

Le, Mai Vo; Gillman, Max; Minford, Patrick

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An Endogenous Taylor Condition in an Endogenous
Growth Monetary Policy Model

Vo Phuong Mai Le, Max Gillman and Patrick Minford

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Cardiff Business School
Aberconway Building
Colum Drive
Cardiff CF10 3EU
United Kingdom
t: +44 (0)29 2087 4000
f: +44 (0)29 2087 4419
business.cardiff.ac.uk

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An Endogenous Taylor Condition in an Endogenous Growth Monetary Policy Model*

Max Gillman, Cardiff Business School; Economics Institute, HAS
Patrick Minford, Cardiff Business School; CEPR
Mai Vo Le, Cardiff Business School

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Abstract

The paper derives a Taylor condition as part of the agent's equilibrium behavior in an endogenous growth monetary economy. It shows the assumptions necessary to make it almost identical to the original Taylor rule, and that it can interchangeably take a money supply growth rate form. From the money supply form, simple policy experiments are conducted. A full central bank policy model is derived that includes the Taylor condition along with equations comparable to the standard aggregate-demand/aggregate-supply model.

Keyword: Taylor Rule, endogenous growth, money supply, policy model

JEL: E51, E52, O0

*Corresponding author: Max Gillman, Cardiff University Business School, Colum Drive, Cardiff, UK CF10 3EU gillmanm@cf.ac.uk

1. Introduction

Endogenous growth monetary models have been able to explain certain long-run evidence on inflation and growth (Gillman and Kejak 2005b), where the central bank simply controls the money supply growth rate and no Taylor (1993) rule is imposed. This paper shows that such an endogenous growth model contains something very much like a Taylor rule within its equilibrium conditions, and further that a reduced form of its equilibrium is analogous to a full central bank policy model with aggregate demand and supply equations. A trick employed is simply to reinterpret the output gap in terms of the endogenous growth rate, something seen in empirical estimations of the Taylor rule.

Minford, Perugini, and Srinivasan (2002) show that rules similar to the Taylor (1993) rule can perform as well as the Taylor rule, suggesting that the rule itself as such is not identified uniquely; see also Cochrane (2006). If not a unique representation of policy, then the issue is what might the Taylor rule actually be. Is it the monetary policy rule followed by central banks or is it just part of the equilibrium nature of the economy, in which the central bank supplies money at some rate? We don't answer that question but do show how it may be a part of the equilibrium behavior of the economy. Similarly, Alvarez, Lucas, and Weber (2001) use an equilibrium condition for the interest rate, which depends on the money supply growth rate, to show how setting the money supply growth rate and setting the nominal interest rate with a Taylor rule can be interchangeable.

The paper contributes a simple deterministic general equilibrium economy in which a Taylor (1993) type condition is derived as an endogenous equilibrium condition, for a government that supplies money. The endogenous growth framework allows not only for the derivation of an equilibrium Taylor equation, but at the same time a full "policy model" that compares to the standard such as in McCallum (1999). However in our paper no Barro and Gordon (1983) tradeoff is required to derive the equilibrium conditions that constitute the policy model including a Taylor condition.

The paper first derives a Taylor (1993) condition, compares it to Taylor's rule using data as Taylor did, and also considers the Taylor condition in a version using the money supply growth rate instead of the inflation rate. Monetary policy experiments are studied using this modified Taylor condition, with a constant money supply growth rate rule and a velocity-offsetting money supply rule for targeting inflation.

The paper's Taylor (1993) condition comes directly from the Fisher equation, as in Alvarez, Lucas, and Weber (2001), but in combination with the endogenous growth rate for physical capital, as in the standard Euler equation; see also Arnwine (2004). Instead of an IS equation, there is an "aggregate demand" equation that depends on the employment rate for its income effect and the input price ratio for its substitution effect; it derives from the equation for the return to human capital that underlies the endogenous growth mechanism and from the sectoral input allocation equations. The aggregate supply equation is an aggregate labor supply equation, coming from the standard marginal rate of substitution between goods and leisure.

Besides the three equations of a Taylor (1993) condition, aggregate demand and aggregate supply, there is a "fourth" equation: the money demand equation as in McCallum (2001) and Meyer (2001). In contrast to models in which the money demand plays no role but is an alternate equation to the Taylor rule, as in McCallum, here it is an independent equation that effects the shadow price of goods versus leisure, and in turn the aggregate supply function. Velocity is endogenous, in contrast to Alvarez, Lucas, and Weber (2001), and directly enters the money supply version of the Taylor condition. The following sections develop the general equilibrium model, derive the Taylor condition, fit this to data, alternately fit the data with money supply versions of the condition, and then set out the full policy model.

2. The Representative Agent Model

The model is as in Gillman and Kejak (2005a) and Gillman and Kejak (2005b). The representative agent maximizes the discounted utility stream with a constant-elasticity of substitution between goods c_t and leisure x_t each period:

$$U_0 = \sum_{t=0}^{\infty} \beta^t \frac{(c_t x_t^\alpha)^{1-\theta}}{1-\theta}. \quad (2.1)$$

This is subject to the income, exchange and human capital investment constraints, which include allocation of time and goods constraints. These latter are that the time used in goods production, l_{Gt} , plus the time in human capital investment, l_{Ht} , plus the time in credit production, l_{Qt} , equal $1 - x_t$, or $l_{Gt} + l_{Ht} + l_{Qt} = 1 - x_t$; the shares of capital in goods production, s_{Gt} and human capital investment, s_{Ht} equal 1, or $s_{Gt} + s_{Ht} = 1$. With human and physical capital, h_t and k_t , and the wage and rental rates w_t and r_t , the income constraint is that the nominal value of wages from renting effective labor $w_t l_{Gt} h_t$ and capital $r_t s_{Gt} k_t$, plus government transfers, V_t , is equal to nominal expenditure on consumption, $P_t c_t$, physical capital investment, $P_t k_{t+1} - P_t k_t (1 - \delta_k)$, money stock, $M_{t+1} - M_t$, and bonds $B_{t+1} - (1 + R_t) B_t$; where R_t is the nominal interest rate.

The exchange constraint is that money stock is a fraction a_t of expenditures on consumption and physical capital investment:

$$M_t = a_t P_t [c_t + k_{t+1} - k_t (1 - \delta_k)] = a_t P_t y_t, \quad (2.2)$$

or that $M_t v_t = P_t y_t$, where velocity $v_t \equiv 1/a_t$.¹

Both money and credit, denoted by q_t in real terms, are used to purchase goods, so that $M_t + q_t P_t = P_t y_t$. The credit is produced by the agent acting in part as a financial intermediary, where real resources are used to produce the

¹An exchange constraint in which only consumption and not investment is purchased in part by money can instead be specified, with velocity then referring to the consumption velocity of money; results of the paper would then be affected only in the empirical estimation of the money supply version of the Taylor condition in which velocity enters.

exchange credit, as in Goodfriend and McCallum (2007). The production function is a constant returns to scale (CRS) specification following the financial services literature, starting with Clark (1984) and Hancock (1985), which specifies that the credit service is produced using inputs of labor, capital and the real deposited funds, denoted by d_t . Here, as in Benk, Gillman, and Kejak (2007), this function is specified for simplification with only labor and deposited funds: $q_t = (1 - a_t) y_t = A_Q (l_{Qt} h_t)^\gamma d_t^{1-\gamma}$. Since all income is deposited in the financial intermediary, the deposits equal income, so that $d_t = y_t$, and the production function is written as

$$q_t = (1 - a_t) y_t = A_Q (l_{Qt} h_t)^\gamma y_t^{1-\gamma}$$

With the extension of a decentralization of this credit sector,² the agent would withdraw money from the bank deposits during the period, thereby drawing down some of the deposits, and then withdraw the rest to pay off the credit debt at the end of each period.

Finally the human capital investment function is CRS in effective labor and capital, with the depreciation rate δ_H :

$$h_{t+1} = A_H (l_{Ht} h_t)^\varepsilon (s_{Ht} k_t)^{1-\varepsilon} + (1 - \delta_H) h_t. \quad (2.3)$$

Given M_0 , k_0 , and h_0 , the present value Hamiltonian for the consumer maximization problem is

²See Gillman, Harris, and Kejak (2007).

$$\begin{aligned}
& \text{Max} \\
& \{c_t, x_t, B_{t+1}, M_{t+1}, k_{t+1}, h_{t+1}, s_{Gt}, l_{Gt}, l_{Qt}\}_{t=0}^{\infty} \\
L = & \sum_{t=0}^{\infty} \beta^t \{u(c_t, x_t) \\
& + \lambda_t [P_t w_t l_{Gt} h_t + P_t r_t s_{Gt} k_t - P_t c_t - P_t k_{t+1} + P_t k_t (1 - \delta_k) \\
& + M_t + V_t - M_{t+1} - B_{t+1} + (1 + R_t) B] \\
& + \mu_t \left\{ \begin{array}{l} M_t - P_t [c_t + k_{t+1} - k_t (1 - \delta_k)] \\ \circ [1 - A_Q (l_{Qt} h_t)^\gamma [c_t + k_{t+1} - k_t (1 - \delta_k)]^{1-\gamma}] \end{array} \right\} \\
& + \eta_t \left[\begin{array}{l} A_H ([1 - x_t - l_{Gt} - l_{Ft}] h_t)^\varepsilon ([1 - s_{Gt}] k_t)^{1-\varepsilon} \\ + h_t (1 - \delta_h) - h_{t+1} \end{array} \right] \}.
\end{aligned} \tag{2.4}$$

The goods producer maximized profit subject to the CRS goods technology of

$$y_t = A_G (l_{Gt} h_t)^\beta (s_{Gt} k_t)^{1-\beta}, \tag{2.5}$$

with the first-order conditions of

$$w_t = \beta A_G (l_{Gt} h_t)^{\beta-1} (s_{Gt} k_t)^{1-\beta}, \tag{2.6}$$

$$r_t = (1 - \beta) A_G (l_{Gt} h_t)^\beta (s_{Gt} k_t)^{-\beta}. \tag{2.7}$$

Given the money supply of the government being equal to

$$M_{t+1} = M_t + V_t, \tag{2.8}$$

and that the rate of growth of money is $\sigma_t \equiv V_t/M_t$, the consumer's income constraint reduces down to the social resource constraint of

$$y_t = c_t + k_{t+1} - k_t (1 - \delta_k). \tag{2.9}$$

3. The Equilibrium Taylor Condition

To derive an equilibrium condition similar to the Taylor (1993) rule, the necessary equations are simply the Fisher equation of interest rates and the Euler equation of the growth rate that as part of the economy's equilibrium conditions.

3.1. Taylor Equilibrium Condition

From the economy's Fisher equation of interest,

$$1 + R_t = (1 + \pi_t) \left(1 + \frac{r_t}{1 + a_t R_t} - \delta_k \right), \quad (3.1)$$

and its Euler equation for physical capital,

$$(1 + g_t)^\theta = \frac{\left(1 + \frac{r_t}{1 + a_t R_t} - \delta_k \right)}{1 + \rho}, \quad (3.2)$$

the equations can be combined by substituting in for $\left(1 + \frac{r_t}{1 + a_t R_t} - \delta_k \right)$ from the Euler equation.³ This gives that

$$1 + R_t = (1 + \pi_t) (1 + g_t)^\theta (1 + \rho). \quad (3.3)$$

Taking the logarithm and using the approximation that $\ln(1 + x) \simeq x$, for small x , gives that

$$R_t \simeq \rho + \pi_t + \theta g_t. \quad (3.4)$$

This is the basis for a Taylor (1993) like condition. One way to see this is to write in at time $t + 1$, with π_t added and subtracted:

$$R_{t+1} \simeq \rho + \pi_t + (\pi_{t+1} - \pi_t) + \theta g_{t+1}. \quad (3.5)$$

3.2. Comparison to Taylor Rule

This Taylor-like equilibrium condition (3.4) is similar to the Taylor (1993) rule with π_t set equal to the desired inflation π^* , and with $\pi_{t+1} = \pi_{t+1}^e$, and with the growth rate being representative of the output gap:

$$R_{t+1} \simeq \rho + \pi^* + (\pi_{t+1}^e - \pi^*) + \theta g_{t+1}. \quad (3.6)$$

³The term $\frac{r_t}{1 + a_t R_t}$ is lower by the $1 + a_t R_t$ factor because investment enters the exchange constraint; see Gillman and Kejak (2005a).

To see this, consider that the original Taylor rule is

$$R_{t+1} = \bar{r} + \pi_{t+1} + 0.5y_{gap,t+1} + 0.5(\pi_{t+1} - \pi^*). \quad (3.7)$$

Adding and subtracting π^* , this writes as

$$R_{t+1} = \bar{r} + \pi^* + (\pi_{t+1} - \pi^*) + 0.5y_{gap,t+1} + 0.5(\pi_{t+1} - \pi^*) \quad (3.8)$$

which simplifies as

$$R_{t+1} = \bar{r} + \pi^* + 1.5(\pi_{t+1} - \pi^*) + 0.5y_{gap,t+1}. \quad (3.9)$$

Comparing this to the Taylor condition (3.6), they are identical if $\bar{r} = \rho$, $\theta = 0.5$, and $y_{gap,t+1} = g_{t+1}$, except that the coefficient of one exists in the Taylor condition for $(\pi_{t+1} - \pi^*)$ while this coefficient is 1.5 in the Taylor (1993) rule. Note that Taylor's definition of the $y_{gap,t+1}$ variable is almost equal to the growth rate of GDP, as in g_t . The difference is that Taylor uses the average trend GDP, call it y^* , as the basis: $y_{gap,t+1} \equiv (y_{t+1} - y^*)/y^*$; compared to $g_{t+1} = (y_{t+1} - y_t)/y_t$.

This comparison how the equilibrium Taylor condition is analogous to the Taylor (1993) rule. Assuming $\pi_{t+1} = \pi_{t+1}^e$, the Taylor condition has a different coefficient on $(\pi_{t+1} - \pi^*)$ than the Taylor rule, it uses the actual π_t and y_t as the base inflation rate and income level, and defines the gap in terms of the growth rate.

4. Taylor Condition versus Actual Data and Taylor Rule

One exercise in Taylor (1993) is to compare the Taylor rule with actual data. Consider a calculation of the nominal interest rate using the equation (3.5). Using data series that are described in the Appendix, Figure 1 shows that the Taylor (1993) condition (graphed as Model Rule1) compares fairly well with the Taylor (1993) rule and the actual nominal interest rate; Taylor's original data span is within the box, 1986-1992. Here we have graphed the short term government bill rate, the 3-month Treasury bill. Compared to the original Taylor version, the

model tracks close to it from the mid-1960s until around 1990, after which the original Taylor rule version remains below the model's Taylor versions. Compared to the actual interest rate, the original Taylor rule and the model's version are above the interest rate from 1966 to 1980. The model tracks close to the actual interest rate in the 1980s while the original Taylor rule is below the actual interest rate; in the 1990s, the original Taylor rule is close on average to the interest rate, while the model is consistently above the actual interest rate. Comparing the Taylor condition and Taylor Rule to the 10 year Treasury bond yield, rather than to the short term T-bill yield, shows a somewhat better fit for the Taylor condition, as seen in Figure 2, in terms of tracking from 1989 up until 2001.

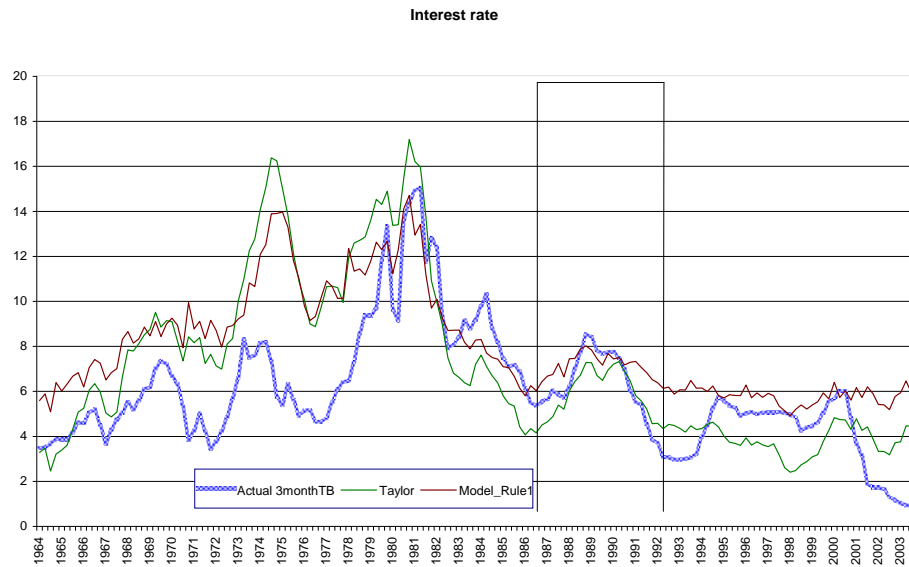


Figure 1. Comparison of Taylor Condition (equation 3.5), Taylor Rule, and Actual Nominal Interest Rate

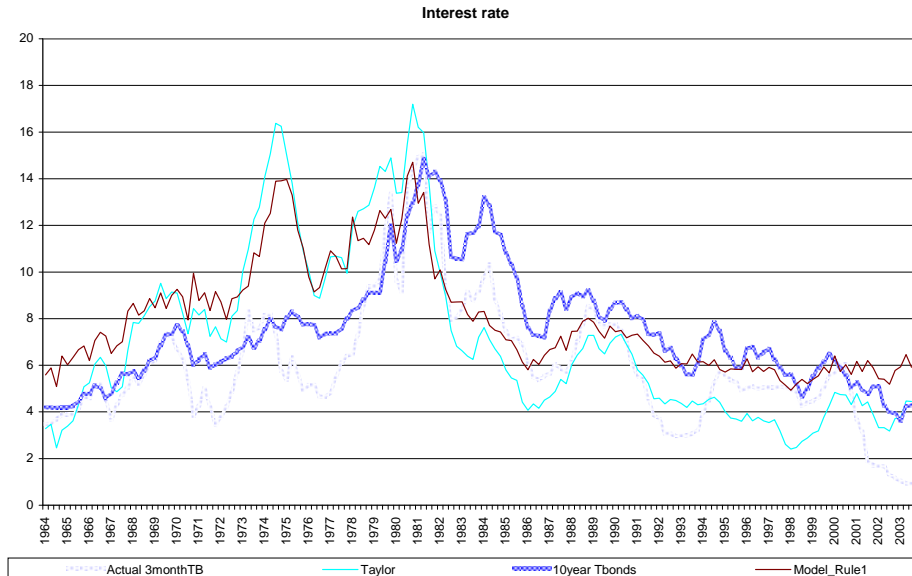


Figure 2. Additional Comparison to 10 year Treasury Bond Yield

5. Policy Experiments

The equilibrium Taylor (1993) condition of the model can be restated in a form in which the money supply growth rate enters instead of the inflation rate. This is done by solving for the inflation rate by using the model's demand equation, and the market clearing condition for the money market. By bringing the economy's money supply into the Taylor condition, different money supply rules can be examined in a spirit similar to McCallum (2000), or Alvarez, Lucas, and Weber (2001).

5.1. Money Supply Version of Taylor Condition

Consider the money demand equation (2.2): $\frac{M_t}{P_t} = a_t y_t$. With velocity defined as $v_t \equiv 1/a_t$, with $g_{vt} \equiv \frac{v_{t+1}}{v_t}$, and with market clearing so that money demand equals

money supply, it follows that

$$\frac{M_{t+1}}{M_t} = 1 + \sigma_{t+1} = \frac{P_{t+1}y_{t+1}v_t}{P_t y_t v_{t+1}} = \frac{(1 + \pi_{t+1})(1 + g_{t+1})}{1 + g_{v,t+1}}. \quad (5.1)$$

Taking logarithms, the approximation is that

$$\sigma_t = \pi_t + g_t - g_{v,t} \quad (5.2)$$

Solving for the inflation rate π_t and substituting for this in the Taylor condition (3.4) gives that

$$R_t \simeq \rho + \sigma_t - (1 - \theta) g_t + g_{v,t}. \quad (5.3)$$

The money-Taylor condition can be also written using money supply growth rate targets, by adding and subtracting the target rate σ^* :

$$R_{t+1} \simeq \rho + \sigma^* + (\sigma_{t+1} - \sigma^*) - (1 - \theta) g_{t+1} + g_{v,t+1}. \quad (5.4)$$

This form of the condition makes it similar to the Taylor condition in equation (3.6), with the difference of money supply growth rates instead of inflation rates, and the additional term of the growth rate in velocity.

5.2. Comparison of Model with Actual Data

Consider a calculation using equation (5.3). Here we conduct money supply policy exercises in a way related to McCallum (2000), by seeing how the data might have looked with a particular money supply rule in place. Figure 3 compares this condition, computed alternately with M0 and with M1, to the inflation rate version of the Taylor condition in equation (3.5), to the original Taylor rule, and to actual short and long term interest rates, again from 1964 to 2004. The two lines in Figure 3 representing the money supply versions, Model Rule2 M0 and Model Rule2 M1, are more spiked during the late 70s and early 80s than is seen in the data or the other models.

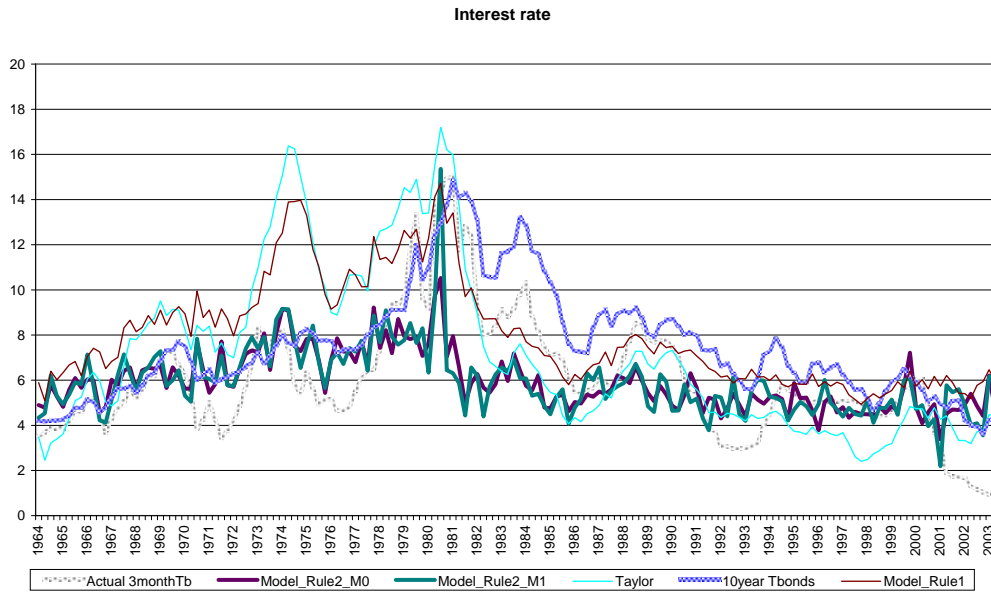


Figure 3. Money Supply Versions of the Taylor Equilibrium Condition

5.3. The Friedman Rule

For experiments with different rules on the money supply, first consider the Friedman (1960) suggestion of a constant money supply growth rate. With $\sigma_{t+1} = \sigma_t = \bar{\sigma}$ for all t , equation (5.3) becomes

$$R_t \simeq \rho + \bar{\sigma} - (1 - \theta) g_t + g_{v,t}. \quad (5.5)$$

The nominal interest rate is determined by a constant and the growth rate of GDP and of velocity. The model's computed interest rate in equation (5.5) is compared in the Figure 4, assuming that the money supply growth rate is 3% (Model Rule2 M0 sigma3, and Model Rule2 M1 sigma3). It shows the similar pattern that during the 1960s and 1970s, the actual interest rates were below what the model equilibrium condition would indicate, and the reverse for after 1980 until around 1987.

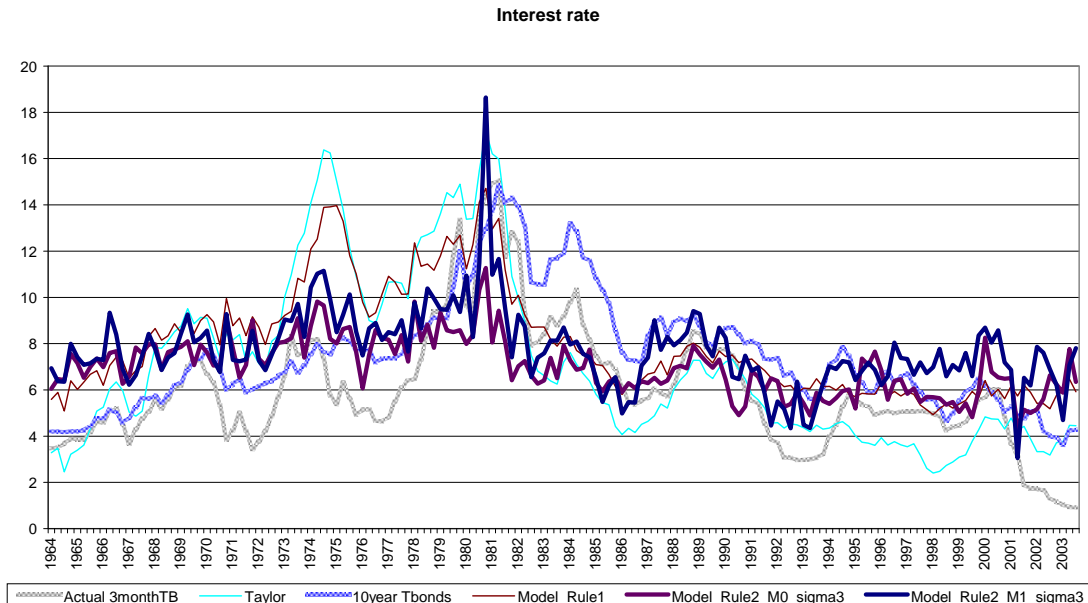


Figure 4. Friedman Rule of a Constant 3% Money Supply Growth Rate; equation (5.5).

5.4. Inflation Rate Targeting

Or consider the Keynes (1923) policy to stabilize the price level, and the related McCallum (1987) concept of stabilizing the inflation rate, by setting the money supply growth rate equal to the output growth rate minus the velocity growth rate plus a constant for the targeted inflation level. From equation (5.2), and with $\pi_t = c$ for all t , this gives a money supply rule of

$$\sigma_t = \pi_t + g_t - g_{v,t} = c + g_t - g_{v,t}.$$

Substituting this into equation (5.3), it gives that

$$R_t \simeq c + \rho + \theta g_t. \tag{5.6}$$

This also follows directly from the condition (3.4) by setting $\pi_t = c$ in that equation. Letting $c = 0.02$, as in a 2% inflation rate target, the interest rate produced

from equation (5.6) is graphed in Figure 5. The graph shows a rather stable nominal interest rate over the whole period.

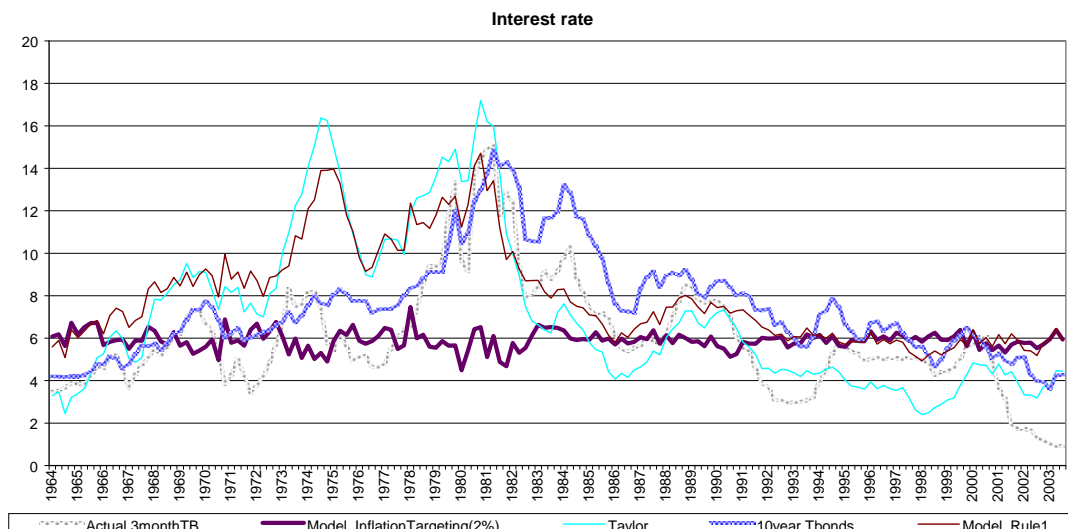


Figure 5. Keynes-McCallum Rule of 2% Inflation Rate Targeting

6. Construction of a Full Policy Model

The equations for the full policy model are a reduced set of equilibrium conditions. It can be shown that the first-order equilibrium conditions imply that

$$g_t = \frac{1}{\theta} \left[A_H (1 - x_t) \epsilon \left(\frac{s_{Ht} k_t}{l_{Ht} h_t} \right)^{1-\epsilon} - \delta_H - \rho \right]. \quad (6.1)$$

This is the "aggregate demand" equation, where the growth rate depends on the level of employment $1 - x$, and the capital to effective labor ratio $\frac{s_H k}{l_H h}$. From the firm side, we have that

$$\frac{w_t}{r_t} = \frac{\beta}{1 - \beta} \frac{s_{Gt} k_t}{l_{Gt} h_t} = \frac{\epsilon}{1 - \epsilon} \frac{s_{Ht} k_t}{l_{Ht} h_t}, \quad (6.2)$$

so that the ratio $\frac{s_H k}{l_H h}$ can be substituted out using the relative factor price $\frac{w_t}{r_t}$. This gives that

$$g_t = \frac{1}{\theta} \left[A_H (1 - x_t) \epsilon \left(\frac{w_t}{r_t} \frac{1 - \epsilon}{\epsilon} \right)^{1 - \epsilon} - \delta_H - \rho \right]. \quad (6.3)$$

The aggregate supply of labor equation comes from the marginal rate of substitution between goods and leisure, where the share of money in output purchases is denoted by $a_t = m_t/y_t$:

$$\frac{U_c}{U_x} = \frac{x_t}{\alpha c_t} = \frac{[1 + a_t R_t + (1 - a_t) \gamma R_t]}{w_t h_t}, \quad (6.4)$$

or

$$1 - x_t = 1 - \left(\frac{[1 + a_t R_t + (1 - a_t) \gamma R_t]}{w_t} \right) \frac{c_t}{h_t}. \quad (6.5)$$

Finally, the money demand equation follows, in which the interest elasticity rises in magnitude as R_t increases, as in the Cagan (1956) model.

$$\frac{m_t}{y_t} = \left[1 - \left(\frac{\gamma R_t}{w_t} \right)^{\frac{\gamma}{1 - \gamma}} A_{Qt}^{1/(1 - \gamma)} \right]. \quad (6.6)$$

Fitting the full model to data vastly extends the scope of the paper, which is designed to go so far as to postulate how a full policy model can be developed within this framework. We can report that experiments with the employment rate, using the aggregate supply equation (6.5), whereby we fit it to data as was done for the Taylor condition, show a trend down in the employment rate until 1983 and a subsequent trend upwards that also exists in the data.

7. Discussion

Taylor's (1993) original rule was fit for the time period of 1986 to 1992. This was a time of relatively stable inflation, a time for which Phillips curve movements were not so discernible as compared to the likely scale of these movements during the 1970's and 1980's. In contrast, the standard use of the Taylor rule has been

as part of a policy model for which there are only departures of output from trend because of unexpected inflation as based on the Lucas (1973) model of supply in which unexpected inflation can cause an output increase. Yet the Taylor condition of the paper, like Taylor's rule, seems to "work" better when there is not much unexpected inflation. They tend to underestimate the accelerating inflation of the 1970s and overestimate the decelerating inflation of the 1980s.

Having used a dynamic general equilibrium model that embodies effects of the inflation tax, we get the Taylor condition combined with an AS curve in which there is a reverse sloping Phillips curve: more of the inflation tax causes less employment. This is a result that has long been a part of such models. It may be that the Taylor condition, rather than being rigidly paired with a Phillips curve world, can in some sense describe equilibria in a world with a possible long run negative effect on employment from higher (inflation) taxation.

8. Conclusion

In summary, the paper derives a four equation system consisting of 1) an aggregate demand equation based on the human capital Euler equation, 2) an aggregate supply based on the marginal rate of substitution between goods and leisure, this being a labor supply curve, 3) a money demand equation that is necessary for feeding back into the labor supply equation, since the money demand effects the shadow price of labor, and 4) an interest rate equation that combines the Fisher equation of interest rates with the physical capital Euler equation, to yield a Taylor (1993)-like equation.

In this model there is an endogenous growth rate instead of an output gap, and no assumed tradeoff between the output gap and the inflation target in creating a Taylor (1993) rule. Rather, the real interest rate rises when the growth rate rises. So the growth rate enters the Taylor-like condition. It remains to be seen if such a model is useful for monetary policy analysis; the paper presents different money supply rules with a view towards this context. However as such the model

lacks important features, for example a liquidity effect, business cycle effects, and uncertainty in general. Benk, Gillman, and Kejak (2007) extend a model similar to that in this paper so as to include shocks to money supply, and credit and goods sector productivities; a more involved policy model related to the illustrative one in this paper might be derived from such a stochastic formulation.

A. Appendix: Data Series Definitions

The data is US postwar quarterly from 1964:1 to 2004:3.

GDP: Real GDP in chained 2000 dollars (GDPC96); from U.S. Department of Commerce: Bureau of Economic Analysis; on the web at <http://research.stlouisfed.org/fred2/data/>

Monetary aggregates: M0 and M1 Money Stock (M1SL); from Board of Governors of the Federal Reserve System.

Inflation: percentage change in the Consumer Price Index (CPIAUCSL with index 2000 =100); from U.S. Department of Labor Bureau of Labor Statistics.

Interest Rates: U.S. Treasury 3 month T-bill and 10 year bond rate.

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