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REAL BUSINESS CYCLES AND THE LUCAS PARADIGM

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ABSTRACT

When the Lucas paradigm is generalized to include real effects, the effects of real factors and monetary factors on the business cycle are always interrelated. Furthermore, in such models monetary factors can affect the long-run behavior or real output, contrary to the commonly held view that they can't. Real business cycle models and Lucas-type models are different paradigms not in the sense of real versus monetary, but in the interrelationships between real and monetary factors intrinsic to the Lucas paradigm as contrasted to the dichotomy between real and monetary factors implied by the real businss cycle literature.

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Business cycle theory in recent years has tended to stress the importance of monetary or nominal disturbances. Prominent in this tradition are models of the type originally proposed by Lucas (1972, 1973, 1975).[1] These models have come to be generally viewed as monetary models, driven by transitory nominal aggregate demand disturbances. Other recent research views business cycles as arising from variations in real factors in the economy such as shifts in government purchases or tax rates or technical and environmental conditions [Kydland and Prescott (1982), Long and Plosser (1983), and King and Plosser (1984)]. These real business cycle models are proposed as [King and Plosser (1984), p. 378] "a coherent alternative framework to the monetary theories of the business cycle advanced by Lucas (1973) and Fischer (1977)."

However the basic framework of Lucas-type models can be generalized to include real effects. Our purpose here is to show, first, that a significant property of this broader class of Lucas-type models is that real factors in the business cycle cannot be isolated from monetary factors--the effects of the two are always interrelated. (This is a property of this <u>genre</u> of model, but of course not of models driven solely by real factors such as those of Kydland and Prescott (1982), Long and Plosser (1983), and King and Plosser (1984).) Second, another significant property of this broader class of models is that monetary factors <u>can affect</u> the long-run, or secular behavior of real output via the variability of inflation--a channel suggested by Friedman (1977), among others. This is contrary to "...a commonly held view that monetary disturbances should have no permanent effects on real output, and thus disturbances that are of a permanent nature must be associated with real rather than monetary sources" (King and Plosser, 1984, p. 374)--the view underlying the statistical analysis of macroeconomic time series in Nelson and Plosser (1982), for example. More generally we demonstrate here that real business cycle models and Lucas-type models are different paradigms not in the sense of real versus monetary, but rather in the interrelationships between real and monetary factors intrinsic to the Lucas paradigm in contrast to the dichotomy between real and monetary factors implied by the real business cycle literature.

In section I we specify the generalized form of the Lucas-type framework used in our analysis. Section II shows how monetary and real factors are interrelated in the determination of transitory, or cyclical, real output behavior, while section III indicates how monetary, as well as real, factors affect the long-run behavior of real output in this generalized framework. Section IV concludes the paper.

I. The Paradigm With Both Real and Monetary Factors

The familiar Lucas (1973) model is driven by nominal aggregate demand. This section presents a generalized Lucas-type model that includes real factors as well. The monetary factor in the business cycle still enters via the demand side, though not exclusively; in addition real factors now come in through the supply side, though again not exclusively. We emphasize at the outset that there are other ways to generalize this framework and that there have been previous versions of the Lucas model that include real factors [e.g. Barro (1976), Cukierman (1982), Froyen and Waud (1984)]. The particular model developed here merely serves to elucidate the interrelationships between real and monetary factors present in the Lucas paradigm but absent in real business cycle models.

Following the tradition of the incomplete information paradigm, we assume that the economy consists of a large number, m, of "scattered, competitive markets." We derive output supply schedules for each of these markets, and then specify the demand schedules, along with expectations formation. Then the reduced form aggregate output equation for this economy is derived.

I.A. Market Supply Equations

Individual market supply equations are derived from factor demand equations for a resource input (such as a raw material or energy input) and a labor input, as well as labor supply functions at the individual market level. The supply equations are short run because the capital stock is taken to be given. The derived factor demand equations take the following form:

$$\begin{bmatrix} Q_t(v) \\ \\ N_t(v) \end{bmatrix} = \begin{bmatrix} a_{10} a_{11} a_{12} a_{13} a_{14} \\ \\ a_{20} a_{21} a_{22} a_{23} a_{24} \end{bmatrix} \begin{bmatrix} 1 \\ p_t(v) \\ W_t(v) \\ q_t(v) \\ K_t(v) \end{bmatrix}, \quad v = 1, \ldots, m \qquad (1)$$

where v indexes the market and for each market,

$Q_t(v)$ = quantity of resource input

$N_t(v)$ = number of labor hours

$p_t(v)$ = market-specific product price

$W_t(v)$ = market-specific money wage

$q_t(v)$ = market-specific price of resource input

$K_t(v)$ = quantity of capital

where all variables are in logs.

The factor demand equations (1) are derived in the usual way by assuming that firms maximize profits subject to the production function constraint. The log linearity of (1) would follow either from the assuming that the production function is Cobb-Douglas or, more generally, as an approximation to factor demand equations based on production functions of the generalized CES type (see R. Sato [1972]).

It is assumed that labor suppliers know the market-specific money wage, $W_t(v)$, but must form an expectation of the economy-wide aggregate price level p_t^* (conditioned on information in market v). Labor suppliers are further assumed to be risk averse and to maximize expected utility received from income and leisure. It can be shown that expected utility maximization gives a specification for labor supply that can be approximated by the log-linear function.[2]

$$N_t(v) = d_0 + d_1 p_t^* + d_2 W_t(v) + d_3 \sigma_p^2 \qquad (2)$$
$$d_1 < 0,\ d_2 > 0,\ d_3 \gtrless 0,$$

where σ_p^2 is the variance of aggregate price and the formulation of the expected price p_t^* will be modeled below. According to (2) labor supply is an increasing function of the expected real wage ($d_1 < 0$, $d_2 > 0$), assuming that the substitution effect from a change in the expected real wage dominates any income effect. A change in the variance of aggregate price can be shown (see Evans (1978) or Snow and Warren (1986)) to have an ambiguous effect on the quantity of labor supplied ($d_3 \gtrless 0$); the direction of the effect can be shown to depend on workers' relative risk aversion.

When (2) is used to substitute $W_t(v)$ out of (1) we can express the quantities of labor and the resource input as functions of the product price, the expectation of the aggregate price level, the resource input price, the capital stock, and the variance of the aggregate price level,

$$\begin{bmatrix} Q_t(v) \\ \\ N_t(v) \end{bmatrix} = \begin{bmatrix} b_{10} b_{11} b_{12} b_{13} b_{14} b_{15} \\ \\ b_{20} b_{21} b_{22} b_{23} b_{24} b_{25} \end{bmatrix} \begin{bmatrix} 1 \\ p_t(v) \\ p_t^* \\ q_t(v) \\ K_t(v) \\ \sigma_p^2 \end{bmatrix} , v=1,\ldots,m. \qquad (3)$$

where $b_{10},\ldots,b_{15}$, $b_{20},\ldots,b_{25}$ are functions of $a_{10},\ldots,a_{14}$, $a_{20},\ldots,a_{24}$ and $d_0,\ldots,d_3$, as given in the appendix, section A.I.

The production function, in accord with our earlier remarks, is assumed to be log-linear of the form

$$y_t(v) = g_0 + g_1 K_t(v) + g_2 N_t(v) + g_3 Q_t(v).$$

The supply function for market v is derived by substituting equations (3) into the production function to give

$$y_t(v) = \beta_0 + \beta_1 p_t(v) + \beta_2 p_t^* + \beta_3 q_t(v) + \beta_4 K_t(v) + \beta_5 \sigma_p^2 \qquad (4)$$

where β_1, $\beta_4 > 0$, β_2, $\beta_3 < 0$, $\beta_5 \lesseqgtr 0$, and $\beta_1,\ldots,\beta_5$ are functions of $g_0,\ldots,g_3$, $b_{10},\ldots,b_{15}$, $b_{20},\ldots,b_{25}$ as shown in the appendix, section A.I.

I.B Demand and Expectations Formation

Market demand is specified (all variables in logs) as

$$p_t(v) = x_t + z_t(v) - y_t(v) \tag{5}$$

where $z_t(v)$ is the market specific demand shock, $y_t(v)$ is market specific real output, and x_t is economy-wide aggregate demand taken to be nominal income. Demand is unit elastic as in Lucas (1973).[3] The market-specific and economy-wide demand shocks, $z_t(v)$ and x_t, are assumed to be distributed as follows:[4]

$$z_t(v) \sim N(0, \sigma_z^2) \tag{6}$$

$$x_t = x_{t-1} + \Delta x_t, \quad \Delta x_t \sim N(\delta, \sigma_x^2). \tag{7}$$

The information conditioning expectations in market v is the current market specific product price $p_t(v)$, the distributions of market specific and aggregate demand shocks, $z_t(v)$ and Δx_t respectively, and the lagged values of aggregate demand. The expectation of the economy-wide aggregate price p_t^* is modeled consistent with the way actual aggregate price is determined in the model. This expectation is given by

$$p_t^* = (1-\theta)p_t(v) + \theta \bar{p}_t \tag{8}$$

where $\bar{p}_t$ is the expectation of aggregate price conditioned on information prior to time period t, i.e., conditioned on available aggregate information, and θ is a function (to be explained below) of the variances of market specific and aggregate demand shocks as well as other variances and parameters to be introduced below. There is a separate equation (8) for each market, conditioned on the individual $p_t(v)$. The assumption that the expectation of aggregate price is conditioned on information prior to period t implies that the aggregate resource input price is not observed contemporaneously. For some kinds of resources there might be contemporaneous observations of their aggregate price--crude oil for example.[5] The implications of allowing the aggregate resource input price to be observed contemporaneously will be discussed below.

To find $\bar{p}_t$ we first equate market supply, equation (4), and demand, equation (5), and assume $\beta_1 = -(\beta_2+\beta_3)$ which means that a proportional increase in product price and the prices of each of the two variable factors of production leaves desired output unchanged. We then eliminate p_t^* from the resulting equation by use of equation (8) and obtain the equilibrium expression for $p_t(v)$,

$$p_t(v) = \frac{1}{1-\beta_2\theta-\beta_3} [x_t + z_t(v) - \beta_0 - \beta_2\theta\bar{p}_t - \beta_3 q_t(v) - \beta_4 K_t(v) - \beta_5\sigma_p^2]. \quad (9)$$

Next we make the following assumptions about resource input prices

$$q_t(v) = q_t + \eta_t(v) \quad (10)$$

and, quite generally,

$$q_t = \lambda p_t + \phi(t) + \mu_t \tag{11}$$

where $q_t(v)$ is the market-specific resource price, q_t the economy-wide aggregate resource price, $\eta_t(v)$ the market-specific resource price disturbance, p_t the aggregate output price, λ a parameter, $\phi(t)$ a function of time, and μ_t the aggregate resource price disturbance,

$$\eta_t(v) \sim N(0,\sigma_\eta^2) \text{ for all } v, \tag{12}$$

$$\mu_t \sim N(0, \sigma_\mu^2) \tag{13}$$

and $\eta_t(v)$ and μ_t are iid and serially uncorrelated.[6,7] If $\lambda = 1$ the resource input price would move proportionally with the price level, aside from the other factors in (11). If $\lambda \neq 1$ it can be shown that anticipated changes in aggregate demand would, by affecting the price level, have an effect on the relative price of the resource input and thereby affect real output. This provides a channel by which anticipated aggregate demand changes affect real output. An alternative way for anticipated aggregate demand changed to have real effects is to introduce labor contracts as in Fischer (1977) and Taylor (1980). In the ensuing discussion we assume $\lambda = 1$ because the anticipated versus unanticipated issue is not pertinent to our concerns in this paper. For the same reason, we do not extend the model to include labor contracts. Our concern is with the interrelationship between monetary and real factors (either anticipated or unanticipated) in explaining the behavior of real output.

Using assumptions (6), (7), (10), (11), (12), and (13), aggregating (9) across markets gives

$$p_t = \frac{1}{1-\beta_2\theta-\beta_3}[\Delta x_t + x_{t-1} - \beta_0 - \beta_2\,\theta\bar{p}_t - \beta_3 q_t - \beta_4 K_t - \beta_5\sigma_p^2] \qquad (9')$$

where K_t is the aggregate capital stock. (For the theoretical underpinnings of such an aggregation procedure see appendix A, p. 607, of Cukierman and Wachtel [1979]). Taking the expectation of p_t conditional on information through period t-1 gives the expression for $\bar{p}_t$.

I.C. Aggregate Output

To derive the aggregate output equation we proceed as follows. Using the assumption that $\beta_1 = -(\beta_2 + \beta_3)$, substituting for p_t^* from (8) and for $\bar{p}_t$ from the expression just derived, the market-specific supply equation (4) can be rewritten

$$y_t(v) = \beta_0 - \beta_2\theta(p_t(v) - \delta - x_{t-1} + \beta_0 + \beta_3\phi(t) + \beta_4 K_t + \beta_5\sigma_p^2)$$
$$+ \beta_3(q_t(v) - p_t(v)) + \beta_4 K_t(v) + \beta_5\sigma_p^2 \qquad (4')$$

Now rewrite the expression for $p_t(v)$ by substituting $x_t = \Delta x_t + x_{t-1}$ into (5). Also substitute (11) for q_t in (10), assuming λ =

1. Then substituting these expressions for $p_t(v)$ and $q_t(v)$ into (4') and aggregating the resulting equation for $y_t(v)$ across markets (again see appendix A of Cukierman and Wachtel [1979]) gives aggregate output y_t as

$$y_t = \beta_0 - \frac{\beta_2\theta}{1-\beta_2\theta}(\Delta x_t - \delta) + \frac{\beta_3}{1-\beta_2\theta} u_t + \beta_3\phi(t) + \beta_4 K_t + \beta_5\sigma_p^2 \qquad (14)$$

Equation (14) indicates that the determinants of real output y_t are:

1) the monetary factor consisting of the difference between the actual change in nominal aggregate demand Δx_t and the expected change δ;
2) the real factor due to the relative price effect of the resource input price disturbance u_t and the time trend function in that price $\phi(t)$ from (11);
3) the real factor due to the capital stock, K_t;[8]
4) the monetary factor and real factor due to the variance of the aggregate price level, σ_p^2. σ_p^2 depends upon the variances of both monetary and real shocks as shown below.

II. Transitory and Cyclical Effects of Monetary and Real Factors

This section shows how monetary and real factors are interrelated in the determination of transitory, or cyclical, real output behavior in this Lucas-type, limited information paradigm. Section III considers how monetary factors, as well as real, play a role in the secular behavior of real output.

II.A Transitory Shocks and the Interrelationships Between Monetary and Real Factors

The coefficients in (14) are functions of supply equation parameters (the β's) and the parameter θ which characterizes the information structure of the model. That is, θ can be shown (see appendix, section A.II) to be a function of the variances of economy-wide and market-specific disturbances

$$\theta = \frac{(\sigma_z^2+\beta_3^2\sigma_\eta^2)/B}{(\sigma_x^2+\beta_3^2\sigma_\mu^2)/A + (\sigma_z^2+\beta_3^2\sigma_\eta^2)/B}, \tag{15}$$

where $A=(1-\beta_2\theta)^2$ and $B=(1-\beta_2\theta-\beta_3)^2$. While (15) is not an explicit expression for θ, it can be shown by use of the implicit function theorem (see appendix, section A.II) that θ is an increasing function of the market-specific variances (σ_z^2 and σ_η^2) and a decreasing function of the variances of the aggregate demand and resource input price disturbances (σ_x^2 and σ_μ^2, respectively). Since θ is a function of these variances, the coefficients in (14) which contain θ also depend on the market-specific and aggregate variances. Specifically, the coefficient on $(\Delta x_t - \delta)$ which characterizes the output response to a nominal aggregate demand shock (a monetary factor) and that on μ_t which characterizes the output response to a resource input price shock (a real factor) depend on market-specific and aggregate variances of both monetary and real shocks.

II.A.1 <u>Output Response to Nominal Aggregate Demand Shocks</u>

Examination of the coefficient $-\beta_2\theta/(1-\beta_2\theta)$ on $(\Delta x_t-\delta)$ in (14) indicates that the response of real output to nominal aggregate demand shocks is a declining function of the variability of such shocks, the variance σ_x^2, and an increasing function of the variability of market-specific demand disturbances, the variance σ_z^2, (since a rise in σ_x^2 lowers θ while a rise in σ_z^2 increases θ, as described above) a familiar result analogous to that in previous Lucas-type models. When the framework is extended to include a resource input price shock, it is apparent from inspection of the coefficient on $(\Delta x_t-\delta)$ in equation (14) that the real output response to a nominal aggregate demand shock is also a declining function of the variability of aggregate resource input price shocks (the variance σ_μ^2), a real factor, and an increasing function of the variability of market-specific resource price shocks (the variance σ_η^2), also a real factor (since a rise in σ_μ^2 lowers θ while a rise in σ_η^2 increases θ). Hence in the extended Lucas-type framework the real output response to nominal aggregate demand shocks, a monetary factor, is a function of the variability of both monetary (nominal) and real factors--specifically, the variability of both nominal demand and real supply-side shocks.

The economic interpretation of this result is expedited by reference to aggregate demand and supply curves in aggregate price-output space. Increases in the variability of either aggregate real or nominal shocks (relative to the variability of market-specific shocks) will cause the aggregate supply curve to become more steeply sloped with the effect that a given aggregate demand shock, represented by a horizontal shift in the aggregate demand curve along the aggregate supply curve, will cause output to change less. Increases in either aggregate demand or aggregate supply shock variability cause agents to attribute a larger portion of any price movement in their market to a change in the aggregate price level and therefore they change output less in response.

II.A.2 Output Response to Resource Input Price Shocks

Examination of the coefficient $\beta_3/(1-\beta_2\theta)$ on u_t in (14) shows that the response of real output to an aggregate resource input price shock, a real factor, is an <u>increasing</u> function of the variability of the nominal aggregate demand shock, the variance σ_x^2, a monetary factor, and a decreasing function of the variability of the market-specific demand shock, the variance σ_z, (again, because a rise in σ_x^2 lowers θ while a rise in σ_z^2 increases θ). The coefficient also indicates that the response is an increasing function of the variability of aggregate resource input price shocks, the variance σ_μ^2, and a decreasing function of the variability of market-specific resource input price shocks, the variance σ_η^2, (again, because of the effects on θ noted above).[9] Thus in the extended Lucas-type framework the real output response to aggregate resource input price shocks, a real factor, is a function of both monetary (nominal) and real factors. Again in terms of aggregate demand and supply curves, increases in the variability of aggregate resource input price shocks (relative to the variability of market specific shocks) will cause the aggregate supply curve to become more steeply sloped with the effect that a given aggregate resource input price shock, represented by a horizontal shift in the aggregate supply curve along the aggregate demand curve, will cause output to change more.[10] The intuition for this is as follows. Individual firms lower output in response to an increase in the resource input price. (The market-specific supply curves therefore shift left.) As all firms cut back output, prices in all markets rise. The positive output response to this price rise (the movement up the leftward shifted supply curve) will be smaller the higher the variances of either aggregate demand or supply shocks (that is, the steeper the supply curves).

II.A.3 The Role of Second Moments

The presence of the variances of both monetary (nominal) and real shocks in the coefficients on $(\Delta x_t - \delta)$ and μ_t in (14) is what makes it impossible to attribute the behavior of real output to separately identifiable monetary and real factors. If we define a given regime as a period of time when σ_x^2, σ_μ^2, σ_z^2, and σ_η^2 and hence θ and the coefficients on Δx_t and μ_t are unchanged, it might be argued that the transitory movements in real output y_t can be separately attributed to either the monetary or the real shock--to either Δx_t or μ_t in (14). However even this interpretation cannot ignore the fact that the given magnitudes of the second moments of both monetary and real shocks will determine the size of the coefficients on Δx_t and μ_t, and hence the degree of the response of real output y_t to any given monetary or real shock.

In particular it is interesting to observe that the greater the variability of nominal aggregate demand shocks (σ_x^2), a monetary factor, the larger will be the impact on real output of an aggregate input price shock μ_t, a real factor. On the other hand, the greater the variability of aggregate input price shock (σ_μ^2), a real factor, the smaller the impact on real output of a nominal aggregate demand shock Δx_t, a monetary factor, as explained above.

II.B Persistence and the Business Cycle

To this point our discussion has focused on the single-period effects of real and monetary (nominal) shocks. But business cycles exhibit multi-period persistence. A legitimate criticism of equation (14) as it stands is that it contains no mechanism for generating such persistence. There are however several ways in which persistence can arise in a Lucas-type framework. Here we briefly note these and show specifically how persistence could arise in (14).

Lucas (1973) introduced such persistence by appealing to adjustment lags, which would be represented by the inclusion of the lagged value of the dependent variable in (14). Sargent (1979, Chapter XVI) constructs a model where persistence of the effects of aggregate demand shocks emerges endogenously due to costs of adjustment in the labor input. Along a somewhat different line, persistence of the effects of aggregate demand shocks in Lucas (1975) is due to information lags combined with an accelerator effect on investment. Within the models of Fischer (1977) and Taylor (1980), the existence of long-term contracts provides an additional reason for the persistence of the effects of nominal aggregate demand shocks. Blinder and Fischer (1981) are able to induce persistence in the effects of aggregate demand shocks by use of gradual inventory adjustment. In Cukierman (1982) persistence is caused by the inability of economic agents to distinguish between permanent and transitory shocks. Both inventory adjustment and confusion between permanent and transitory shocks induce persistence in the model of Brunner, Cukierman,and Meltzer (1983).

Another possible source of persistence is introduced if there is serial correlation in the aggregate resource input price shock μ_t.[11] For example, suppose the input price shock μ_t is specified as

$$\mu_t = \rho\mu_{t-1} + \varepsilon_t, \quad 1 > \rho > 0 . \tag{16}$$

With this modification, the term containing μ_t on the right hand side of (14) would be replaced by[12]

$$\beta_3 \ \rho \ \mu_{t-1} + \frac{\beta_3}{1-\beta_2\theta} \ \varepsilon_t \tag{17}$$

$$\varepsilon_t \sim N(0,\sigma_\varepsilon^2).$$

In contrast to nominal aggregate demand shocks, (17) implies that for an aggregate input price shock both the anticipated and unanticipated components will affect real output (because input price shocks are relative price shocks and therefore not neutral). The anticipated component, in addition to its direct effect on output, will also increase labor suppliers' expectation of the aggregate price level with consequent upward pressure on the money wage and, therefore, a further effect on output. Note that while the impact of the anticipated component of (17) is not a function of the variances of the real and monetary shocks, that of the unanticipated component still is by virtue of the presence of θ.[13]

III. Secular Effects of Monetary and Real Factors

The expanded version of the Lucas-type paradigm represented by (14) admits a long-run role for monetary, as well as real factors. Our discussion is expedited by separating equation (14) into those variables which cause cyclical or transitory fluctuations in output, $y_{c,t}$, consisting of the stationary variables, and those nonstationary variables which affect the long-run, or natural rate of output, $y_{n,t}$. It is quite reasonable to assume that the capital stock follows a nonstationary process, and that the variance of the price level, σ_p^2, is also nonstationary to the extent that it is subject to periodic regime shifts.[14] Breaking up (14) in this way we have

$$y_t = y_{n,t} + y_{c,t} \tag{18}$$

where

$$y_{n,t} = \beta_0 + \beta_3\phi(t) + \beta_4 K_t + \beta_5\sigma_p^2 \tag{19}$$

$$y_{c,t} = -\frac{\beta_2\theta}{1-\beta_2\theta}(\Delta x_t-\delta) + \frac{\beta_3}{1-\beta_2\theta}u_t \tag{20}$$

and where it can be shown (see appendix, section A.II) that

$$\sigma_p^2 = \frac{1}{(1-\beta_2\theta)^2}(\sigma_x^2 + \beta_3^2\sigma_u^2). \tag{21}$$

According to (19) the long-run or natural rate of output is a function of the real factors represented by the time trend component $\phi(t)$ of the aggregate resource input price, given by (11), and the capital stock K_t. It is also a function of the variance of the aggregate price level σ_p^2 which, by (21) is a function of the variance of nominal aggregate demand disturbances σ_x^2, a monetary factor, and the variance of the resource input price disturbances σ_μ^2, a real factor, as well as θ which is a nonlinear function (see (15)) of aggregate and market-specific variances, representing both monetary and real factors.

III.A <u>Conventional Views on Long-Run Monetary Factors</u>

It is consistent with conventional views that real factors are a determinant of the long-run or natural rate of output, as is the case in (19). However it is not conventional to view monetary factors as playing a long-run role in the familiar Lucas-type incomplete information model. As Nelson and Plosser (1982, p. 139) observe, somewhat more generally:

> It is common practice in macroeconomics to decompose real variables such as output, and sometimes nominal variables, into a secular or growth component and a cyclical component. In the case of output, the secular component is viewed as being in the domain of growth theory with real factors such as capital accumulation, population growth, and technological change as the primary determinants.

In the expanded Lucas-type framework derived here we see that, contrary to this common view, monetary factors do play a role in the determination of the long-run or natural rate of output, indicated in (19) by the presence of σ_p^2 as defined by (21). σ_p^2 entered the model in the derivation of equation (2), via maximization of expected utility under the assumption that workers are risk averse, as previously noted. As we emphasized at the outset, one of our objectives was to illustrate how generalization of the Lucas-type incomplete information paradigm can give rise to a long-run (nontransitory) role for monetary factors. Our derivation is merely illustrative--other variations on this generalization would likely yield this result.

III.B. Price Level Variability and Regime Change

The idea that variability in the aggregate price level or the inflation rate has long-run effects on the level of output has been suggested and examined by a number of economists.[15] Marshall (1886) and Keynes (1924) suggested a relationship between output and aggregate price uncertainty.[16] Friedman (1977) and Okun (1981) have hypothesized a relationship between price variability and output or employment. In Friedman's view price variability affects the natural rate of output partly through the creation of price uncertainty, but perhaps through broader channels as well.[17,18] Tests of Friedman's hypotheses such as those by Levi and Makin (1980), Mullineaux (1980), Makin (1982), and Froyen and Waud (1987), have employed measures of price uncertainty, relying on the close relationship between variability and uncertainty, while Froyen and Waud (1984, 1985) have tested the Friedman hypothesis using a variability measure (see also the closely related study by Evans (1983)). The evidence from these studies tends to support the notion that price uncertainty and/or variability affects the long-run or natural rate of output.

It might be argued that the role of the monetary factor as a determinant of the natural rate via (21) and the presence of σ_p^2 in (19) are only important when there is a regime shift. In this regard one would be concerned to identify changes in the variability of the aggregate price level. The behavior of the wholesale price index in the United Kingdom and the United State, shown in Charts 1 and 2, suggests that such regime shifting does exist.[19]

IV. Conclusion

The view that the Lucas-type incomplete information paradigm is essentially a monetary model of the business cycle is an unnecessarily narrow view. The framework can be generalized to include real factors as well. Significantly, such generalization gives rise to models in which real factors cannot be isolated from monetary factors in the business cycle; the two always have interrelated effects on the transitory or cyclical behavior of real output. Moreover, monetary factors can affect the secular behavior of real output through their effect on the variability of the aggregate price level in such models.[20] Within this expanded

Chart 1
Wholesale Price Index, United Kingdom

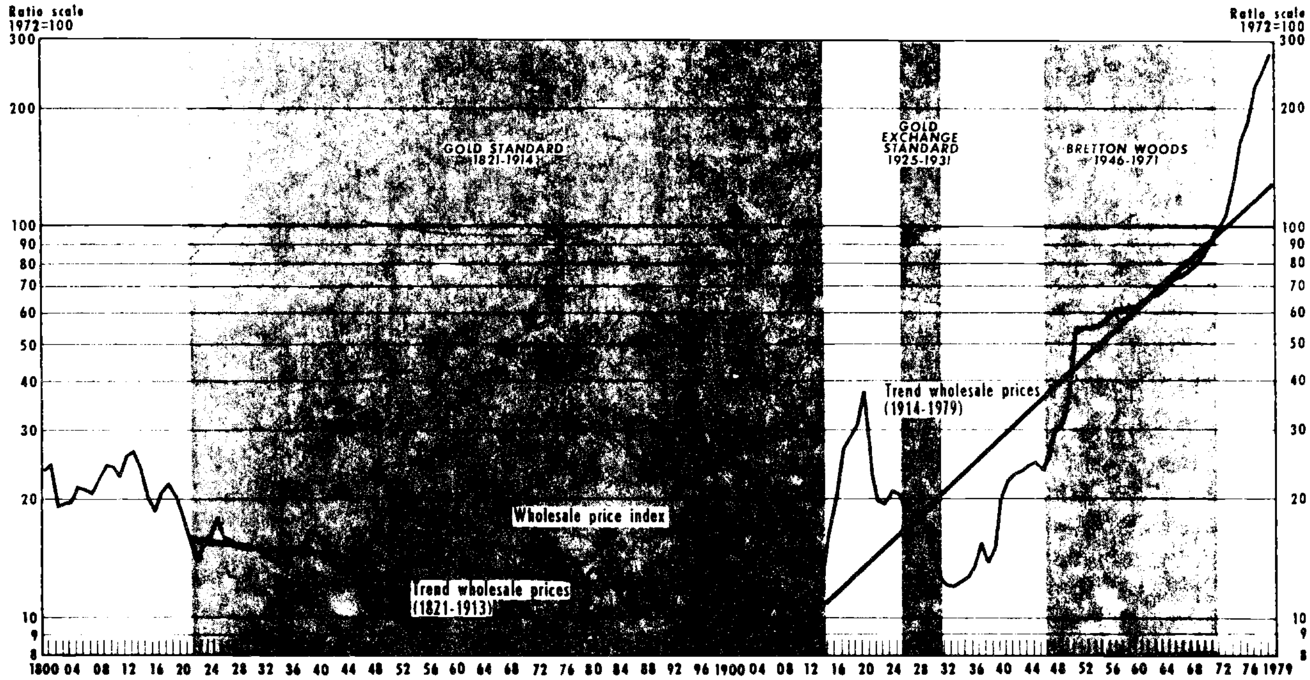
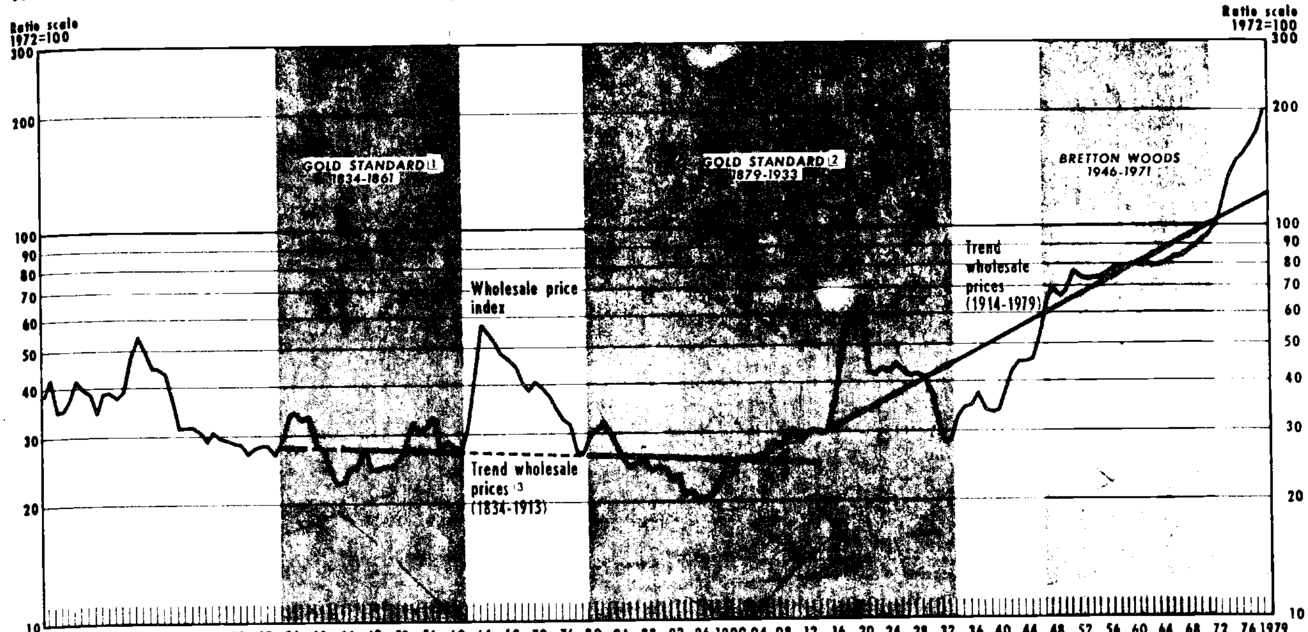


Chart 2
Wholesale Price Index, United States



1 Excludes 1838-1843 when specie payments were suspended.
2 United States imposes gold export embargo from September 1917 to June 1919.
3 Broken line indicates years excluded in computing trend.

Lucas-type framework, one can not attribute long-term changes in real output solely to real factors. Finally, the contrast between real business cycle models and Lucas-type models can be seen not in terms of real versus monetary, but rather as a contrast between the interrelationships between real and monetary factors intrinsically present in the Lucas paradigm but absent from real business cycle models.

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FOOTNOTES

[1]Other models in this tradition include Barro (1976), Fischer (1977), and Taylor (1980), where in the latter two models labor contracts are a key feature.

[2]This is shown for example in Evans (1978) and in Snow and Warren (1986). Tax and/or transfer variables might also be included in the labor supply function. This would open up an additional channel through which real variables (e.g., the marginal tax rate) could affect real output. Azariadis (1981) has shown how the second moments of both nominal and real disturbances can affect the labor-leisure decision in a two-period overlapping generations model.

[3]In this model aggregate demand x is nominal in the sense that all shocks (i.e., Δx_t) represent shifts in a rectangular hyperbola in price-real output space; that is, they represent shifts (or changes) in total nominal expenditures. Of course, in more complicated models real factors (for example, real government spending) can also affect aggregate demand.

This simple specification does preclude several channels by which price uncertainty might affect aggregate demand. In particular, in models where there is outside money, or if government bonds are part of net wealth, then wealth effects associated with price uncertainty may play a role.

[4]It should be noted that the mean δ of Δx_t could be a function of time without changing the ensuing analysis in any significant way.

[5]Some resource input prices (for example, import prices) can be observed only with a lag or with error. (An example of the latter would be newspaper reports of "the" price of oil). It is these kinds of cases that motivate the specification in the text.

[6]More complicated specifications for the behavior of μ_t are of course possible, a point which we will return to below.

[7]Alternatively, we could specify a less than perfectly elastic resource input supply function, subject to stochastic shocks, without affecting our central conclusions.

[8]For simplicity, the capital stock is assumed to be fixed in our analysis. Effects on the stock of capital are clearly a channel by which real factors affect real output. Additionally there may be other shocks to the production function in the form of technological change; see for example Kydland and Prescott (1982), Long and Plosser (1983), and King and Plosser (1984).

[9]As noted earlier, we have assumed that the aggregate resource input price is not contemporaneously observable. We also have considered the case where the aggregate resource input price is contemporaneously observable. In our model, as in Blinder

(1981), observing the aggregate resource input price is not the same as observing the real shock μ_t, see (11), so there is still a signal extraction problem even when the aggregate resource input price is contemporaneously observable--neither p_t nor μ_t are directly observable. Consequently even with this modified version of (14) the output response to changes in μ_t, via the coefficient on μ_t, still depends on ratios of variances of market-specific and aggregate real and nominal shocks, though in a more complex manner than in (14). A case where θ, or its analogue, would not appear in the coefficient on μ_t would be where real shocks themselves were directly observable. For more on the implications of contemporaneous aggregate information in the Lucas-type framework see King (1981).

[10]Note however that the impact of the resource input price shock is smaller in the incomplete information case than when there is full information, in which case the aggregate supply curve is vertical (since the coefficient on μ_t becomes $\beta_3 > \beta_3/(1-\beta_2\theta)$.

[11]An examination of data measuring either energy price or import price shocks, as proxies for the resource input price, for the 1957-1980 period for the United States suggests a significant pattern of first-order autocorrelation in μ_t--see Froyen and Waud (1985).

[12]With the aggregate resource input price shock given by (16), the lagged value of that input price now conveys information about the current input price, and therefore about the current aggregate price level. The equation for $\bar{p}_t$ must be recomputed taking account of this fact. The expression for θ now contains σ_ε^2 instead of σ_μ^2. The modified form of (14) containing the expression (17) is not derived simply by substituting (16) into (14).

[13]If the capital stock were allowed to vary in (14), an additional source of persistence of output movements could be the time-to-build requirement considered by Kydland and Prescott (1982). Persistence of output movements occurs in the model of Long and Plosser (1983) via shocks to the production function.

[14]Technological change could also come in through the natural rate.

[15]Within the model derived here, since the lagged value of the price level is given, the variance of the inflation rate can be shown to equal the variance of the aggregate price level.

[16]As expressed by Marshall (1886, p. 9) a century ago, "A great cause of the discontinuity of industry is the want of a certain knowledge as to what a pound is going to be worth a short time hence."

[17]Okun (1981) argued, along somewhat different lines, that increased variability of aggregate demand would both steepen the Phillips curve and cause the curve to shift upwards, increasing the "inflation rate associated with the cycle average unemployment rate."

[18]More formally rigorous models developed by Azariadis (1981) and Stultz and Wasserfallen (1985) also show how the behavior of nominal magnitudes such as the money supply can affect the trend or natural growth rate of output.

[19]A. C. Harvey (1985) examines five of the same time series previously examined by Nelson and Plosser (1982)--real GNP, Industrial Production, Unemployment Rate, Consumer Prices, and Common Stock Prices. Harvey concludes among other things that the properties of the series over the 1948-1970 period are "very different" from the properties of the same series before 1948. Froyen and Waud (1980) find evidence of significant regime shifts in aggregate price variability between the periods 1957-1966 and 1967-1976 in Great Britain, the United States, and several other industrialized countries. Froyen and Waud (1987) also find evidence of substantial shifts in a measure of price uncertainty for Canada, Great Britain, and the United States during the 1970s and early 1980s. Cukierman and Wachtel (1979) found evidence of several shifts in a survey-based measure of expected inflation over the 1947-1975 period in the United States.

[20]We have estimated models of this type [Froyen and Waud (1984, 1985)] for the United Kingdom and the United States. Bernanke (1983) estimates a model for the U.S. in the Great Depression period which combines elements of the Lucas incomplete paradigm together with a real factor (disintermediation due to the financial collapse).

APPENDIX

A.I Parameters of Equation (3) Defined

When (2) is used to substitute $W_t(v)$ out of (1) to get (3) in the text, the b's in (3) are readily shown to be functions of the a's and d's in (1) and (2) as follows

$$b_{10} = a_{10} + \frac{a_{12}}{d_2}(b_{20} - d_0),$$

$$b_{11} = a_{11} + \frac{a_{12}b_{21}}{d_2},$$

$$b_{12} = \frac{a_{12}}{d_2}(b_{22} - d_1),$$

$$b_{13} = a_{13} + \frac{a_{12}b_{23}}{d_2},$$

$$b_{14} = a_{14} + \frac{a_{12}b_{24}}{d_2}$$

$$b_{15} = \frac{a_{12}}{d_2}(b_{25} - d_3),$$

$$b_{20} = \frac{a_{20}d_2 - a_{22}d_0}{(d_2 - a_{22})},$$

$$b_{21} = \frac{a_{21}d_2}{(d_2 - a_{22})},$$

$$b_{22} = \frac{-a_{22}d_1}{(d_2 - a_{22})},$$

$$b_{23} = \frac{a_{23}d_2}{(d_2 - a_{22})},$$

$$b_{24} = \frac{a_{24}d_2}{(d_2 - a_{22})},$$

$$b_{25} = \frac{-a_{22}d_3}{(d_2 - a_{22})}.$$

Substituting the equations in (3) into the production function to get (4) in the text it can be readily shown that

$$\beta_0 = (g_0 + g_2 b_{20} + g_3 b_{10})$$

$$\beta_1 = (g_2 b_{21} + g_3 b_{11})$$

$$\beta_2 = (g_2 b_{22} + g_3 b_{12})$$

$$\beta_3 = (g_2 b_{23} + g_3 b_{13})$$

$$\beta_4 = (g_1 + g_2 b_{24} + g_3 b_{14})$$

$$\beta_5 = (g_2 b_{25} + g_3 b_{15})$$

A.II Expectations Formation

We now derive the optimal expectation of the aggregate price p_t^*, given by (8), and show how θ is a function of the market-specific demand and resource price variances (σ_z^2 and σ_η^2 respectively), the aggregate demand and resource price variances (σ_x^2 and σ_μ^2 respectively), and the parameters β_2 and β_3. The information conditioning the expectation p_t^* in market v is assumed to be the current market product price $p_t(v)$ and the distributions given by (6), (7), (12) and (13). The optimal expectation of the aggregate price p_t^* conditioned on this information is then given by (see for example Hogg and Craig, pp. 211-13, Introduction to Mathematical Statistics, Macmillan, New York, 1959).

$$p_t^* = \rho_{p_t p_t(v)} \frac{\sigma_p}{\sigma_{p(v)}} [p_t(v) - \bar{p}_t] + \bar{p}_t \qquad \text{(i)}$$

where σ_p^2 and $\sigma_{p(v)}^2$ are the variances of the aggregate price and market-specific prices respectively, and $\rho_{p_t p_t(v)}$ is the correlation coefficient between p_t and $p_t(v)$.

To obtain σ_p^2 use (9') and (11) to express p_t as

$$p_t = -\beta_0 - \frac{\beta_2\theta\delta}{1-\beta_2\theta} - \beta_3\phi(t) + x_{t-1} + \frac{1}{1-\beta_2\theta}\Delta x_t - \frac{\beta_3}{1-\beta_2\theta}\mu_t$$

$$- \beta_4 K_t - \beta_5\sigma_p^2$$

Substituting this expression for p_t together with its expectation conditional on information through period t-1 into

$$\sigma_p^2 = E(p_t - \bar{p}_t)^2$$

we get

$$\sigma_p^2 = E\left[\frac{\Delta x_t - \delta - \beta_3 \mu_t}{1-\beta_2\theta}\right]^2$$

or

$$\sigma_p^2 = \frac{1}{(1-\beta_2\theta)^2}(\sigma_x^2 + \beta_3^2\sigma_\mu^2) \qquad \text{(ii)}$$

assuming Δx_t and μ_t are distributed independently. Note from (ii) that the variance of the aggregate price depends upon the variance of the aggregate demand shock and the variance of the aggregate resource input price shock, as well as the market specific variances (via θ).

The variance of the market-specific price $\sigma_{p(v)}^2$ is equal to the sum of the variance of the aggregate price σ_p^2 and the variance of market-specific price about the aggregate price level σ_τ^2, or

$$\sigma_{p(v)}^2 = \sigma_p^2 + \sigma_\tau^2 \qquad \text{(iii)}$$

where

$$\sigma_{\tau}^{2} = E\left[p_t(v) - p_t\right]^2.$$

Substituting (9) and (9') for $p_t(v)$ and p_t respectively and using (10) gives

$$p_t(v) - p_t = \frac{1}{1-\beta_2\theta-g_3}\,(z_t(v) - \beta_3\eta_t(v)).$$

From (6) and (12) it follows that

$$\sigma_{\tau}^{2} = \frac{1}{(1-\beta_2\theta-\beta_3)^2}\,(\sigma_z^2 + \beta_3^2\sigma_\eta^2). \qquad \text{(iv)}$$

assuming that z and η are independently distributed. Note from (iv) that the variance of market-specific price about the aggregate price depends upon the variance of the market-specific demand disturbance and the variance of the market-specific resource input price disturbance, as well as the aggregate resource price and demand variances (via θ). Substituting (ii) and (iv) into (iii) gives

$$\sigma_{p_t}^{2}(v) = \frac{1}{A}\,(\sigma_x^2 + \beta_3^2\,\sigma_\mu^2) + \frac{1}{B}\,(\sigma_z^2 + \beta_3^2\sigma_\eta^2) \qquad \text{(v)}$$

where

$$A = (1-\beta_2\theta)^2$$

$$B = (1-\beta_2\theta-\beta_3)^2.$$

Now note that

$$Cov(p_t,\ p_t(v)) = E(p_t(v)-\bar{p}_t)(p_t-\bar{p}_t) = E(p_t(v)p_t) - \bar{p}^2.$$

Since

$$p_t(v) = p_t + \frac{1}{1-\beta_2\theta-\beta_3}(z_t(v) - \beta_3\eta_t(v))$$

it follows that

$$E(p_t(v)p_t) = E(p_t^2) + \frac{1}{1-\beta_2\theta-\beta_3}E[p_t(z_t(v)-\beta_3\eta_t(v))]$$

and therefore, since $E[p_t(z_t(v)-\beta_3\eta_t(v))] = 0$,

$$Cov(p_t,\ p_t(v)) = \sigma_p^2 .$$

Hence

$$\rho_{p_t p_t(v)} = \frac{Cov(p_t,\ p_t(v))}{\sigma_p \cdot \sigma_{p(v)}} = \frac{\sigma_p}{\sigma_{p(v)}}$$

and (i) may be written

$$p_t^* = \frac{\sigma_p^2}{\sigma_{p(v)}^2} [p_t(v) - \bar{p}_t] + \bar{p}_t. \qquad \text{(i')}$$

Now from (8), (i'), (ii), and (v) it can readily be seen that

$$\theta = \frac{(\sigma_z^2 + \beta_3^2\sigma_\eta^2)/B}{(\sigma_x^2 + \beta_3^2\sigma_\mu^2)/A + (\sigma_z^2 + \beta_3^2\sigma_\eta^2)/B} \qquad \text{(vi)}$$

To show that θ is inversely related to σ_x^2 denote the right-hand side of (vi) as X and rewrite (vi) as the implicit function

$$\phi = \theta - X = 0.$$

Then

$$\frac{d\phi}{d\sigma_x^2} = -\frac{\phi_{\sigma_x^2}}{\phi_\theta} = \frac{X_{\sigma_x^2}}{1 - X_\theta} \qquad \text{(vii)}$$

Note that X, the right-hand side of (vi), can be rewritten

$$X = \left[\frac{B(\sigma_x^2 + \beta_3^2\sigma_\mu^2)}{A(\sigma_z^2 + \beta_3^2\sigma_\eta^2)} + 1\right]^{-1}$$

and that

$$X_{\sigma_x^2} = -\left[\frac{B(\sigma_x^2 + \beta_3^2\sigma_\mu^2)}{A(\sigma_z^2 + \beta_3^2\sigma_\eta^2)} + 1\right]^{-2} \frac{B}{A(\sigma_z^2+\beta_3^2\sigma_\eta^2)} < 0 \qquad \text{(viii)}$$

Letting $a = \sigma_x^2 + \beta_3^2\sigma_\mu^2$ and $b = \sigma_z^2 + \beta_3^2\sigma_\eta^2$ also note that

$$X_\Theta = -\left[\frac{Ba}{AB} + 1\right]^{-2} \frac{a(B_\Theta A - A_\Theta B)}{A^2 b} > 0 \qquad \text{(ix)}$$

since

$$B_\Theta A - A_\Theta B = -2\beta_2(1-\beta_2\Theta-\beta_3)(1-\beta_2\Theta)\beta_3 < 0.$$

where

$$A_\Theta = -2\beta_2(1-\beta_2\Theta)$$

and

$$B_\Theta = -2\beta_2(1-\beta_2\Theta-\beta_3).$$

It reasonably can be argued that

$$X_\Theta < 1$$

since then

$$-ab(B_\theta A - A_\theta B) < (Ba+Ab)^2$$

or, substituting for A, B, a, b, A_θ and B_θ,

$$2\beta_2\beta_3(\sigma_x^2+\beta_3^2\sigma_\mu^2)(\sigma_z^2+\beta_3^2\sigma_\eta^2)(1-\beta_2\theta)(1-\beta_2\theta-\beta_3)$$

$$< (1-\beta_2\theta-\beta_3)^4(\sigma_x^2+\beta_3^2\sigma_\mu^2)^2$$

$$+ 2(\sigma_x^2+\beta_3^2\sigma_\mu^2)(\sigma_z^2+\beta_3^2\sigma_\eta^2)(1-\beta_2\theta)^2(1-\beta_2\theta-\beta_3)^2$$

$$+ (1-\beta_2\theta)^4(\sigma_z^2+\beta_3^2\sigma_\eta^2)^2$$

which can be seen by careful inspection to be true for economically reasonable values of β_2 and β_3. Hence from (vii), (viii), and (ix) it follows that

$$\frac{d\theta}{d\sigma_x^2} < 0. \qquad \text{(x)}$$

A symmetric argument will show that

$$\frac{d\theta}{d\sigma_\mu^2} < 0. \qquad \text{(xi)}$$

Also note, from (x), (xi) and inspection of (ii), it can be seen that

$$\frac{d\sigma_p^2}{d\sigma_x^2} > 0$$

and

$$\frac{d\sigma_p^2}{d\sigma_\mu^2} > 0.$$