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PERFECT FORESIGHT, NON-LINEARITY AND HYPERINFLATION *

by

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Introduction

Traditionally, attempts to model hyperinflationary processes have followed one of two routes. Cagan (1956) concentrated on hyperinflation within a fixed output environment. Later writers for example Sargent (1977) Sargent & Wallace (1973) and Flood and Garber (1980) retained this assumption but extended the basic model by incorporating rational expectations.

The second route relates to models which consider inflation within a growing economy. Here the basic formulation is due to Sidrauski (1967) where one standard characteristic is of steady-state superneutrality.

One factor common to both traditional approaches is the view that high, or hyper, inflation is a purely monetary phenomena and that the interesting issues to pursue relate to expectation formation. In such models the real side of the economy is either characterised by a simple production technology exhibiting constant returns to scale or by a constant level of output assumption. In such models, accelerating inflation arises, either implicitly or explicitly, as a result of government policies which increase the rate of growth of the nominal money supply.

The purpose of this paper is to present an alternative approach to the modelling of a growing economy which is experiencing a high, stable, rate of inflation.

We will present a model in which the normal explanation of hyperinflation is inapplicable as the rate of growth of nominal money will be fixed throughout. However, unlike the classical dichotomy world of Cagan, Sargent and Sidrauski, the model presented will be 'coupled', the real and the monetary sectors interacting through the real rate of interest.

In Section 1 we will outline the basic properties of a Cagan type hyperinflation model, considering in section 2 models of growing inflationary economies. In Section 3 we will explain the fundamentals of our point of departure, while in Section 4 the formal model will be presented. Section 5 provides an analysis of the model, with Section 6 devoted to an explanation of the numerical simulation results. Section 7 concludes.

1. Cagan type models of hyperinflation

Cagan's explanation of hyperinflation relies heavily on the form of the demand for real money balances:

$$\log\ (M_t/P_t) = \alpha \hat{P}_t^e + \lambda \log Y_t + \psi + U_t$$

$$\alpha < 0 \qquad \lambda > 0 \qquad \qquad ....(1)$$

where M_t relates to nominal money balances, P_t the price level, $\hat{p}_t^e$ expected rate of inflation, Y_t being real income, U_t a stochastic error term, α, λ, ψ, being parameters.

Cagan made several crucial assumptions which generate his policy conclusions. Firstly Y is assumed constant over time. This effectively dichotomises the real and monetary sectors allowing no feedback of inflation effects on output etc. or vice-versa. Inflation will only occur as a monetary phenomena. Secondly the Cagan model is log-linear. This severely restricted the dynamic modelling possibilities of the inflation process allowing only explosive or monotonically convergent solutions. Thirdly, accelerating inflation is the result of expectations of future price increases fuelled endogenously by a demand determined, equilibrium, money growth process. Because of the assumed form of the demand for money function, the steady state inflation rate must be equated with the nominal money gowth rate in order to generate a constant, steady state, level of real money balances.

Expectations in the original Cagan model were extrapolative, however extensions incorporating rational expectations have been considered, without fundamentally affecting the qualitative properties of the model, see e.g. Sargent & Wallace (1973).

2. Money, Growth and Inflation

Cagan assumed fixed output in his hyperinfation model, however the dynamics of inflation in a growing economy have been considered by several authors, including Sidrauski (1967), Kurz (1968) and Fischer (1979). Typically the models are formulated as an infinite horizon, individual utility maximisation problem which exhibits unique convergent paths to steady-state. In the Sidrauski (linearised) model, the steady-state is characterised by superneutrality, whereas Fischer (1979), utilising a constant relative risk aversion utility function, demonstrates that this property does not generally hold on the transition path to steady state. On such paths capital accumulation is faster the higher the rate of money growth. When one looks at the actual models of money, growth and inflation, however, again we find that the systems of equations are generally linear, or linearised as in the Sidrauski models, with the production function exhibiting constant returns to scale throughout. The major qualitative difference of allowing growth to enter the dynamics of the inflationary process is that on the equilibrium growth path the expected rate of inflation will be equal to the rate of monetary expansion minus the economy's warranted rate of growth. In a perfect foresight world (or in steady-state where expectations are fulfilled) one can equate expected inflation with actual inflation.

3. A Point of Departure

As we have seen, hyperinflation models of the Cagan variety implicitly assume prices are rising so fast as to be able to assume output is fixed. Alternatively models of money and growth of the Sidrauski type assume simple, constant returns to scale production functions. The model we will develop has the following properties many of which are absent in traditional models. Firstly the real and monetary sectors interact; the model is 'coupled', the main linkage operating via the rate of interest. The demand for money depends upon income and the nominal rate of interest composed of the real rate of interest, equal to the marginal product of capital, plus the fully anticipated rate of inflation. This is in effect, an asset market equilibrium condition under perfect foresight. The real rate of interest is determined by the real side of the economy and as we will see can vary, the variation being particularly interesting given the specification of the production function. Output depends only on the capital input, for simplicity.

Taken in isolation some of these properties appear standard, for example see the form of the demand for money function in Sargent & Wallace (1973), and the assumed equality of the real rate of interest with the marginal product of capital in Begg (1982). However in Sargent and Wallace the system is assumed linear with a constant m.p.k. (marginal product of capital). This New Classical assumption of a constant m.p.k. is also a characteristic of Begg's model.

The model we propose, however, incorporates a production function which exhibits variable returns to scale and as such is inherently non-linear. This is a crucial property of the model and one we feel is important in a dynamic model which allows growth, over long periods of time, plus inflation. An alternative approach which would probably generate similar qualitative results would be to assume some endogenously determined technical progress function of a Kaldorian type.

A further property of the model will be the assumption of a constant growth of the nominal money stock. This has the effect of ruling-out the Cagan explanation of accelerating inflation. At the policy level, we will see that within such a framework the widely accepted x% money growth rule conclusions do not hold. A fixed money growth rate rule can lead to accelerating inflation as the economy experiences, on the real side, variable returns to scale.

The final property of the model will be perfect foresight. This may seem naive, however as is now well known, see George & Oxley (1985) the qualitative behaviour of perfect foresight and certainty equivalence rational expectations models is identical. More importantly, however, the non-linearities in the model considerably complicate the standard rational expectations solution techniques without affecting the qualitative properties of the model.

4. A Simple Alternative Model

The production function is chosen to exhibit variable returns to scale, this being the source of non-linearity in the model. A constant labour input is assumed, for the sake of simplicity, so output depends only on the capital input:

$$Y = F(K) = \tan^{-1}(K - \alpha) + \frac{\pi}{2} \qquad (\alpha > 0) \qquad ...... (2)$$

where Y = output

K = capital

With this specification the marginal product of capital increases with K for $K < \alpha$, decreases for $K > \alpha$ and is momentarily constant for $K = \alpha$. The point $K = \alpha$ will be called the <u>switch point</u>. The production function (2) has the property that $F(o) > o$, but an alternative specification with $F(o) = 0$ is given by:

$$Y = \tan^{-1}(K - \alpha) + \tan^{-1}(\alpha) \qquad ..... (2a)$$

In this case, $K = \alpha$ is a <u>Frisch point</u> at which returns to scale switch from increasing to decreasing.

A proportional consumption function is assumed:

$$C = cY \quad (o < c < 1) \qquad ..... (3)$$

giving a macroeconomic equilibrium condition:

$$Y = cY + \dot{K} + \delta K \quad (o < \delta < 1) \qquad ..... (4)$$

where δ = depreciation rate of capital

$\dot{K}$ = net investment

(n.b. the 'dot' notation represents time derivatives throughout).

A constant exogenous growth rate (θ) is assumed for the nominal money supply (M):

$$\dot{M} = \theta M \qquad ..... (5)$$

A standard demand for money function of the following form is assumed:

$$\frac{M}{P} = b_1 Y - b_2 r \qquad (b_1, b_2 > o) \qquad ..... (6)$$

where: P = price level

r = nominal interest rate

Note that the demand for real money balances depends on the nominal rate of interest. This rate represents the opportunity cost of holding money rather than bonds, the former being assumed to earn no interest. (See for example Wonnacott, 1984 for further discussion).

The money market is assumed permanently in equilibrium.

Equation (6) gives:

$$r = \left[\frac{b_1}{b_2} \right] Y - \frac{M}{Pb_2} \qquad \ldots\ldots (7)$$

The nominal rate is taken to be the sum of the real interest rate and the perfectly foreseen rate of inflation. The real interest rate is assumed equal to the marginal product of capital (d). Thus:

$$r = d + \frac{\dot{P}}{P} \qquad \ldots\ldots (8)$$

This condition ensures that the sum of total profit and total (perfectly foreseen) capital gain $(PF(K) - rPK + \dot{P}K)$ is continuously maximised. From (2) or (2a) we have:

$$d = F'(K) = \frac{1}{1 + (K - \alpha)^2} \qquad \ldots\ldots (9)$$

Equation (4) gives:

$$\dot{K} = (1 - c)\ Y - \delta K \qquad \ldots\ldots (10)$$

Equation (8) gives:

$$\dot{P} = P\ (r - d) \qquad \ldots\ldots (11)$$

To permit exposition in two dimensions we combine the nominal money supply and the price level into a single variable, the real money suppy (m):

$$m = \frac{M}{P} \qquad \ldots\ldots (12)$$

From (12), (5) and (11) it is readily seen that:

$$\dot{m} = m(\theta - r + d) \qquad \text{..... (13)}$$

which, from (9) and (7), yields:

$$\dot{m} = m(\theta - \frac{b_1 F(K)}{b_2} + \frac{m}{b_2} + F'(K)) \qquad \text{..... (14)}$$

Equations (10) and (2) together yield:

$$\dot{K} = (1-c) F(K) - \delta K \qquad \text{..... (15)}$$

Equations (14) and (15) together constitute a dynamical system in m and K, though note that (15) can be solved independently of (14) since the former equation does not involve m. The phase portrait of this dynamical system is depicted in figure 1. Note that only positive values of m and K are considered since negative ones would be economically meaningless. Note also that the system has six equilibria, three saddlepoints (A, B and C), two stable nodes (D and F) and one unstable node (B). The "boundary line" of figure 1 divides the positive quadrant into two segments. Paths lying above this line exhibit m tending to infinity, paths lying below it exhibit m tending to zero and paths actually lying in the boundary exhibit m tending to a positive, finite value (either m_1* or m_2*).

5. Analysing the model

The standard approach to analysing this type of model would be linearise it about an equilibrium by (sometimes implicit) appeal to Hartman's Theorem. This theorem ensures that the phase portrait of the linearisation is (in most cases) locally homeomorphic to the phase portrait of the original system. The use of this theorem in the context of dynamic economic models involves considerable difficulties (see George and Oxley 1985 for a fuller discussion), some of which are associated with the local nature of the equivalence. For example, the standard analysis of the model of section 4 would involve linearising it about an equilibrium such as A or C. These are clearly saddlepoints and the corresponding linearisations have the appearance of figure 2. Note that no equilibria with m = o (such as D or F in fig. 1) appear in the linearisation. This is because Hartman's Theorem applies only locally, in this case, in a neighbourhood of the equilibrium A (or C).

Figure 2, then, depicts a linear saddlepoint in which there is a single "stable branch". Any paths with initial conditions lying on this stable branch converges to the equilibrium; all other paths exhibit diverging m. In particular, paths with initial conditions lying below the stable branch exhibit m diverging to $-\infty$. Since it is economically meaningless for the real money supply to be negative, these paths would be ruled out of consideration. This analysis might be augmented by noting that a divergent path will not in general satisfy the transversality condition arising from a standard intertemporal utility maximising problem (see George and Oxley 1985 for a further discussion of this argument).

But how is convergence to be guaranteed? In the standard analysis, the situation is saved by the intervention of so-called "jump variables", usually prices, which adjust infinitely fast to ensure initial conditions which do lie on the stable branch, thus guaranteeing convergence. In this model the price level could play this role, allowing the real money supply to adjust appropriately. The capital stock would be treated as a "pre-determined" or "backward looking" variable.

In the linearisation, convergent paths entail the real money supply tending to a positive limiting value as $t \to \infty$, which in turn, implies a steady state rate of inflation equal to the (exogenous) rate of nominal money supply growth. In such a case the steady state rate of inflation is constrained to equal the rate of nominal money growth in true monetarist fashion. But when the model is considered globally, another possibility emerges. There exists a whole additional class of convergent paths, all of which converge to an equilibrium, such as D or F in figure 1, at which $m = 0$. In contrast to the linearisation, the original phase portrait has no paths which start in the positive quadrant but eventually leave it. Along paths converging to equilibria such as D or F, the real money supply is always strictly positive, but tending to zero. In fact along such paths, the price level cannot accelerate indefinitely. The rate of inflation ($\dot{P}/p$) tends to a limiting (or "steady state") value which, in general, is many times greater than θ, the rate of growth of the money supply.

This situation will not arise of course if the price level jumps so as to place the system initially on the boundary line in figure 1. But why should such a jump occur? The rate of change of prices is determined by equation (8) which is a kind of arbitrage condition in the asset market. The nominal rate of interest is fixed at each instant via equilibrium in the money market and the marginal product of capital is fixed at each instant by the amount of capital in existence. Thus $\dot{P}$ is always finite; the price level can never jump. Suppose at time zero the price level is P_o; such that the initial conditions (K_o, m_o) lie below the boundary line in figure 1. Then the economy will follow a path tending to $m = o$: it may grow or contract (see figure 1 for examples of both types of path). In such cases, the steady state inflation rate is many times the rate of growth of the nominal money supply. Note that all paths in figure 1 are perfect foresight paths. We have thus demonstrated a simple model with perfect foresight, in which all markets clear continuously and the growth rate of the nominal money supply is exogenous, but which nevertheless has a steady state inflation rate many times greater than the rate of growth of the nominal money supply.

6. Numerical Solutions of the Model

As far as we know the dynamical system composed of equations (14) and (15) cannot be solved analytically. A simple Fortran programme has therefore been employed to provide numerical solutions. A schematic representation of the programme is given in figure 3:

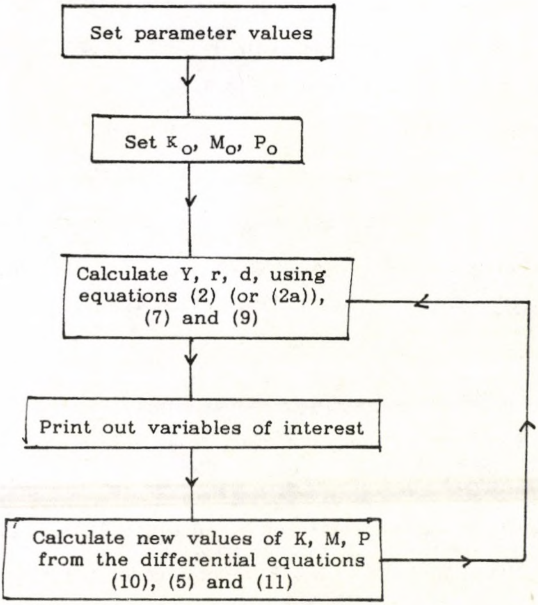

Figure 3

Figures 4, 5 and 6 show time paths for output, (Y), inflation rate ($\dot{P}/P$), nominal interest rate (r) and real interest rate (d) for three different sets of parameter values and initial conditions. It should be noted that in all cases the nominal money supply grows at an exogenous, constant rate of 5%.

In figure 4 the economy starts off with an increasing marginal product of capital and, with a low (3%) depreciation rate, grows steadily. The inflation rate increases gradually at first, reaching 35% when the switch point is reached in period 39. As the marginal product of capital begins to decrease hyperinflation takes off. The inflation rate reaches 248% by period 50. By period 99 it has reached 280%, 56 times the rate of growth of the money supply. In figure 5 the economy starts off with a diminishing marginal product of capital but, even with a higher depreciation rate (6%) can still grow. By period 91 output has converged to its equilibrium value of 2.9355 and the inflation rate has converged to its equilibrium value of 264%, approximately 53 times the rate of growth of the money supply.

In figure 6 the depreciation rate is so high (12%) that the economy shrinks towards a 'low K' equilibrium. By period 73, inflation has converged to its equilibrium value of 14.9%, approximately three times the growth rate of the nominal money supply.

Thus for plausible parameter values, equilibrium rates of inflation are generated which are many times greater than the growth rate of the money supply. This is true even for the contracting economy of figure 5, though the result is numerically less striking. Of course it is true that this model cannot generate <u>indefinitely accelerating</u>

inflation but rates of price increase of the order of 200% - 300% might reasonably be called hyperinflation.

7. Conclusions

In a perfect-foresight, market clearing model with an exogenously growing nominal money supply it is possible for the steady state rate of inflation to be many times greater than the rate of money growth. This type of inflation is of the bootstrap variety and cannot acelerate indefinitely. Nevertheless plausible parameter values indicate possible rates of inflation of the order of 200%-300%, enough to worry most policymakers.

These conclusions weaken the orthodox argument that firm control of the money supply is sufficient to control the inflation rate in the medium to long run. They are derived from a more or less orthodox model by the addition of a simple non-linearity and the simultaneous abandoning of local linearisation methods and rejection of the "jump variable" notion. A full global analysis of the model's dynamics is presented and no ad hoc jump mechanism is invoked. Price dynamics are explained simply by the structural equations of the model. The paper therefore provides an example of how striking analytical (including policy) results may depend as much on the method of analysing a model as on the economic assumptions upon which it is based.

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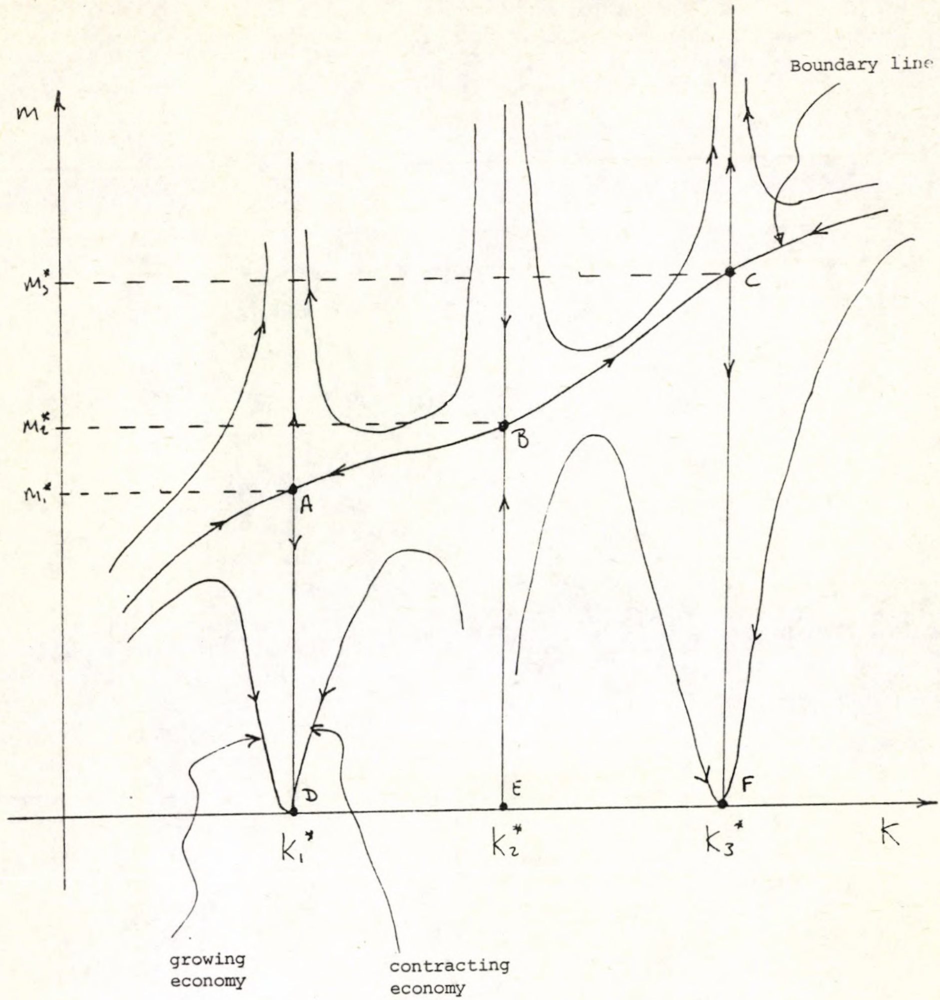


Figure 1: Phase portrait for the dynamical system composed of equations (14) and (15)

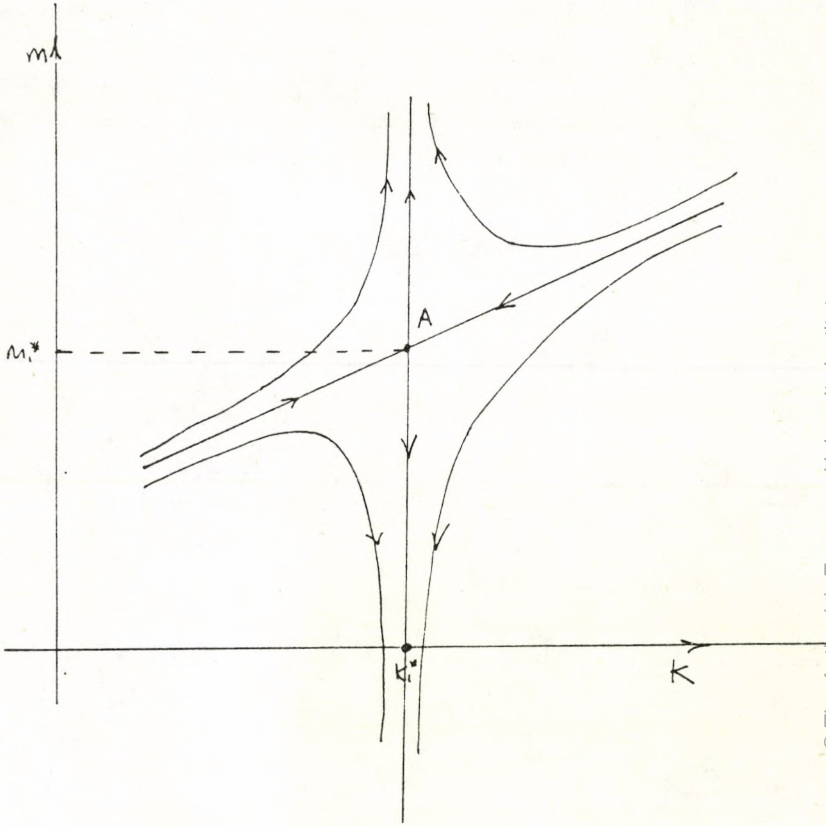
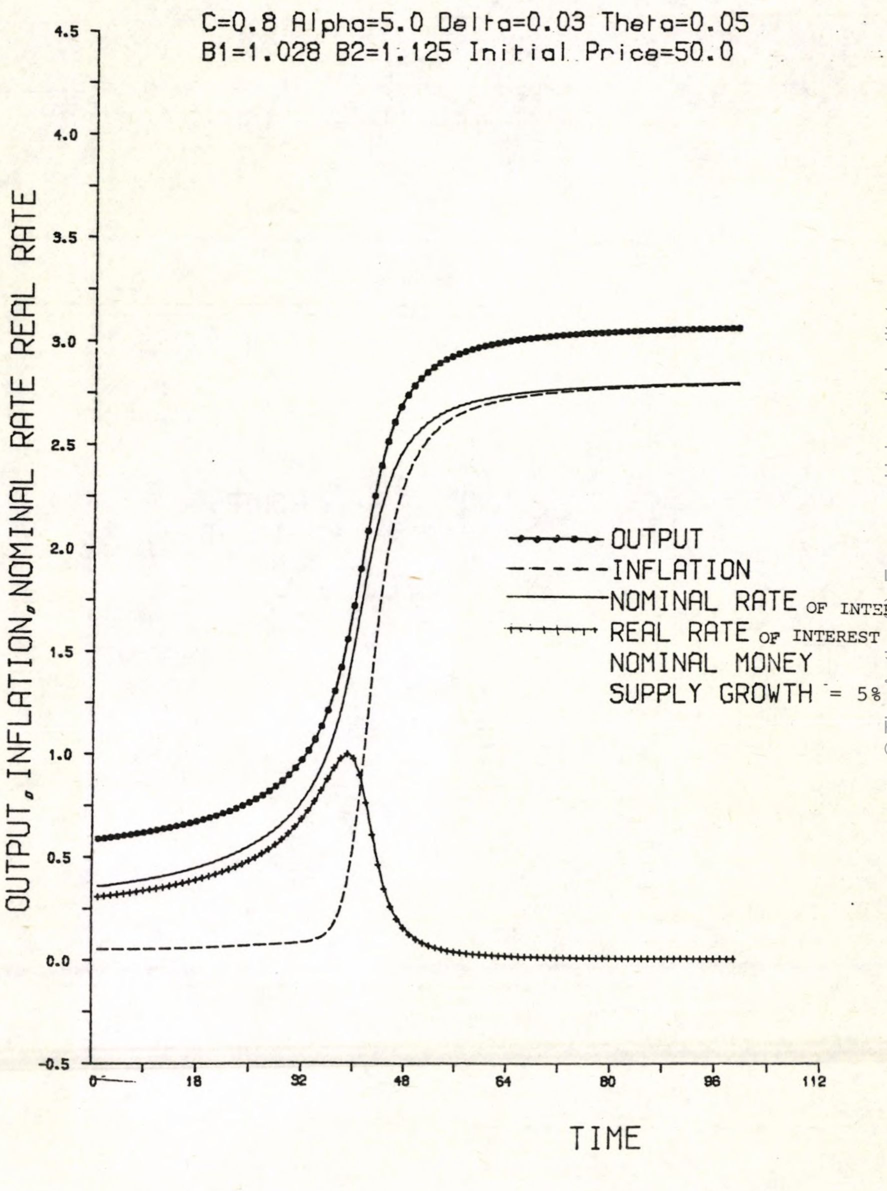


Fig 2: Linearisation about the equilibrium A

FIGURE 4.



C=0.8 Alpha=5.0 Delta=0.03 Theta=0.05
B1=1.028 B2=1.125 Initial Price=50.0
OUTPUT, INFLATION, NOMINAL RATE REAL RATE
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
OUTPUT
INFLATION
NOMINAL RATE OF INTEREST
REAL RATE OF INTEREST
NOMINAL MONEY
SUPPLY GROWTH = 5%
0
16
32
48
64
80
96
112
TIME

FIGURE 5.

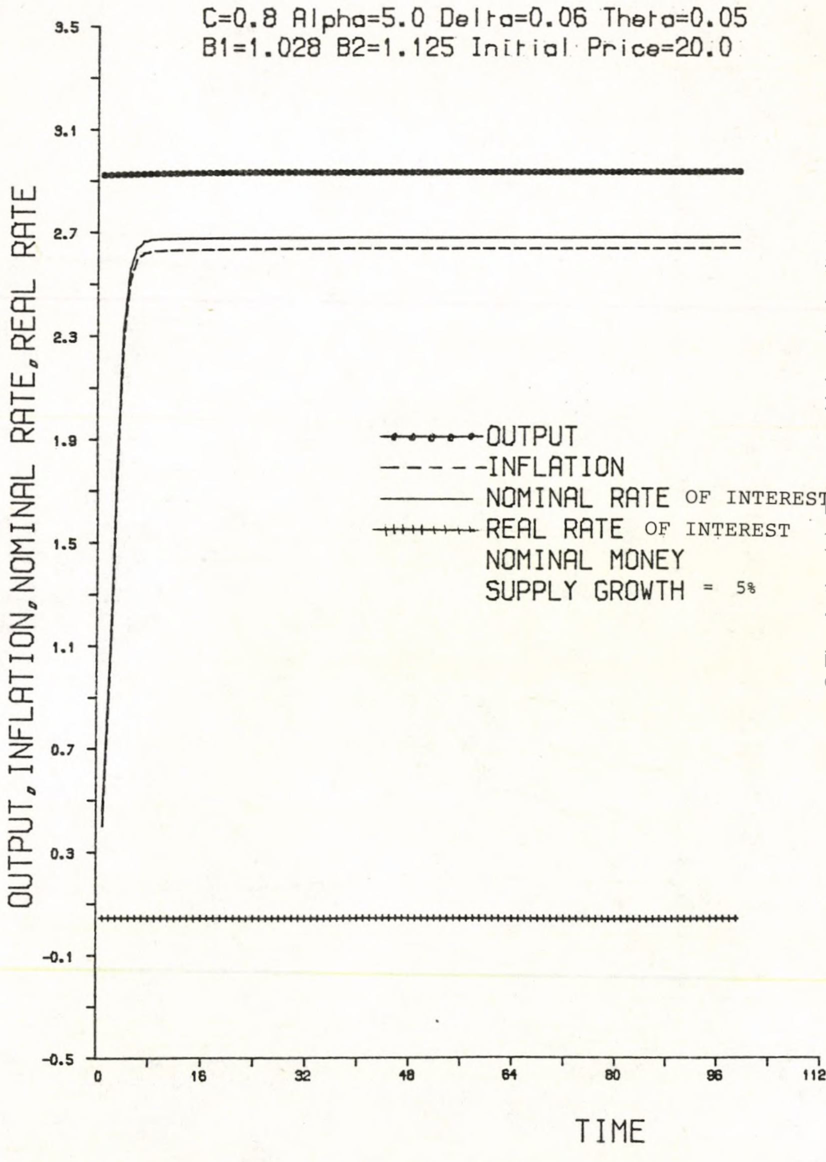
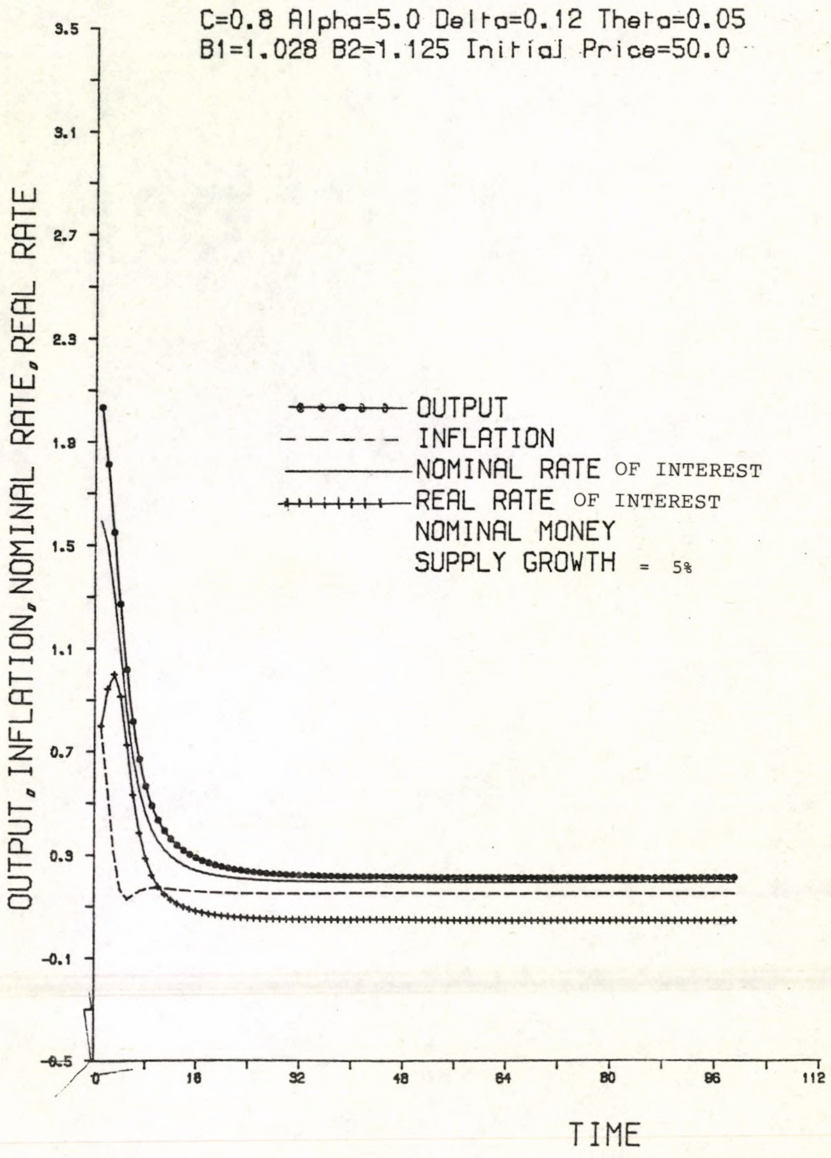

C=0.8 Alpha=5.0 Delta=0.06 Theta=0.05
B1=1.028 B2=1.125 Initial Price=20.0
OUTPUT,INFLATION,NOMINAL RATE,REAL RATE
3.5
3.1
2.7
2.3
1.9
1.5
1.1
0.7
0.3
-0.1
-0.5
0
16
32
48
64
80
96
112
TIME
OUTPUT
INFLATION
NOMINAL RATE OF INTEREST
REAL RATE OF INTEREST
NOMINAL MONEY
SUPPLY GROWTH = 5%

FIGURE 6.



C=0.8 Alpha=5.0 Delta=0.12 Theta=0.05
B1=1.028 B2=1.125 Initial Price=50.0
OUTPUT
INFLATION
NOMINAL RATE OF INTEREST
REAL RATE OF INTEREST
NOMINAL MONEY
SUPPLY GROWTH = 5%
OUTPUT, INFLATION, NOMINAL RATE, REAL RATE
3.5
3.1
2.7
2.3
1.9
1.5
1.1
0.7
0.3
-0.1
-0.5
0
16
32
48
64
80
96
112
TIME

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