the check-list (optimal coefficients in the money supply rule) can then be derived.

This paper is developed as follows: a stochastic model of a small open economy is presented in Section 2. The check-list of monetary indicators is formally defined in Section 3. In Sections 4 and 5 the model is solved and an optimal "check-list" is derived under different objective criteria. Section 6 discusses the policy implications of the theoretical analysis. The relationship of this paper to other literature is briefly discussed in Section 7.

2. A STOCHASTIC MODEL OF AN OPEN ECONOMY

Consider a small open economy operating under a regime of perfectly flexible exchange rates. The economy is assumed to be specialised in the production of a single (composite) commodity, part of which is consumed domestically and the remainder of which is exported. In exchange, the economy imports from abroad, taking the foreign currency price of imports as given. Domestic and foreign securities are assumed to be perfect substitutes in the world capital market. Since the economy is small in the world economy, it faces a given world interest rate.

The government is assumed to have pre-planned a time path for the economy which is consistent, in the absence of unexpected shocks, with an announced time path for the nominal money stock. For notational convenience, the model is expressed relative to this pre-planned time path, so that all variables can be interpreted in deviation form. The model can be summarised as follows:

\[ Y_t = \alpha_1 (S_t + PF_t) + \alpha_2 R_t + u_{1t} \quad \alpha_1 > 0, \alpha_2 > 0 \]  
\[ M_t = \beta_1 Y_t + \beta_2 R_t + u_{2t} \quad \beta_1 > 0, \beta_2 > 0 \]  
\[ P_t - P_{t-1} = \gamma Y_t + u_{3t} \quad \gamma > 0 \]  
\[ R_t = RF_t + ES_{i, t} - ES_{i, t-1} \]  
\[ C_t = \delta P_t + (1 - \delta) (S_t + PF_t) \quad 0 \leq \delta \leq 1 \]  
\[ RF_t = u_{4t} \]  
\[ PF_t = u_{5t} \]

where

\[ Y_t = \text{real output} \]  
\[ P_t = \text{price of domestic output, expressed in logarithms} \]  
\[ PF_t = \text{price of foreign output, expressed in logarithms} \]  
\[ S_t = \text{exchange rate (measured in terms of units of domestic currency per unit of foreign currency), expressed in logarithms} \]  
\[ C_t = \text{domestic consumer price index (CPI), expressed in logarithms} \]  
\[ R_t = \text{nominal domestic interest rate} \]  
\[ RF_t = \text{nominal foreign interest rate} \]  
\[ M_t = \text{nominal money supply, expressed in logarithms} \]

3 In a small open economy such as that represented here, domestic policies can have no influence on foreign prices or foreign interest rates. In planning a path for the economy, the monetary authority will forecast likely paths for these foreign variables and make its pre-planned path consistent with those forecasts.
EX = expectations for the variable X formed at time t (defined more fully below) 

\[ u_t = \text{randomly distributed disturbance, having zero mean, finite variance, zero covariance and no serial correlation.} \]

In particular, \( \text{Var}(u_t) = E(u_t^2) = \sigma^2_t \).

At any point in time, private sector agents are assumed to have full information concerning all lagged variables, summarised by the information set \( I_{t-1}^* \). Private sector agents are also assumed to know the variances of present and future shocks, \( \sigma^2_t \); to be aware of the monetary authority’s pre-planned time path for the economy and the stance of monetary policy (defined below by a money supply rule); and to have full knowledge of all structural parameters in the economy, i.e. \( \alpha \), \( \beta \), \( \gamma \), \( \delta \). This additional information is defined by \( \Phi \). The information sets, \( \Phi, I_{t-1}^* \) are the only information available to private agents in the economy at time t. Specifically, current values of endogenous variables and current shocks, \( u_t \), are not observable by any private agents in the economy. Using this information, we can define \( E X \) more formally as the mathematical expectation of \( X \) given the information sets \( I_{t-1}^* \) and \( \Phi \):

\[ E X = E(X | I_{t-1}^*, \Phi) \quad (1b) \]

The model is a discrete-time, stochastic version of the model presented by Dornbusch (1976). Equation (1a) describes the reduced form for the domestic goods market, where the demand for domestic output depends positively upon the relative price of foreign to domestic goods and negatively upon the nominal interest rate. Money market equilibrium is specified by equation (1b) and is standard. Equation (1c) defines the rate of price adjustment in the domestic economy in terms of a simple Phillips Curve. Uncovered

interest parity is described by equation (1d). The domestic CPI (which is assumed to be relevant to the policy-maker’s objective function, defined below) is defined in equation (1e) as a weighted average of the price of the domestic good and the domestic price of the imported good. Equations (1f, 1g) define the foreign interest rate and foreign price level as deviating from the pre-planned path only by some unexpected shock.

The model embodies the familiar features of the Dornbusch model, with domestic goods prices evolving sluggishly, so that at any point of time the domestic price level is predetermined by history, while the exchange rate is forward looking, allowing it to undergo endogenous jumps as new information impinges on the economy.

To close the model, it is necessary to define a monetary policy rule. This is done in the next Section.

3. A CHECK-LIST OF MONETARY INDICATORS

A description of the check-list of monetary indicators is included in the quotes from the Governor of the Reserve Bank presented in the introduction. Making use of those quotes, the check-list can be characterised by the following properties:

(i) the check-list defines monetary policy;
(ii) the check-list makes use of the information contained in a large number of endogenous variables within the economy;
(iii) the purpose of the check-list is to keep economic variables as close as possible to some appropriately chosen pre-planned path.

---

4 Consistent with a sluggishly evolving product market, the expected rate of domestic inflation is assumed to be zero in this model. Hence the expected real interest rate equals the expected nominal interest rate.

5 Note that the nominal money stock in equation (1b) is deflated by the price of domestic output. The general conclusions of this paper are sustained if the deflator is in terms of the domestic CPI.
The information available to private agents in the economy was discussed in Section 2 and is summarised by the information sets \( I_{t-1} \) and \( \Phi \). This information is assumed to be also available to the monetary authority. In addition, the monetary authority is assumed to have access to the contemporaneous interest rate and exchange rate, represented by the variables, \( R_t \) and \( S_t \). Thus asymmetric information is assumed with the monetary authority having more information than private agents in the economy.\(^6\)

Given this information set, a check-list with properties (i) and (ii) listed above can be represented by a money supply rule of the form:

\[
M_t = \mu_1 S_t + \mu_2 R_t + \mu_3 P_{t-1} + \mu_4 Y_{t-1} + \ldots
\]

(2')

where the dots denote the addition of all lagged variables in the economy. In this model nearly all these lagged variables are redundant and an appropriate check-list can be reduced to a money supply rule of the form:

\[
M_t = \mu_1 S_t + \mu_2 R_t + \mu_3 P_{t-1}
\]

(2)

With the check-list expressed in this form, \( \mu_1, \mu_2 \) and \( \mu_3 \) can be interpreted as weights given to corresponding variables in the check-list.

To incorporate property (iii) into the definition of the check-list, it is first necessary to define a measure of deviations from the pre-planned path. This can be represented by the loss function:

\[
L = k \mathbb{E} Y_t^2 + (1 - k) \mathbb{E} e_t^2, \quad \text{where} \quad 0 \leq k \leq 1
\]

(3)

\(^6\) Because of sluggish price adjustment in this model, the general properties of the check-list presented in this paper would be similar if private agents formed exchange rate expectations based on the same information set as the monetary authority. Siemp (1988) demonstrates this proposition in a similar framework.
This loss function gives differing weights to expected deviations in output and the CPI from the pre-planned path. The weights given to these deviations from a pre-planned path are determined by the choice of $k$. By choosing $k$ close to 1, predominant weight in the loss function is given to deviations in output from the pre-planned path; similarly by choosing $k$ close to zero, predominant weight can be given to deviations in the CPI from the pre-planned path.

Given a choice of loss function (with $k$ chosen as deemed appropriate) optimal values for the weights in the check-list can be defined as the values of the $\mu_i$'s which minimise the loss function $L$.

The outcome of monetary authority's optimisation decision is demonstrated in Figure 1. This diagram assumes that the monetary authority has an objective devoted solely to output stabilisation ($k = 1$). Then, under a money supply fixed at a pre-announced level, unexpected shocks to the economy will mean that over time the path of output will tend to deviate quite markedly from its pre-announced path. Under an optimal money supply rule or check-list, output will tend to stay closer to the pre-announced path. However, even under the check-list, the effect of unexpected shocks may not be completely eliminated. The path of output may continue to show some deviation from the pre-planned path.

4. SOLVING THE MODEL

Substituting, equation (2) into equation (1b), and solving the system of equations given by equations (1a - 1g, 2) the model given in Section 2 can be reduced to:

$$(\alpha_1 \beta_1 - 1)P_1 + \mu_2 P_{-1} = (\alpha_2 \beta_1 - \mu_1)S_1 + (\alpha_2 \beta_1 + \beta_2 + \mu_2)(E \ S_1 - ES_{-1}) + V_t$$

$$(4a)$$

$$\{1 + \gamma_1\}P_t - P_{-1} = \gamma_1 S_1 + \gamma_2(E \ S_1 - ES_{-1}) + W_t$$

$$(4b)$$

where

$$V_t = \beta_1 u_{t-1} + u_{t-2} - (\alpha_2 \beta_1 + \beta_2 + \mu_2)u_{t-1} + \alpha_2 \beta_1 u_{t-1}$$

$$(4c)$$

$$(\mu_1 - \alpha_1 \beta_1)\varphi_1 + (\alpha_2 \beta_1 + \beta_2 + \mu_2)(\pi_1 - 1)\varphi_1 = (1 - \alpha_1 \beta_1)\pi_1 - \mu_3$$

$$(7a)$$

$$(1 + \gamma_1)\pi_1 - 1 = \gamma_1 \varphi_1 + \gamma_2(\pi_1 - 1)\varphi_1$$

$$(7b)$$

$$4\mu_1 - \alpha_1 \beta_1)\pi_2 = (1 - \alpha_1 \beta_1)\pi_2 + 1$$

$$(7c)$$

$$(1 + \gamma_1)\pi_2 = \gamma_1 \pi_2$$

$$(7d)$$

$$(\mu_1 - \alpha_1 \beta_1)\pi_3 = (1 - \alpha_1 \beta_1)\pi_3$$

$$(7e)$$

The objective of the monetary authority can then be summarised as:

$$\min \mu_1 \mu_2 \mu_3 L$$

subject to equations (4a - 4d).

$$\{5\}$$

Solution to the system given by equations (4a-4d), is obtained using an adaptation of the method of undetermined coefficients, as suggested by McCallum (1983). The McCallum solution procedures involves expressing all variables as functions of a minimal set of state variables. For the model presented here the minimal set comprises $P_{-1}$, $V_t$ and $W_t$. Using this methodology $P_t$ and $S_t$ can be expressed as:

$$P_t = \pi_1 P_{-1} + \pi_2 V_t + \pi_3 W_t$$

$$(6a)$$

$$S_t = \phi_1 P_{-1} + \phi_2 V_t + \phi_3 W_t$$

$$(6b)$$

Also, from equations (6a, 6b, 1b):

$$ES_{-1} = \phi_1 P_{-1}$$

$$(6c)$$

$$ES_{-1} = \phi_1 P_{-1}$$

$$(6d)$$

Substituting equations (6a - 6d) into equations (4a - 4b) and equating like terms, the $\pi_i$'s, $\varphi_i$'s satisfy:

$$(\mu_1 - \alpha_1 \beta_1)\varphi_1 + (\alpha_2 \beta_1 + \beta_2 + \mu_2)(\pi_1 - 1)\varphi_1 = (1 - \alpha_1 \beta_1)\pi_1 - \mu_3$$

$$(7a)$$

$$(1 + \gamma_1)\pi_1 - 1 = \gamma_1 \varphi_1 + \gamma_2(\pi_1 - 1)\varphi_1$$

$$(7b)$$

$$4\mu_1 - \alpha_1 \beta_1)\pi_2 = (1 - \alpha_1 \beta_1)\pi_2 + 1$$

$$(7c)$$

$$(1 + \gamma_1)\pi_2 = \gamma_1 \pi_2$$

$$(7d)$$

$$(\mu_1 - \alpha_1 \beta_1)\pi_3 = (1 - \alpha_1 \beta_1)\pi_3$$

$$(7e)$$
\[ (1 + \gamma x_1) \pi_3 = \gamma x_1 \pi_3 + 1 \quad (7f) \]

Equations (7a, 7b) yield a polynomial equation for \( \pi_1 \) of the form:

\[ (\gamma x_1 + \gamma x_2 (1 - \pi_1)) \{ (1 - \alpha_1 \beta_1) \pi_1 + \mu_3 \} = \{(1 - \alpha_1 \beta_1) \pi_1 \} + (\alpha_2 \beta_1 + \beta_2 + \mu_3 (\pi_1 - 1)) \} \{ (1 + \gamma x_1 \pi_1 - 1) \} \quad (8a) \]

Then equations (7a - 7f) can be solved to yield:

\[ \phi_1 = \frac{(1 + \gamma x_1) \pi_1 - 1}{\gamma x_1 - \gamma x_2 (1 + \pi_1)} \quad (8b) \]

\[ \pi_2 = \frac{\gamma x_2}{\Delta} \quad (8c) \]

\[ \phi_2 = \frac{1 + \gamma x_2}{\Delta} \quad (8d) \]

\[ \pi_3 = \frac{\mu_3 - \alpha_1 \beta_1}{\Delta} \quad (8e) \]

\[ \phi_3 = \frac{1 - \alpha_2 \beta_1}{\Delta} \quad (8f) \]

where \( \Delta = \mu_3 (1 + \gamma x_1) - \alpha_1 (\beta_1 + \gamma) \).

Using these solution values for the \( \pi_i \)'s, \( \phi_i \)'s it is now possible to express all endogenous variables in the economy as functions of \( P_{t+1}, V_t, W_t \) as well as the \( \mu_i \)'s and structural parameters in the economy.

5. **OPTIMAL WEIGHTS IN THE CHECK-LIST**

These solutions can be used to derive optimal weights in the check-list, with the optimal weights defined by optimal values of \( \mu_1, \mu_2 \) and \( \mu_3 \).

Firstly, note that the loss function given by

\[ L = k \ E_1 Y_t^2 + (1 - k) \ E_2 C_t^2 \]

can be decomposed into:

\[ L_1 = k \ E_1 (Y_t - Y_t^*)^2 + (1 - k) \ E_1 (C_t - C_t^*)^2 \quad (9a) \]

\[ L_2 = k \ (Y_t^*)^2 + (1 - k) \ (C_t^*)^2 \quad (9b) \]

where

\[ Y_t^* = E Y_t^* \quad C_t^* = E C_t^* \]

It is possible to choose values for \( \mu_1, \mu_2, \mu_3 \) sequentially so that \( L_1 \) is first minimised by the choice of \( \mu_1, \mu_2 \) and \( L_2 \) is then minimised by the choice of \( \mu_3 \).

As a consequence

\[ \min_{\mu_1, \mu_2, \mu_3} L = \min_{\mu_1, \mu_2} L_1 + \min_{\mu_3} L_2 \quad (10) \]

In this section, optimal weights in the check-list are derived. The cases when the monetary authority has an output stabilisation objective \( (k = 1) \), a CPI stabilisation objective \( (k = 0) \) and a mixed stabilisation objective \( (0 < k < 1) \) are now examined in turn.

5.1 **OUTPUT STABILISATION OBJECTIVE**

Output, \( Y_t \), can be represented by the equation:

\[ Y_t = \frac{1}{\gamma} [ (\pi_1 - 1) P_{t+1} + \pi_2 V_t + \pi_3 W_t - \theta_3 ] \quad (11) \]
Then, under an output stabilisation objective, the loss functions are given by:

\[
\begin{align*}
\gamma^2L_1 &= (\pi_1^2 + \pi_2^2 + \pi_3^2)^2 + \alpha_1^2 \sigma_1^2 + \alpha_2^2 \sigma_2^2 - (\pi_1 - \lambda)^2 \sigma_3^2 \\
&\quad + \pi_1 (\alpha_3 \beta_1 + \alpha_2 \beta_2 + \alpha_3 \beta_3) \sigma_3^2 + \pi_2 (\alpha_3 \beta_1 + \beta_2 + \alpha_3) \sigma_4^2 \\
&\quad + \pi_3 (\alpha_3 \beta_1 + \alpha_2 \beta_2 + \alpha_3) \sigma_4^2 \\
&\quad + \pi_1 (\alpha_3 \beta_1 + \alpha_2 \beta_2 + \alpha_3) \sigma_4^2 \\
\gamma^2L_2 &= (\pi_1 - \lambda)^2 \sigma_1^2 \\
\end{align*}
\]

(12a)

(12b)

Substituting the solutions for \(\pi_2, \pi_3\) given in equations (8c, 8e) into equation (12a) and making use of equation (8a), it is then possible to find values of \(\mu_1, \mu_2, \mu_3\) that minimise \(L_1\) and \(L_2\). The full derivation of these optimal values for the \(\mu_i\)'s is contained in the Appendix.

The optimal check-list or money supply rule under the output stabilisation criterion is then given by

\[
M_t = \mu_1 S_t + \mu_2 R_t + \mu_3 P_t - 1
\]

(13a)

where

\[
\begin{align*}
\mu_1 &= -\alpha_1 \Psi \\
\beta_2 + \mu_2 &= +\alpha_2 \Psi \\
\mu_3 &= 1 + \alpha_4 \Psi \\
\end{align*}
\]

(13b)

(13c)

(13d)

and

\[
\begin{align*}
\Psi &= \frac{\Lambda_2}{\Lambda_0} \\
\Lambda_2 &= (1 + \gamma) \sigma_1^2 + (1 - \alpha_1 \beta_1) \sigma_3^2 \\
\Lambda_0 &= (\beta_1 + \gamma) (\sigma_1^2 + \alpha_1^2 \sigma_2^2 - \alpha_1 (1 - \alpha_1 \beta_1)) \sigma_3^2
\end{align*}
\]

(13e)

(13f)

(13g)

This optimal money supply rule which represents the check-list can be re-written in the form:

\[
M_t = \Psi (-\alpha_1 S_t + \alpha_2 R_t + \alpha_3 P_{t-1} - \beta_2 R_t + P_t - 1)
\]

(14)

In this form it is clear that the weights in the check-list depend on the shocks in the economy. The magnitudes of such shocks are represented by the \(\alpha_i\)'s which determine the value of \(\Psi\). It is illustrative to examine the polar cases when the shock from only one sector is dominant. These polar cases are summarised in Table 1.

Thus, when the dominant shock comes from the demand-side (a shock to the IS curve or a shock to foreign prices) the optimal money supply response will depend on the contemporaneous interest rate and feed-back from previous period prices; for example, when contemporaneous interest rates are below the pre-announced path and previous period prices are above the pre-announced path, the monetary authority will respond by setting the money stock higher than previously planned. When the dominant shock is a domestic financial shock (a shock to the LM curve), a form of targeting is optimal, with the monetary policy designed to preserve a specific relationship between contemporaneous interest rates, exchange rates and previous period prices. In the case of a domestic price shock (a shock to the Phillips Curve) the money supply response will depend on the information about current shocks contained in the contemporaneous interest rate and exchange rate. Finally, under a dominant foreign interest rate shock, there are a class of money supply responses which will eliminate the effect of the unexpected shock.

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When a form of targeting is optimal, the interpretation of this analysis should be that the money supply adjusts so that the targeting relationship between other variables is preserved.

In an extended model which included a variable for nominal wages, a shock to the Phillips Curve could also be interpreted as a real wages shock.
TABLE I

OPTIMAL CHECK-LISTS - OUTPUT STABILISATION - POLAR CASES

<table>
<thead>
<tr>
<th>REAL DEMAND SHOCK</th>
<th>( M_t = -\beta_2 R_t + P_{t-1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_1 \neq 0, \sigma_2 = \sigma_3 = 0 ) ( (\Psi = 0) )</td>
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<tr>
<th>DOMESTIC FINANCIAL SHOCK</th>
<th>( \alpha_1 S_t = \alpha_3 R_t + \alpha_1 P_{t-1} )</th>
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</thead>
<tbody>
<tr>
<td>( \sigma_2 \neq 0, \sigma_1 = \sigma_3 = \sigma_5 = 0 ) ( (\Psi = \infty) )</td>
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<table>
<thead>
<tr>
<th>DOMESTIC PRICE SHOCK</th>
<th>( M_t = S_t - \frac{\alpha_2}{\alpha_1} R_t - \beta_2 R_t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_3 \neq 0, \sigma_1 = \sigma_2 = \sigma_5 = 0 ) ( (\Psi = -\frac{1}{\alpha_1}) )</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FOREIGN INTEREST RATE SHOCK</th>
<th>consistent with any check-list of the same form as equation (14) including any of the above check-lists</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_4 \neq 0, \sigma_2 = \sigma_3 = \sigma_5 = 0 ) ( (\text{any value of } \Psi) )</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FOREIGN PRICE SHOCK</th>
<th>same check-list as under a dominant real demand shock</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_5 \neq 0, \sigma_2 = \sigma_3 = 0 ) ( (\Psi = 0) )</td>
<td></td>
</tr>
</tbody>
</table>

Diagrams can be used to demonstrate the manner in which the check-lists operate. Figure 2 presents the IS curve (equation 1a), the LM curve (equation 1b) and the Phillips Curve (PH) (equation 1c) as curves in Y-P space. In addition to \( Y_t \) and \( P_t \), these curves also depend on \( S_t, M_t, R_t \), \( P_f \) and \( P_{t-1} \) as marked on the diagram. No money supply rule at time \( t \) is able to have any impact on current period foreign prices, \( P_f \), or previous period domestic prices, \( P_{t-1} \). In addition the money supply rule can only influence the domestic interest rate, \( R_t \), through the impact of the money supply rule on exchange rate expectations. In an equilibrium situation, \( S_t \) and \( R_t \) adjust so that the three curves intersect at the same point, which also determines equilibrium values of \( P_t \) and \( Y_t \).

Under a fixed money supply (\( M_t = \bar{M} \)), when there are no foreign shocks (\( P_f = P_{t-1} = \bar{P} \)), the domestic interest rate, \( R_t \), will be predetermined by history (\( R_t = \bar{R} \)) as will previous period prices (\( P_{t-1} = \bar{P} \)). The three curves then combine to determine \( Y_t, P_t \) and \( S_t \). Following an unexpected shock, \( S_t \) adjusts so that the three curves all intersect at an appropriate equilibrium point, which also defines equilibrium values for \( P_t \) and \( Y_t \).

The optimal money supply rules used here to represent the check-lists operate by changing the slopes of the three curves in such a way that the effects of unexpected shocks are minimised.

The manner in which the money supply rules operate is illustrated in Figure 3, which examines the impact of an unexpected shock to real demand (a shock to the IS curve) under an output stabilisation objective. Since under a fixed money supply rule (Figure 3A) the Phillips Curve (PH curve) and the LM curve are predetermined by history, all adjustment will have to occur through the IS curve. Following a positive shock to the IS curve, which moves the curve to IS', there will be an appreciation of the exchange rate (\( S_t \) decreases) until the pre-shock equilibrium is reached. But there is no reason why this equilibrium should be on the pre-planned path for output where \( Y_t = 0 \), so expected deviations in output will not necessarily be minimised.
**FIGURE 2**  
MODEL EQUILIBRIUM UNDER FIXED MONEY SUPPLY

**FIGURE 3**  
OUTPUT STABILISATION UNDER REAL DEMAND SHOCKS

**FIGURE 3A: FIXED MONEY SUPPLY**

**FIGURE 3B: OPTIMAL CHECK-LIST**
The equilibrium under an optimal money supply rule (or check-list) is illustrated in Figure 3B. Substituting the optimal money supply response from the first row of Table 1 into equation (1b) yields a new LM curve given by:

$$P_{t+1} - P_t = \beta_1 Y_t$$  (15)

Then the LM curve drawn in Y-P space is predetermined by previous period prices ($P_{t-1} = \bar{P}$) and the Phillips Curve (PH) and LM curve intersect on the planned path for output, where $Y_t = 0$. Following an unexpected shock to the IS curve (which moves the curve to IS') the interest rate and exchange rate will readjust so that equilibrium satisfies $Y_t = 0$, thus ensuring that the stabilisation objective is met.

In cases when a dominant shock comes from another domestic sector of the economy, this will be reflected in a shock to one and only one of the three curves presented in Figure 2. In each of these polar cases, the optimal money supply rule will ensure that the remaining two curves will always intersect on the planned path where $Y_t = 0$, irrespective of contemporaneous values for $R_t$ and $S_t$ and of previous history. Accordingly, following a shock, the domestic interest rate, $R_t$, and the exchange rate, $S_t$, will adjust to eliminate any effects of the shock on output, $Y_t$, and the output stabilisation objective will be met.

Under the output stabilisation criterion, previous deviation of prices from the pre-announced path are reinforced by the monetary authority's rule. If previous period prices are above the pre-announced path ($P_{t-1} > 0$), the monetary authority adopts a more expansionary monetary policy than was previously intended. If previous period prices are below the pre-announced path ($P_{t-1} < 0$), the monetary authority adopts a more contractionary monetary policy. The policy maker ignores the fact that previous prices deviated from the desired path and attempts to keep prices at the previous period's level. This policy minimises the deviation of output from its desired path but has the cost that deviations by other variables which do not appear in the loss function (such as prices) are actually greater than would have been the case without intervention by the monetary authority.

5.2 CPI STABILISATION OBJECTIVE

The CPI, $C_t$, can be represented by the equation:

$$C_t = [\delta \pi_1 + (1 - \delta) \phi_1]P_{t-1} + [\delta \pi_2 + (1 - \delta) \phi_2]Y_t + [\delta \pi_3 + (1 - \delta) \phi_3]W_t$$

$$+ (1 - \delta) \mu_{\text{st}}$$  (16)

Under an objective function, devoted excessively to CPI stabilisation, the loss functions are given by:

$$L_1 = [\beta_1(\delta \pi_2 + (1 - \delta) \phi_2) + \gamma(\delta \pi_1 + (1 - \delta) \phi_1)]^2 + [\delta \pi_2 + (1 - \delta) \phi_2]^2$$

$$+ [\delta \pi_3 + (1 - \delta) \phi_3]^2 + (\alpha_0 \beta_1 + \beta_2 + \mu_2)[\delta \pi_2 + (1 - \delta) \phi_2]$$

$$+ \gamma(\delta \pi_1 + (1 - \delta) \phi_1 + 1 - \delta)^2$$  (17a)

$$L_2 = [\delta \pi_1 + (1 - \delta) \phi_1]P_{t-1}^2$$  (17b)

Using solutions for the $\pi_i$'s, $\phi_i$'s given in equations (8a - 8f), values of $\mu_1$, $\mu_2$ and $\mu_3$ that minimise equations (17a, 17b) can be found. The full derivation of these optimal values for the $\mu_i$'s is contained in the Appendix.

The optimal check-list or money supply rule under the CPI stabilisation criterion will depend on the degree of openness of the economy represented by the magnitude of the parameter $\delta$ in the CPI. A value of $\delta$ close to 1 represents a completely closed economy with respect to the trading of goods (though not with respect to trading in financial assets). A smaller $\delta$ represents a more open economy.

In the general case, the optimal money supply rule is given by:
\[ M_1 = \mu_1 S_1 + \mu_2 R_1 + \mu_3 P_{t-1} \]  \hspace{1cm} (18a)

where

\[ \mu_1 = \Theta \]  \hspace{1cm} (18b)

\[ \beta_2 + \mu_2 = \frac{\sigma_2 (1 - \delta)(\beta_1 + \gamma) + \delta \gamma \Theta}{\gamma \alpha_1 + (1 - \delta)} \]  \hspace{1cm} (18c)

\[ \mu_3 < 0 \]  \hspace{1cm} (18d)

and

\[ \Theta = \frac{\Omega_b}{\Omega_b} \]  \hspace{1cm} (19a)

\[ \Omega_a = (1 - \delta)(\beta_1 + \gamma) + (1 + \gamma \alpha_1)(1 + \gamma \alpha_1 - \delta) \sigma_2^2 \]

\[ + (1 - \alpha_1 \beta_1)(1 - \alpha_1 \beta_1 - \delta) \sigma_3^2 \]  \hspace{1cm} (19b)

\[ \Omega_b = \delta(\beta_1 + \gamma) + (1 - \alpha_1 \beta_1) \sigma_2^2 + \alpha_1(\beta_1 + \gamma)(1 + \gamma \alpha_1 - \delta) \sigma_3^2 \]  \hspace{1cm} (19c)

Equations (18a - 18d, 19a - 19c) demonstrate the optimal money supply rules in the general case when the economy is not necessarily completely closed (\( \delta \leq 1 \)). Here, as in the case of an output stabilisation objective, the check-list will depend on the source of shocks in the economy. Again, in the case of a dominant financial shock (L), the optimal response involves some form of targeting with the money supply reacting to preserve a particular relationship between variables in the economy. This result remains if the only other significant shock is a shock to foreign interest rates. When other shocks in the economy are significant the optimal check-list will involve a money supply rule that moves gradually in response to deviations in the paths of specific variables from pre-planned paths. As before, the weights in this check-list will depend upon the structural parameters in the economy and the source and magnitude of shocks in the economy.

Unlike under the output stabilisation criterion, under the CPI stabilisation criterion, the optimal check-list will tend to offset previous deviations in prices from their pre-announced path. This is reflected in the choice of \( \mu_3 < 0 \). This policy will minimise the deviation of the CPI from its desired path but will have the cost that deviations in output will be increased. Once again, it is observed that there is no such thing as a free lunch, with stabilisation of the CPI only being achieved by increasing the volatility of other variables that do not appear in the monetary authority's objective criterion, such as output.

5.3 MIXED STABILISATION OBJECTIVE

If some weight is given to both output stabilisation and CPI stabilisation objectives (0 < k < 1), then under a dominant financial shock some form of interest rate or exchange rate targeting will still be optimal. Under all other shocks, the optimal money supply will continue to move gradually in response to deviations from the pre-planned path. Depending on the magnitude of k, the coefficient of lagged prices, \( P_{t-1} \), in the money supply rule may be greater or less than zero. In any case, it will be unlikely under a mixed stabilisation objective that prices and output will both fall on their pre-planned paths. In general, provided 0 < k < L2 > 0 and the expected loss, L, will be non-zero. Thus it will not be possible to completely eliminate the effects of shocks on both variables in the stabilisation objective.

6. IMPLICATIONS FOR POLICY

In this section, the earlier theoretical analysis is used to draw implications for real world policy. To do this, one must first question how realistic the assumptions underlying the analysis have been? How realistic is the underlying model and, in particular, how realistic are the assumptions about information available to different agents?
Similar to other theoretical analyses of this type, the model used here has been rudimentary. As pointed out in the introduction, it does have many properties in common with one large macro model of the Australian economy, the AMPS model. It also provides a useful paradigm within which issues associated with monetary policy in a small open economy can be canvassed. Clearly the simple model presented here cannot hope to represent the complexities of the Australian economy. No apologies are made for that. However, there are some issues of model construction that bear strongly on whether such a model is an appropriate vehicle for the examination of monetary policy. It is those issues that are now addressed more fully.

Firstly, there is the question of what the appropriate definition of the nominal money stock, \( M_n \), should be. Throughout the analysis, no explanation has been made as to whether \( M_n \) refers to \( M_1, M_3, \) Broad Money or some other monetary aggregate. The theoretical analysis can be best interpreted if \( M_n \) is interpreted as that monetary aggregate which gives a best fit to an estimated money demand function. The money demand equation residual should then be interpreted as a component of the unexpected shock, \( u_{2t} \). In addition, the nominal money stock may only be able to be controlled subject to error. Such error in controlling the money stock can also be interpreted as a component of the unexpected shock, \( u_{2t} \).

Secondly, it has been argued that the short-term interest rate rather than the monetary aggregate is now the instrument of monetary policy. This issue is addressed by Dotsey (1987). The money supply rule that defines the check-list only describes a specific relationship that must be preserved between variables in the economy. If the lag structure of the economy was as simple as that presented in this model then the optimal money supply rule derived here to represent the check-list could easily be inverted to give an interest rate reaction function. As such, it can equally be represented by an interest rate rule of the form:

\[
R_t = \eta_1 s_t + \eta_2 M_t + \eta_3 P_{t+1}\tag{19a}
\]

where

\[
\eta_2 = \frac{\mu_2}{\mu_2} \tag{19b}
\]

\[
\eta_3 = \frac{\beta_3}{\mu_2} \tag{19d}
\]

For example equation (14), the optimal money supply rule under an output stabilisation objective, can be inverted to give:

\[
R_t = \left( \frac{1}{(\alpha_2 \Psi \cdot \beta_2)} \right) \left[ M_t \cdot P_{t+1} + \alpha_1 \Psi (S_t \cdot P_{t+1}) \right] \tag{20}
\]

Of course the lag structure in the economy is far more complex than the simple lag structure presented here. That leads to a third point. Oster (1988) shows that the length and variability of monetary lags has important policy implications. He describes a process of monetary transmission, starting with adjustment of short-term interest rates and follows their impact on other variables in the economy. Econometric theory is generally unable to derive lag structures that are robust over different estimation periods. While the analysis presented here is based on a simple lag structure, the same methodology could be implemented for any other agreed lag structure.

With respect to the assumptions about information available to different agents in the economy, the information available to private agents in the economy was defined in Section

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10 When \( \Psi = \frac{\beta_2}{\alpha_2} \), then the optimal interest rate rule will be independent of the interest rate. In this case the interest rate, \( R_t \), should be adjusted so that the appropriate relationship between other variables is preserved.
2 and is summarised by the information sets \( I_{t-1}^* \) and \( \Phi \). \( I_{t-1}^* \) is defined to contain full information concerning all lagged variables. \( \Phi \) is defined to contain the variances of present and future shocks (given by the \( \sigma_i^2 \)’s); to contain the monetary authority’s pre-planned path for the economy; to contain the \( \mu_i^2 \)’s that define the money supply rule associated with the check-list; and to contain all structural parameters that define the economy.

This information is used by private agents to form expectations about future values of the exchange rate given by:

\[
E S_1 = \Phi_1 P_{t-1} \tag{6c}
\]

\[
E S_{t+1} = \Phi_1 \pi_1 P_{t-1} \tag{6d}
\]

These expectations use the lagged information set \( I_{t-1}^* \) and knowledge of the coefficients \( \Phi_1 \), \( \pi_1 \). But these coefficients can be derived using only knowledge about the pre-planned path for the economy, the monetary authority’s stabilisation objectives, and the structure of the economy. In particular, to form expectations, private agents do not need to know the source of shocks (values of \( \sigma_i^2 \)’s) or the precise structure of the check-list.

Recent years have seen a tendency for the Reserve Bank to provide more information about its policies. In the words of the Governor (Governor of the Reserve Bank, 1987a): “We have sought to provide more - and more frequent - statistical and narrative information about what is being done in the market place. But we need constantly to examine whether we cannot do more. We are now mainly dependent on the use of private financial markets to give effect to monetary policy. That means as far as possible avoiding arbitrary actions and having well-informed markets.” Thus it seems likely that the authorities are attempting to provide private agents with an understanding of planned future paths of economic variables, of the Reserve Bank’s stabilisation objectives and of its interpretation of the state of the economy.

Even given the increased availability of information, the model has assumed an asymmetry of information, with the monetary authority being also aware of contemporaneous exchange rates and interest rates. Stemp (1988) demonstrates that because of the sluggish price adjustment inherent in this model, the optimal money supply rules derived in this paper would be little changed if the same information was used in the formation of exchange rate expectations as is used by the monetary authority.

In practice, the monetary authority is not going to know with certainty what the magnitudes of shocks in the economy are going to be. An assessment will have to be made as to where future shocks are likely to occur. This assessment will then influence the choice of a monetary policy rule. As demonstrated above, the conclusions of the theoretical analysis hold even if the monetary authority does not convey to private sector agents its interpretation of likely future shocks and its choice of monetary response. Private sector agents will make an appropriate response if they only understand the government’s plans for the economy and its interpretation of the underlying economic structure.

Given the preceding analysis, there are several general principles that can be elicited concerning the operation of an optimal check-list. These principles are:

(a) The weights in the check-list will differ, depending on the monetary authority’s interpretation of the source and magnitude of shocks in the economy and on the monetary authority’s stabilisation priorities.

(b) Private sector agents require knowledge about the pre-planned path for the economy, the monetary authority’s stabilisation objectives, and the structure of the economy.

(c) Private sector agents do not need to know the source of shocks (values of \( \sigma_i^2 \)’s) or the precise structure of the check-list. The monetary authority can make its own

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11 Private agents can then use equations (9b, 8b) to derive values for \( \Phi_1 \), \( \pi_1 \).
assessment of likely future shocks, providing it implements policy in accord with the information made available to the private sector in (b).

(d) When the monetary authority believes the economy is subject only to financial sector shocks (comprising shocks to the LM curve and foreign interest rate shocks), some form of interest rate and exchange rate targeting will be appropriate.

(e) When the monetary authority believes there are other sources of shocks to the economy, the optimal check-list will typically relate money supply to other economic variables which are known to the monetary authority and which contain information about contemporaneous and past shocks.

(f) While monetary policy can be chosen so that certain aggregates are stabilised, the pursuit of a specific stabilisation objective will typically mean that other variables, not contained in the stabilisation objective, become more volatile.

(g) Even when full weight is given to one variable in the stabilisation objective, it may not be possible to completely eliminate the effects of shocks on the path of this variable.

(h) At no point in the analysis was any pre-planned path for the economy specified. In principle any path can be chosen provided it is feasible in the absence of shocks. The planned path for the economy will imply an expected path for the nominal money supply (as well as fiscal and wages policy). Such a path should be made known to private sector agents as described in (b).

In particular, the analysis allows examination of a specific proposition about recent Australian monetary policy. This asserts that, in spite of rhetoric about the use of a check-

list to determine monetary policy since January 1985, the Reserve Bank has reoriented monetary policy toward a de facto exchange rate target zone. The proposition has been put forward by several commentators with the relevant historical episodes summarised by Hogan and Nguyen (1987). Point (d) above shows that, under an optimal check-list regime, some form of exchange rate targeting would be appropriate in times when the Reserve Bank determined that the economy was dominated by financial sector shocks. This may well have occurred in the economic climate after financial deregulation. Some evidence in support of this interpretation of events is provided by recent tests for stability of the Australian demand for money equation (Stevens, Thorp and Anderson, 1987; Blundell-Wignall and Thorp, 1987). These studies provide evidence that previously robust money demand relationships tended to break down in the 1980's.

7. RELATED LITERATURE

Throughout this paper, emphasis has been given to the Australian policy debate with little discussion of the international literature. In this section, important theoretical contributions are briefly acknowledged.

The implications of the dissemination of information between public and private sector agents has been extensively examined in the theoretical literature. Typically a Poole-type combination policy is obtained when there is an asymmetry of information between the public and private sector (Barro, 1976; Woglom, 1979; Canzoneri, Henderson and Rogoff, 1983; Dotsey and King, 1986). This conclusion breaks down in a world in which all market expectations are formed rationally and in which no variables evolve sluggishly (Sargent and Wallace, 1975; Dotsey and King, 1983). Stemp (1988) examines the robustness of optimal money supply rules under different expectations scenarios.

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12 The optimal choice of a pre-planned path for the nominal money supply is discussed in Stemp and Tumovsky (1987).

In an open economy framework, analogy with the Poole-type combination policy suggests that the optimal monetary policy should involve a money supply rule which includes the exchange rate as well as the interest rate and other indicators in the economy. This conclusion is supported by studies which have emphasised the relationship between monetary policy and exchange rate policy (Boyer, 1978; Roper and Turnovsky, 1980a; Artis and Currie, 1981; Gardner, 1983; Daniel, 1985).

Other works by Kareken, Muench and Wallace (1973), and Le Roy and Lindsey (1978) have emphasised that the pegging of money supply is, in general, a sub-optimal form of stabilisation policy. Subsequent research has examined the use of broader monetary aggregates, such as M2 and M3. Barnett (1980, 1982) has argued that the choice of aggregates should be expanded to a much wider range of possibilities. Roper and Turnovsky (1980b) argue that an optimal aggregate for stabilisation can be found by defining the monetary aggregate more broadly. Horne and Monajemi (1985) extend this approach to Australia. Clearly, definition and targeting of an appropriate monetary aggregate is another approach that could be adopted in Australia, though uncertainties evolving from financial deregulation make such an approach unlikely to be successful in the near term.

APPENDIX

In this Appendix, necessary conditions for minimising the loss functions, \( L_1 \) and \( L_2 \), are derived under the output and CPI stabilisation criteria.

OUTPUT STABILISATION

Define

\[
\gamma^* L_{Y} = (\pi_2 \beta_1 + \pi_3 \gamma)(\sigma_1^2 + \alpha_1^2 \sigma_3^2) + \pi_2^2 \sigma_2^2 + (\pi_3 - 1)^2 \sigma_3^2
\]  

(A.1)

Since \( \pi_2, \pi_3 \) are independent of \( \mu_2 \) and \( \mu_3 \), it follows that so is \( L_Y^* \). Hence equations (12a, 12b) can be minimised by choosing \( \mu_1 \) to minimise \( L_Y^* \), then choosing \( \mu_2 \) so that:

\[
\pi_3(\alpha_2 \beta_1 + \beta_2 + \mu_2) + \pi_3 \gamma \pi_2 = 0
\]  

(A.2a)

and then choosing \( \mu_3 \) so that:

\[
\pi_1 = 1
\]  

(A.2b)

The value of \( \mu_1 \) that minimises \( L_Y^* \) will satisfy:

\[
\left( \frac{L_Y^*}{\partial \mu_1} \right) = \left[ \pi_1 \pi_2 \frac{\partial \pi_2}{\partial \mu_1} + \gamma \frac{\partial \pi_3}{\partial \mu_1} \right] \sigma_1^2 + \alpha_1^2 \sigma_3^2
\]

\[
+ \pi_2 \pi_3 \sigma_2^2 + (\pi_3 - 1) \frac{\partial \pi_1}{\partial \mu_1} \sigma_3^2 = 0
\]  

(A.3a)

and equation (A.3a) can be reduced to:
\[
\left(\frac{3\lambda^2}{2}\right)\frac{\partial L^*_C}{\partial \mu_1} = -\gamma(\gamma + \gamma) \mu_1 (\sigma_1^2 + \alpha_1^2 \sigma_2^2) + \gamma(\gamma + \gamma) (1 + \gamma \alpha_1) \sigma_2^2
\]
\[
- \gamma(\gamma + \gamma) (1 - \mu_1) (1 - \alpha_1 \beta_1) \sigma_3^2 = 0
\]  
(A.3b)

Manipulation of equation (A.3b) yields equation (13b).

Equation (A.2a) reduces to:
\[
(\gamma + \gamma)(\alpha_2 \beta_1 + \beta_2 + \mu_2) + \gamma \alpha_2 (\mu_1 - \alpha_1 \beta_1) = 0
\]  
(A.4)

which reduces to equation (13c).

Finally substituting equation (A.2b) into equation (8a) yields:
\[
\mu_3 = 1 - \mu_1
\]  
(A.5)

which reduces to equation (13d).

**CPI STABILISATION**

Define:
\[
L^*_C = (\beta_1 \delta \sigma_2 + (1 - \delta) \phi_2) - \gamma(\delta \sigma_3 + (1 - \delta) \phi_3) \sigma_1^2
\]
\[
+ (\delta \sigma_2 + (1 - \delta) \phi_2) \sigma_2^2 + (\delta \sigma_3 + (1 - \delta) \phi_3) \sigma_3^2
\]
\[
+ (\alpha_1 \beta_1 \delta \sigma_2 + (1 - \delta) \phi_2) + \gamma \alpha_2 \delta \sigma_3 + (1 - \delta) \phi_3) + 1 - \delta \sigma_3^2
\]  
(A.6)

\(L^*_C\) is independent of \(\mu_2\) and \(\mu_3\) and equations (17a, 17b) can be minimised by choosing \(\mu_1\) to minimise \(L^*_C\), then choosing \(\mu_2\) so that:
\[
(\alpha_2 \beta_1 + \beta_2 + \mu_2) (\delta \sigma_2 + (1 - \delta) \phi_2) + \gamma \alpha_2 \delta \sigma_3 + (1 - \delta) \phi_3) = 0
\]  
(A.7a)

and then choosing \(\mu_3\) so that:
\[
\delta \sigma_1 + (1 - \delta) \phi_1 = 0
\]  
(A.7b)

The value of \(\mu_1\) that minimises \(L^*_C\) will satisfy:
\[
\left(\frac{\partial L^*_C}{\partial \mu_1}\right) = -(1 + \gamma + \gamma)(\beta_1 + \gamma)(1 - \delta)(\beta_1 + \gamma) + \delta \mu_1 \sigma_1^2
\]
\[
+ (\gamma + \gamma)(1 + \gamma + \gamma) \sigma_2^2 + (1 - \alpha_1 \beta_1) \delta \mu_1 + (1 - \delta - \alpha_1 \beta_1) \sigma_3^2
\]
\[
+ \alpha_1 (\beta_1 + \gamma)(1 + \gamma + \gamma) \mu_1 \sigma_3^2 = 0
\]  
(A.8)

Manipulation of equation (A.8) yields equation (18b).

Equation (A.7a) implies that:
\[
(\alpha_2 \beta_1 + \beta_2 + \mu_2)(1 + \gamma + \gamma) + \gamma \alpha_2 (\delta \mu_1 + (1 - \delta - \alpha_1 \beta_1) = 0
\]  
(A.9)

leading to equation (18c).

Combination of equations (8b, A.7b) shows that the optimal value of \(\pi_1\), given by \(\pi_1\), satisfies:
\[
0 \leq \pi_1 \leq \frac{(1 - \delta)}{\gamma \alpha_2}
\]  
(A.10a)

and substituting \(\delta = 1\) into equations (A.7a, A.10a, 8a) yields:
\[
\mu_3 = \frac{\mu_1 - \alpha_1 \beta_1}{\gamma \alpha_1} < 0
\]  
(A.10b)

By continuity in \(\delta\), for \(\delta\) sufficiently close to 1, \(\mu_3 < 0\), as in equation (18d).
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