

# A Theory of the Capacity Utilization/Inflation Relationship

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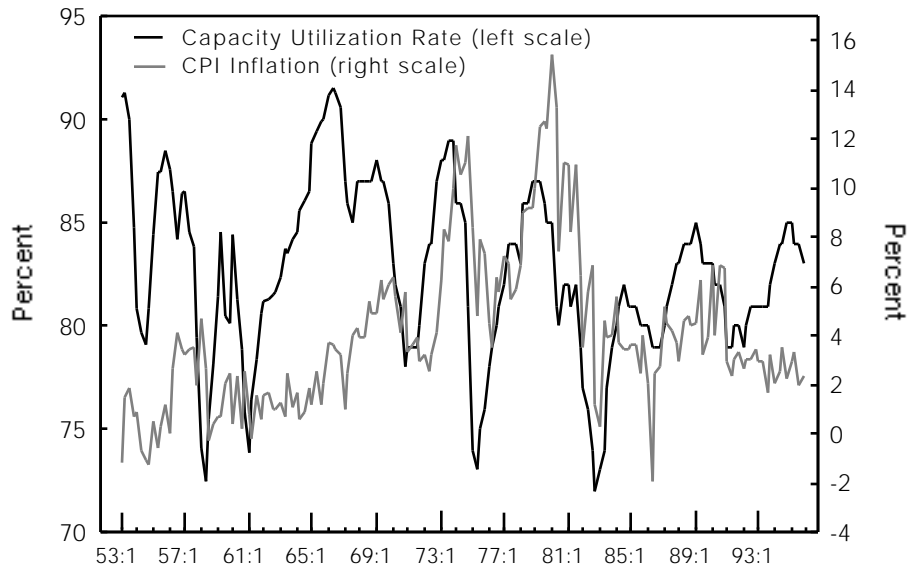
**T**he relationship between capacity utilization and inflation is quite variable. Figure 1 shows the time paths of utilization and inflation for the United States over the period 1953:1 to 1995:4. Two features characterize this relationship. First, inflation and utilization often move in opposite directions. The most dramatic episodes of negative comovement coincided with the 1973/1974 and 1979 periods of sharp energy price rises. Then, utilization plummeted while inflation soared. Second, inflation and utilization also frequently move together. In fact, the instances of positive comovement slightly dominate those of negative covariation—the average historical correlation between utilization and inflation is 0.09. The question is, why do inflation and utilization behave in this way?

Macroeconomics provides many theories of the relations between real economic activity and inflation. But there is no single theory explaining the foregoing features of the utilization/inflation relationship.<sup>1</sup> Thus to address the question posed above, this article develops a new theory. The new theory is based on the standard neoclassical theory advanced by Kydland and Prescott (1982) and Prescott (1986), which emphasizes the importance of technology shocks for the behavior of real variables such as output, consumption, investment, and employment. Building on the standard theory, the new theory blends together ingredients from various other neoclassical theories. The extensions include endogenous capacity utilization (following Greenwood, Hercowitz, and Huffman [1988]), a role for money and inflation (as in Greenwood and

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<sup>1</sup> Finn (1995b) shows that a popular theory, based on a variant of traditional Keynesian theory, does not explain many aspects of the utilization/inflation relationship.

**Figure 1 Capacity Utilization Rate and CPI Inflation 1953:1 to 1995:4**

Note: CPI inflation is measured quarter to quarter at annualized rates.

Huffman [1987] and Cooley and Hansen [1989]), energy price shocks (see Finn [1995a]), and a rule governing money growth that generally allows the money supply to respond to the state of the economy (following Greenwood and Huffman [1987] and Gavin and Kydland [1995]).

The key ideas of the new theory are as follows. Energy price increases that are as sizeable and surprising as those that occurred in 1973/1974 and 1979, and that are not accompanied by contractions of money growth, cause sharp declines in utilization and rises in inflation. The reason is that a rise in energy prices, by making energy usage more costly, reduces energy input into production. Because the utilization of capital requires energy, utilization must decline along with energy. As productive inputs fall, so too does output. The output contraction induces a rise in inflation, absent an offsetting reduction in money growth. Thus, negative comovement of inflation and utilization occurs in response to energy price shocks.

Exogenous changes in money growth generate a small degree of opposite movement in utilization and inflation. An expansion of money growth directly raises current inflation. By also increasing anticipated future inflation, the rise in money growth reduces the effective return to labor effort. The ensuing reduction of labor implies that the marginal productivity of capital utilization

is now lower and thus causes a fall in utilization. But since the inflation tax on real economic activity is small, the effect of money growth on real variables, including utilization, is small.<sup>2</sup> Therefore, money growth induces a small amount of negative covariation between inflation and utilization.

Allowing money growth to respond significantly and directly to the general state of economic activity, represented by technology, creates a mechanism that results in utilization and inflation moving together whenever technology shocks occur. An increase in technology enhances the productivity of all factors of production, including capital, and thereby stimulates an increase in their usage. The resultant output expansion is a force working to reduce inflation. But when the response of money growth to technology is sufficiently strong, the rise in money growth is the dominating force on inflation and causes inflation to increase. Consequently, accounting for the endogeneity of money growth, technology shocks engender positive comovement of inflation and utilization.

The remainder of the article is organized as follows. Section 1 describes the structure of the model economy and its competitive equilibrium. Section 2 shows how the theory works in principle to explain qualitatively the relationship between utilization and inflation. Section 3 calibrates the model economy to analyze quantitatively the theory's implications for the utilization/inflation relationship. Section 4 offers concluding comments.

## 1. THE MODEL ECONOMY

This section outlines the model economy's structure and competitive equilibrium.

### Structure

The economy produces a good from three factors of production: labor, capital, and energy. In doing so, the degree to which capacity, or the capital stock, is utilized varies endogenously. Capital is never fully utilized because of the costs of utilization, which consist of depreciation and energy costs. The good is consumed, invested, and used to pay for energy purchases from abroad. All households are identical, as are firms. Firms are owned by households. Thus, the economy's representative agent is a combined firm and household. Markets are perfectly competitive and prices are fully flexible.

Money's role is to facilitate transactions. Specifically, money is needed to purchase the consumption good. The supply of money is under the control of a monetary authority. It enters into circulation through transfer payments to the representative agent. Because prices are flexible, money affects real economic activity through one channel only: anticipated future inflation that acts like a

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<sup>2</sup> Inflation can affect both the average level and the cyclical behavior of real economic variables. In this study only the cyclical real effects of inflation are analyzed.

tax. By increasing anticipated inflation, a rise in money growth makes activities requiring money, e.g., consumption, more costly relative to activities that do not, e.g., leisure. Thus, increases in money growth cause agents to substitute away from consumption and into leisure.

Stochastic exogenous shocks to production technology, energy prices, and money growth are the sources of fluctuations in the economy. However, not all money growth is exogenous. The monetary authority's rule for money growth allows money growth to partially and directly respond to technology shocks but not to energy price shocks. This endogeneity of money growth captures the idea that the monetary authority accommodates "normal" output fluctuations stemming from technology shocks but not the dramatic fluctuations in output due to the more surprising and larger energy price shocks. A more exact description of the economy's structure follows, with most attention devoted to explaining the extensions on the standard neoclassical model.<sup>3</sup>

The representative agent is infinitely lived with preferences over consumption and labor defined in

$$E \sum_{t=0}^{\infty} \beta^t U(c_t, l_t) \quad , \quad U(c_t, l_t) = \log c_t + \eta \log(1 - l_t), \quad (1)$$

$$0 < \beta < 1 \quad , \quad \eta > 0,$$

where  $c$  and  $l$  are the agent's consumption and labor supply, respectively,  $\beta$  is the subjective discount factor, and  $\eta$  is a parameter. Available time each period is normalized at unity. Momentary utility  $U$  displays standard features and a unitary elasticity of substitution across consumption and leisure.

The agent produces a good from labor and capital services according to

$$y_t = F(z_t l_t, k_t u_t) = (z_t l_t)^\alpha (k_t u_t)^{(1-\alpha)} \quad , \quad 0 < \alpha < 1, \quad (2)$$

where  $y$  is the output of the good,  $z$  is an exogenous shock to technology,  $k$  is the agent's stock of capital in place at the beginning of the period,  $u$  is the utilization rate of  $k$ ,  $ku$  is the service flow from capital, and  $\alpha$  is labor's output share. The production function  $F$  has the usual properties, constant returns to scale and a unitary elasticity of substitution between labor and capital services. It differs from the standard neoclassical production function solely by the inclusion of  $u$ . The manner in which  $u$  enters into (2) follows Greenwood, Hercowitz, and Huffman (1988), allowing a direct relationship between labor's productivity and utilization.

Goods production also requires energy. In particular, energy compliments capital services in accordance with

$$e_t/k_t = a(u_t) \quad , \quad a(u_t) = \frac{\nu_0}{\nu_1} u_t^{\nu_1} \quad , \quad \nu_0 > 0 \quad , \quad \nu_1 > 1, \quad (3)$$

<sup>3</sup> See Hansen (1985) for a description of the standard neoclassical model.

where  $e$  is the agent's energy usage and  $\nu_0$  and  $\nu_1$  are parameters. The technical relationship  $a$  in (3) is the same as the one in Finn (1995a). It states that energy is essential to the utilization of capital, with increases in utilization requiring more energy usage per unit of capital, at an increasing rate.

Some of the good is invested by the agent to form capital as follows:

$$k_{t+1} = [1 - \delta(u_t)]k_t + i_t \quad , \quad \delta(u_t) = \frac{\omega_0}{\omega_1} u_t^{\omega_1}, \quad (4)$$

$$0 < \delta(\cdot) < 1 \quad , \quad \omega_0 > 0 \quad , \quad \omega_1 > 1,$$

where  $i$  is gross investment and  $\omega_0$  and  $\omega_1$  are parameters. This capital accumulation equation is a standard one except for the variable depreciation rate. Depreciation  $\delta$  is an increasing convex function of  $u$ , as in Greenwood, Hercowitz, and Huffman (1988). Therefore, Keynes's notion of the user cost of capital is captured—higher utilization causes faster depreciation, at an increasing rate, because of wear and tear on the capital stock. In summary, there are two costs of utilization: energy and depreciation, either of which would keep capital from being fully utilized.

At the beginning of any time period, the agent holds money that was carried over from the previous period and receives additional money through a transfer payment from the monetary authority. The agent must use these money balances to purchase the consumption good later in the period. More formally, the agent faces the cash-in-advance constraint:

$$m_{t-1} + (g_t - 1)M_{t-1} \geq P_t c_t \quad , \quad g_t \equiv M_t/M_{t-1}, \quad (5)$$

where  $m$  is the agent's chosen money holding,  $M$  is the per capita aggregate money supply, the gross growth rate of which is  $g$ ,  $(g_t - 1)M_{t-1}$  is the transfer payment, and  $P$  is the price level. The constraint applies to the agent's purchases of the good only when it is used for consumption purposes and not when it is invested or exchanged for energy inputs. Greenwood and Huffman (1987) and Cooley and Hansen (1989) specify a similar transactions role for money.

Another restriction on the agent's activities is the budget constraint, setting total income equal to total spending each period:

$$y_t + [m_{t-1} + (g_t - 1)M_{t-1}]/P_t = c_t + i_t + p_t^e e_t + m_t/P_t, \quad (6)$$

where  $p^e$  is the exogenous relative price of energy in terms of the final good. In equation (6), income derives from goods production and total start-of-period money balances; spending is on consumption, investment, energy, and end-of-period money balances. The agent's problem may now be stated: to maximize lifetime utility in (1) subject to the constraints in (2) – (6), taking prices and transfer payments as given.

The description of the economy is completed by specifying the exogenous  $z$  and  $p^e$  processes and the money authorities' rule determining the evolution

of  $g$ .  $z$  and  $p^e$  are stationary, positively correlated, and independent random variables. Their laws of motion are

$$\log z_t = (1 - \rho_z) \log \bar{z} + \rho_z \log z_{t-1} + \epsilon_t^z \quad , \quad 0 < \rho_z < 1, \text{ and} \quad (7)$$

$$\log p_t^e = (1 - \rho_p) \log \bar{p}^e + \rho_p \log p_{t-1}^e + \epsilon_t^p \quad , \quad 0 < \rho_p < 1, \quad (8)$$

where  $\epsilon^z$  and  $\epsilon^p$  are independent white-noise innovations with zero means and standard deviations  $\sigma_z$  and  $\sigma_p$ , respectively,  $\rho_z$  and  $\rho_p$  are parameters, and  $\bar{z}$  and  $\bar{p}^e$  are the respective means of  $z$  and  $p^e$ . Evidence that technology and the relative price of energy are persistent variables is in Prescott (1986) and Finn (1995a). By treating  $p^e$  as exogenous it is implicitly assumed that  $p^e$  is determined on a world market that is not substantially affected by the economy under consideration.

The monetary authorities determine money growth in such a way that money growth is a stationary, positively autocorrelated process that partially responds to the state of economic activity. Specifically, the rule governing money growth is

$$\log g_t = \log \bar{g} + \log x_t + \theta \log(z_t/\bar{z}) \quad , \quad \theta > 0, \quad (9)$$

where  $x$  is the exogenous component of  $g$  with a unitary mean,  $\theta$  is a parameter, and  $\bar{g}$  is the mean of  $g$ . The endogenous component of  $g$  is  $\theta \log(z/\bar{z})$ , so called because it depends on the state of the economy as captured by  $z$ . Greenwood and Huffman (1987) and Gavin and Kydland (1995) similarly endogenize the money supply process. Thus, the temporary and autocorrelated movements in  $z$  around its mean induce the same types of movements in  $g$ . The degree of responsiveness of  $g$  is directly determined by the size of  $\theta$ . Accordingly, this monetary rule has the effect of making money growth accommodate the output fluctuations sparked by changes in  $z$  but not those engineered by changes in  $p^e$ . It is motivated from empirical evidence that money growth positively responds to technology shocks (see Coleman [1996], Gavin and Kydland [1995], and Ireland [1996]). But not all variations in  $g$  stem from responses to the economy. An exogenous part of  $g$  follows a stationary, positively autocorrelated process that is independent of any other variable:

$$\log x_t = \rho_x \log x_{t-1} + \epsilon_t^x \quad , \quad 0 < \rho_x < 1, \quad (10)$$

where  $\epsilon^x$  is a white-noise, zero-mean innovation with standard deviation  $\sigma_x$ , which is independent of both  $\epsilon^z$  and  $\epsilon^p$ , and  $\rho_x$  is a parameter. Thus, purely exogenous and persistent movements in  $g$  also occur, consistent with the empirical findings of Cooley and Hansen (1989).

### Competitive Equilibrium

Competitive equilibrium is obtained when agents solve their optimization problems and all markets clear. Money market clearing requires  $m_t = M_t$ . The

competitive equilibrium is determined implicitly by equations (3), (4), (7) – (10), and the following equations:

$$\frac{\eta}{(1-l_t)} = \lambda_t \alpha \frac{y_t}{l_t}, \quad (11)$$

$$(1-\alpha) \frac{y_t}{u_t} = \omega_0 u_t^{(\omega_1-1)} k_t + p_t^e \nu_0 u_t^{(\nu_1-1)} k_t, \quad (12)$$

$$\lambda_t = \beta E \left[ \lambda_{t+1} \left\{ (1-\alpha) \frac{y_{t+1}}{k_{t+1}} + [1-\delta(u_{t+1})] - p_{t+1}^e a(u_{t+1}) \right\} \right], \quad (13)$$

$$y_t = (z_t l_t)^\alpha (k_t u_t)^{(1-\alpha)} = c_t + i_t + p_t^e e_t, \quad (14)$$

$$M_t/P_t = c_t, \text{ and} \quad (15)$$

$$\lambda_t = \beta E \left[ \frac{P_t}{P_{t+1} c_{t+1}} \right], \quad (16)$$

where  $\lambda$  denotes the marginal utility of real income, i.e., the Lagrange multiplier for the budget constraint (equation [6]). Equation (11) is the intratemporal efficiency condition determining  $l$  by equating the marginal utility cost of foregone leisure to the marginal income value of labor's marginal product. The sum of the marginal depreciation and energy costs of utilization is set equal to the marginal product of utilization in equation (12), thereby determining  $u$ . Equation (13) is the intertemporal efficiency condition governing investment. It equates the current marginal income cost of investment to the discounted expected future marginal income value of the return to investment. That return is the marginal product of capital plus undepreciated capital less capital's marginal energy cost. The resource constraint for the economy is in equation (14), obtained by imposing the money market clearing condition on (6). The constraint sets net income,  $y - p^e e$ , equal to expenditure,  $c + i$ , for the representative agent. Equation (15) states the quantity theory of money, with unitary velocity and consumption as the transaction scale variable.<sup>4</sup> The evolution of money holdings over time is implicitly determined by equation (16). This equation shows that the current marginal real income cost of acquiring one nominal money unit today,  $\lambda_t/P_t$ , equals the discounted expected future marginal consumption value of selling one nominal money unit tomorrow,  $\beta E(1/P_{t+1}c_{t+1})$ .

The term  $p^e e$  in equation (14) may be interpreted as value added to the production of final output  $y$  by the rest-of-the-world's energy good. Thus,  $y - p^e e$  is the value added by the domestic economy. In this interpretation, the economy

<sup>4</sup> An implicit assumption is that the interest rate is always positive, ensuring that the cash-in-advance constraint binds each period.

exports final goods to and imports energy goods from the rest of the world. International trade balances each period—the value of exports equals the value of imports, which is  $p^e e$ .

From equation (16) it follows that anticipated future inflation operates similarly to a tax on economic activity. An increase in future inflation erodes money's expected future purchasing power, causing declines in the marginal utility of real income (see equation [16]) and in desired money holdings. These declines, in turn, induce a reduction in most market activities—such as consumption and labor—stemming from the requirement that money is necessary to finance consumption (see equation [15]).

## 2. QUALITATIVE WORKINGS OF THE MODEL ECONOMY

To provide some intuition on the workings of the model economy, particularly on the utilization/inflation relationship, this section discusses the main qualitative general equilibrium effects of one-time innovations to each of the three exogenous variables:  $z$ ,  $p^e$ , and  $x$ .

### Innovation to $z$

Suppose there is a positive innovation to  $z$ , i.e.,  $\epsilon^z > 0$ , causing  $z$  to increase. The rise in  $z$  has a positive income effect because it improves the relationship between productive inputs and output. In response to the positive income effect,  $c$  rises and  $l$  falls. By directly increasing labor's marginal productivity, the higher  $z$  generates a strong intratemporal substitution force that enhances the rise in  $c$  and outweighs the income effect on  $l$ , causing  $l$  to increase. The higher  $z$  also improves the marginal product of  $u$ , inducing a rise in  $u$  and, concomitantly, in  $e$ . As  $z$ ,  $l$ , and  $u$  increase, so too does  $y$ . Because the expansion of  $z$  is persistent, returns to investment are now higher. This rise in returns prompts an intertemporal substitution effect that increases  $i$ .

Because the money supply rule directly links  $g$  to  $z$ , the rise in  $z$  unambiguously raises  $g$ . What happens to inflation (henceforth denoted by  $\pi$ ) depends on the strength of this linkage, i.e., on the size of  $\theta$ . The reason is that the increases in  $g$  and consumption growth exert opposing influences on  $\pi$ ;  $\pi$  is increasing in  $g$  and decreasing in consumption growth. When the endogenous response of  $g$  is significant, i.e., when  $\theta$  is sufficiently positive, the rise in  $g$  exceeds the rise in consumption growth, causing an increase in  $\pi$ . Note that since  $z$  is positively autocorrelated and  $i$  rises, all of the effects discussed above (relative to the steady state) persist for some time. Therefore, for a sufficiently high value of  $\theta$ , positive shocks to  $z$  induce increases in both  $u$  and  $\pi$ . Or, more generally, when monetary policy significantly responds to the state of economic activity represented by  $z$ , shocks to  $z$  are a source of positive comovement between  $u$  and  $\pi$ .



**Innovation to  $p^e$** 

Next consider the effects of an increase in  $p^e$  due to a positive realization of  $\epsilon^p$ . The increase in  $p^e$  is tantamount to a terms-of-trade deterioration and, thus, has a negative income effect. As a result of this effect,  $c$  falls and  $l$  rises. By directly raising the cost of energy, the  $p^e$  increase engenders sharp declines in both  $e$  and  $u$ . Because the contraction of  $u$  significantly reduces labor's marginal productivity, a strong intratemporal substitution force is set in motion to reinforce the fall in  $c$  and overcome the income effect on  $l$ , so that  $l$  decreases. The reductions in  $u$  and  $l$  imply a contraction of  $y$ . Since the rise of  $p^e$  is persistent, the lower levels of  $u$  and  $l$  extend into the future. Thus, not only is the future marginal energy cost of capital higher but also the future marginal product of capital is lower. Reduced returns to investment instigate an intertemporal substitution effect that decreases  $i$ .

The rule governing money growth ensures  $g$  is unaffected by the rise in  $p^e$ . Therefore,  $\pi$  unambiguously increases in response to the decline in consumption growth. All of the above effects (relative to the steady state) last into the future because of the positive autocorrelation of  $p^e$  and the contraction of  $i$ . In short, positive shocks to  $p^e$  cause decreases in  $u$  and increases in  $\pi$ . More generally, shocks to  $p^e$  that are not "offset" by appropriate changes in money growth are a source of opposite movements in  $u$  and  $\pi$ .

**Innovation to  $x$** 

Finally, suppose a positive value of  $\epsilon^x$  occurs, causing a rise in (current)  $x$ . The expansion of  $x$  directly increases (current)  $\pi$ . Stemming from the serial correlation of the  $x$  process, the rise in  $x$  generates an increase in expected future  $x$  and, thus, in anticipated future  $\pi$ . This signal on future  $\pi$  is important. It is the source of monetary nonneutrality in the model economy. If the signal were absent, the rise in  $x$  would simply cause once-and-for-all equiproportionate expansions of the money supply and price level and have no real effects. But when anticipated future  $\pi$  rises, as in the case under discussion, agents expect a shrinkage in the purchasing power of future money balances, which causes a reduction in the marginal utility of real income ( $\lambda$ ) and other ensuing real effects.

The fall in  $\lambda$  reduces the marginal income value of the return to work effort, thereby engendering an intratemporal substitution effect that decreases  $l$  and  $c$  and increases leisure. This fall in  $c$  reinforces the rise in  $\pi$  noted above. Because the reduction in  $l$  adversely affects the marginal productivity of  $u$ , contractions of  $u$  and  $e$  occur.  $y$  must also fall since both  $u$  and  $l$  are lower. While the effect on capital's future marginal productivity is ambiguous, the current value of  $\lambda$  clearly decreases more than does the future value of  $\lambda$ , because the anticipated inflation effect of the current shock to  $x$  diminishes with the passage of time. Therefore, an intertemporal substitution force working through the reduction of the marginal cost relative to the marginal benefit of  $i$  is created, which tends to

raise  $i$ . An alternative way of viewing  $i$ 's response is to recall that the increase in  $\pi$  erodes money's purchasing power. This erosion makes  $c$ , which uses money, more costly relative to  $i$ , which does not use money. Hence, the rise of  $\pi$  induces substitution out of  $c$  and into  $i$ . The serially correlated nature of  $x$  imparts some persistency to all of the effects (relative to the steady state) mentioned above. In summary, the positive shock to  $x$  sets into motion a decline in  $u$  and an increase in  $\pi$ . In general,  $x$  shocks are sources of negative covariation between  $u$  and  $\pi$ .

### 3. QUANTITATIVE MODEL ANALYSIS

This section quantitatively explores the model's implications for the relationship between  $u$  and  $\pi$ .

#### Methodology

The calibration procedure advanced by Kydland and Prescott (1982) is adopted. In this procedure, values are assigned to the model's parameters and steady-state variables. Some of these values are based on information drawn from other studies or first moments of empirical data. The remaining values are those implied by the model's steady-state relationships. Steady-state variables are denoted using the same notation as before except that time subscripts are omitted. The model's time period is defined as one quarter and the calibration recognizes this definition. Table 1 presents the complete set of calibrated values, with new notation specified in the key. Some details follow.

The values for  $\beta$ ,  $\alpha$ ,  $\delta$ , and  $l$  are the same as those often used in quantitative studies (Kydland and Prescott 1991; Greenwood, Hercowitz, and Krusell 1992).  $\bar{g}$  equals 1.01, the quarterly average per capita gross growth of M2 in the U.S. economy since 1959 (see Coleman [1996]). The average value of capacity utilization in the United States since 1953 gives 82 percent for  $u$ .  $\bar{p}^e/y$  is set equal to 0.043, which is the average energy share of output in the U.S. economy (1960–1989) calculated in Finn (1995a). Given the aforementioned number settings, together with the normalization of  $y$  and  $\bar{p}^e$  at unity, the model's steady-state relationships imply numerical solutions for  $\eta$ ,  $\nu_0$ ,  $\nu_1$ ,  $\omega_0$ ,  $\omega_1$ , and all remaining steady-state variables.

No empirical estimate of  $\theta$  is available in existing studies. Therefore, a sensitivity analysis of  $\theta$ 's values is undertaken here. Specifically, the implications of a range of values for  $\theta$  from 0 to 0.48, capturing no response to maximum response of  $g$  to  $z$ , are analyzed. The upper bound on  $\theta$  is that value of  $\theta$  implied by making the variation in the  $g$  process entirely endogenous or dependent exclusively on the movements in  $z$ .<sup>5</sup>

<sup>5</sup> More precisely, setting  $\log x_t = 0$  in equation (9) implies  $\bar{\theta} = s_g/s_z$ , where  $\bar{\theta}$  is the upper bound on  $\theta$ , and  $s_g$  and  $s_z$  are the respective standard deviations of  $g$  and  $z$ . The calibrated values of  $s_g$  and  $s_z$  follow from the descriptions in the subsequent text and footnote 6.

**Table 1 Parameter and Steady-State Variable Values**

| Preferences                           | Other Steady-State Variables |  |
|---------------------------------------|------------------------------|--|
| $\beta = 0.99$                        | $y = 1$                      |  |
| $\eta = 2.07$                         | $c = 0.774$                  |  |
|                                       | $i = 0.183$                  |  |
| <b>Production</b>                     | $e = 0.043$                  | $\bar{p}^e e/y = 0.043$                      |
| $\alpha = 0.70$                       | $l = 0.300$                  |  |
| $\nu_0 = 0.01$                        | $k = 7.322$                  | $\delta(u) = 0.025$                          |
| $\nu_1 = 1.66$                        | $u = 0.820$                  |  |
| $\omega_0 = 0.04$                     | $\pi = 0.010$                |  |
| $\omega_1 = 1.25$                     |                              |  |
| <b>Monetary Rule</b>                  |                              |  |
| $\bar{g} = 1.01$                      |                              |  |
| $\theta \in [0, 0.48]$                |                              |  |
| <b>Stochastic Exogenous Processes</b> |                              |  |
| $\bar{z} = 1.55$                      | $\rho_z = 0.95$              | $\sigma_z = 0.007$                           |
| $\bar{p}^e = 1$                       | $\rho_p = 0.95$              | $\sigma_p = 0.032$                           |
|                                       | $\rho_x = 0.50$              | $\sigma_x = f(\theta)$ , given $s_g = 0.011$ |

Key:  $f(\cdot)$  denotes “function of”;  $s_g$  is the standard deviation of  $g$ .

Next consider the parameters of the stochastic exogenous processes. The  $\rho_z$ ,  $\sigma_z$ , and  $\rho_x$  values equal those frequently used in other studies (Kydland and Prescott 1991; Cooley and Hansen 1995). The standard deviation of  $g$  (denoted by  $s_g$ ) is set equal to 0.011, the standard deviation of quarterly per capita M2 growth in the United States since 1959 (see Coleman [1996]). The value of  $\sigma_x$  depends on the values of  $\rho_z$ ,  $\sigma_z$ ,  $\rho_x$ ,  $s_g$ , and  $\theta$ . Thus, the value of  $\sigma_x$  varies as  $\theta$  changes.<sup>6</sup>

Finn (1995a) estimates the parameters governing the relative price of energy process for the United States (1960–1989). While those estimates do not directly give the values for  $\rho_p$  and  $\sigma_p$  of the present study because they pertain to annual data, they do provide some guidance. Consistent with Finn’s (1995a) findings of highly persistent energy price movements,  $\rho_p$  is equated to 0.95, and of the relative variability of innovations to energy prices and to technology,  $\sigma_p$  equals 0.032.<sup>7</sup>

The quantitative examination of the model focuses on the  $u, \pi$  relationship and consists of two different types of analyses. The first one is an impulse

<sup>6</sup> Equation (7) implies  $s_z^2 = \sigma_z^2 / (1 - \rho_z^2)$ , where  $s_z$  is the standard deviation of  $z$ . Equation (9) implies  $s_x^2 = s_g^2 - \theta^2 s_z^2$ , where  $s_x$  denotes the standard deviation of  $x$ . Equation (10) implies  $\sigma_x^2 = (1 - \rho_x^2) s_x^2$ . Therefore,  $\sigma_x$  is determined by  $\rho_z$ ,  $\sigma_z$ ,  $\rho_x$ ,  $s_g$ , and  $\theta$ .

<sup>7</sup> In Finn (1995a),  $\sigma_p = 4.57\sigma_z$ . Substituting 0.007, the value of  $\sigma_z$  from Table 1, into the latter equation gives  $\sigma_p = 0.032$ .

response analysis, which traces out the effects of one-time innovations to each of the three exogenous variables  $z$ ,  $p^e$ , and  $x$ . The impulse response analysis thus permits isolation of the effects of each shock and does not require knowledge of the shock variances (i.e.,  $\sigma_z$ ,  $\sigma_p$ , and  $\sigma_x$ ). It is the quantitative counterpart of the qualitative discussion in Section 2. The second analysis is a simulation study, where the model economy experiences ongoing innovations to all three exogenous variables. It requires knowledge of the shock variances since these determine the average frequency and/or magnitude of the shocks. The simulation study provides the basis for the computation of the correlation between  $u$  and  $\pi$  that summarizes the average relationship between  $u$  and  $\pi$ .

Both quantitative exercises require the model's numerical solution for the endogenous variables. The steps involved in the solution are indicated as follows. First, the nonstationary nominal variables are transformed into a stationary form. The transformation divides  $M_t$  and  $P_t$  by  $M_{t-1}$ . Second, the model's parameters and steady-state variables are calibrated. Third, the stationary model is linearized around its steady state and solved using standard solution methods for linear dynamic equations (see Hansen and Sargent [1995]). Fourth, the stationarity-inducing transformation is reversed to give solutions for  $M_t$  and  $P_t$ .

In addition, for simulation analysis 1,000 random samples of 100 observations on  $\epsilon^z$ ,  $\epsilon^p$ , and  $\epsilon^x$  are generated. These samples, together with the model's solution, give rise to 1,000 corresponding samples of 100 observations on the endogenous variables. The correlation between  $u$  and  $\pi$  is computed for each sample and then averaged across the 1,000 samples. By averaging across a large number of samples, sampling error is reduced.

### Impulse Response Analysis

The impulse response analysis shows the quantitative effects on  $u$  and  $\pi$  of once-and-for-all innovations to  $z$ ,  $p^e$ , and  $x$ . Specifically, beginning from the steady state (say at time 0), the three experiments are characterized by the time profiles of innovations in the following schematic:

| Exogenous Shock To | Time Path of Innovations |                                |   |
|--------------------|--------------------------|--------------------------------|---|
| $z$                | $\epsilon_1^z = 0.01$    | $\epsilon_t^z = 0$ for $t > 1$ | $\epsilon_t^p = \epsilon_t^x = 0$ for all $t$ |
| $p^e$              | $\epsilon_1^p = 0.50$    | $\epsilon_t^p = 0$ for $t > 1$ | $\epsilon_t^z = \epsilon_t^x = 0$ for all $t$ |
| $x$                | $\epsilon_1^x = 0.01$    | $\epsilon_t^x = 0$ for $t > 1$ | $\epsilon_t^z = \epsilon_t^p = 0$ for all $t$ |

The innovations  $\epsilon_1^z$  and  $\epsilon_1^x$  are set equal to 1 percent because innovations of that size are sufficient to show the effects of  $z$  and  $x$  shocks. Moreover, they may be regarded as typical since  $\sigma_z$  and  $\sigma_g$  are close to 1 percent. The case of  $\epsilon_1^p$  is different. Because of the low energy share of output, a 1 percent shock

to  $p^e$  has minuscule economic effects. But, large shocks to  $p^e$  have substantive effects. In particular, a 50 percentage point rise in  $p^e$ , the approximate value of the  $p^e$  increases during the two energy crises of 1973/1974 and 1979 (see Tatom [1991]), significantly affects the economy. Thus,  $\epsilon_1^p$  is equated to 0.50 to see the effects of one of the largest historical rises in  $p^e$ .

A value of  $\theta$  must be chosen for the  $z$  shock experiment only—since in the other two experiments  $z$  is held constant and, thus, regardless of  $\theta$ 's value,  $z$  does not affect  $g$ . As mentioned earlier, a sensitivity analysis of  $\theta$  was undertaken. It turns out that changes in  $\theta$ 's value within the range  $[0, 0.48]$  have only small quantitative effects on real variables, stemming from the fact that the inflation tax on real variables is small. But, the value of  $\theta$  matters substantially for the behavior of  $\pi$ . When  $\theta$  is less than 0.25, an increase in  $z$  engenders a bigger rise in consumption growth than in  $g$ , resulting in a decline in  $\pi$ . For  $\theta$  greater than (or equal to) 0.25, whenever  $z$  rises, the induced expansion of  $g$  exceeds that of consumption growth so that  $\pi$  increases. Therefore, recalling the discussion in Section 2, 0.25 is the threshold value of  $\theta$  at which the endogenous response of  $g$  to  $z$  becomes sufficiently strong to ensure that  $z$  shocks are a source of positive comovement between  $u$  and  $\pi$ . The effect of  $z$  on  $\pi$  is directly related to the size of  $\theta$ . In the ensuing  $z$  shock experiment,  $\theta = 0.35$  is taken as a representative, sufficiently high value of  $\theta$ .

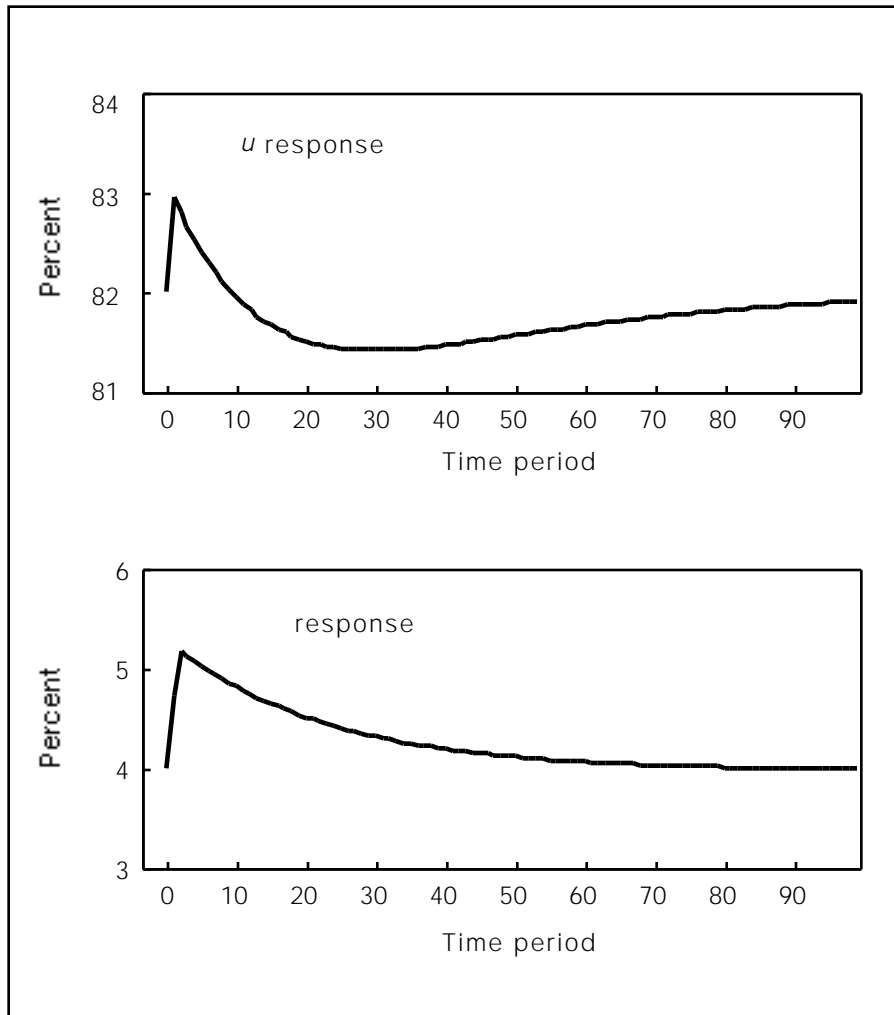
Figure 2 shows the  $u$  and  $\pi$  effects of the 1 percent rise in  $z$ . At first  $u$  rises from 0.82 to 0.83 and then begins to return to its steady-state value.<sup>8</sup> On impact  $\pi$  (expressed at annual rates) increases from 4 percent to 5.2 percent before gradually returning to its steady-state value. Thus, it is seen that  $z$  shocks induce strong positive comovement of  $u$  and  $\pi$ .

In Figure 3 the responses of  $u$  and  $\pi$  to the 50 percent increase in  $p^e$  are displayed.  $u$  immediately falls from 0.82 to 0.72; subsequently  $u$  rises back toward its original value.  $\pi$  jumps from 4 percent to 11.9 percent when the increase in  $p^e$  occurs; later  $\pi$  falls to return to its initial value. Consequently,  $u$  and  $\pi$  sharply move in different directions when large shocks to  $p^e$  occur.

The effects on  $u$  and  $\pi$  due to the 1 percent expansion of  $x$  are shown in Figure 4. Initially  $u$  slightly declines from 0.82 to 0.819 and next rises to return to its steady state.  $\pi$  increases from 4 percent to 9.9 percent at first and subsequently begins its return to the steady state. Therefore, shocks to  $x$  cause a small amount of negative covariation between  $u$  and  $\pi$ .

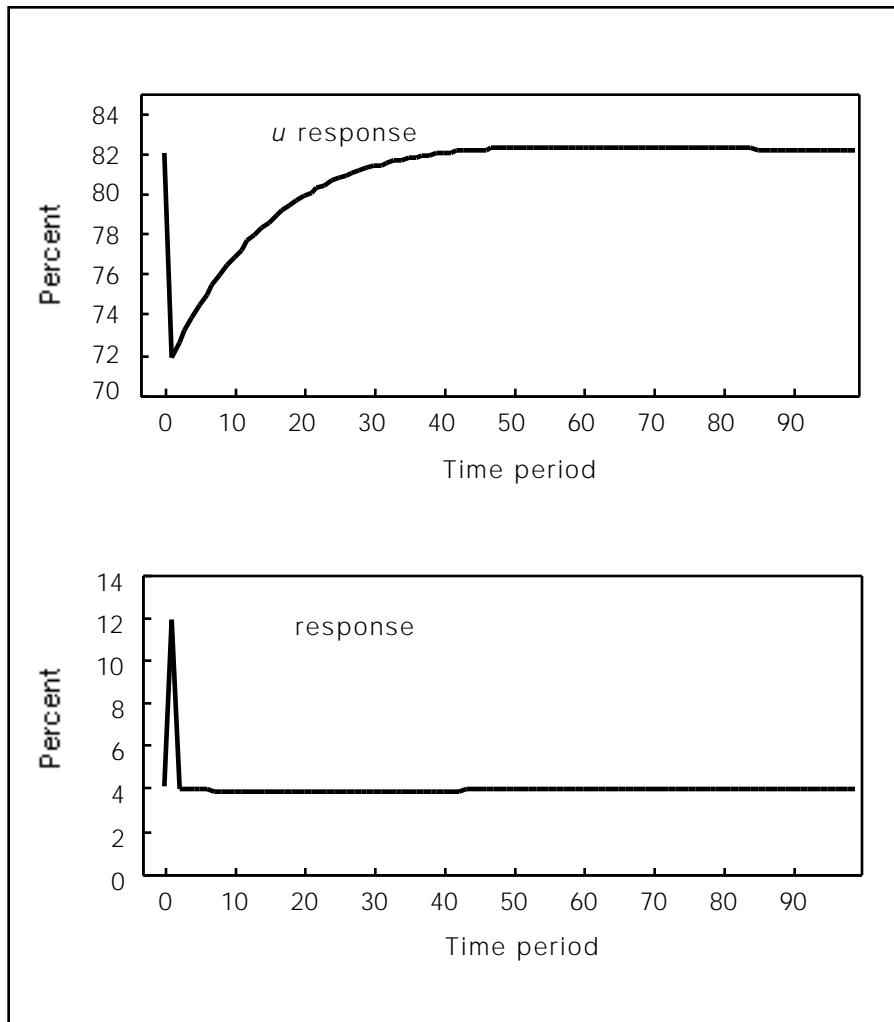
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<sup>8</sup> The return path of  $u$  is characterized by oscillation. This fluctuation is due to similar behavior in  $l$ , which directly affects the marginal productivity of  $u$ . The oscillation in  $l$ , in turn, stems from the hump-shaped response of  $k$  to  $z$  shocks, reflecting gradual capital buildup when technology improves, typical in the standard neoclassical model.

**Figure 2 Response of  $u$  and  $\pi$  to a 1 Percent Rise in  $z$** 

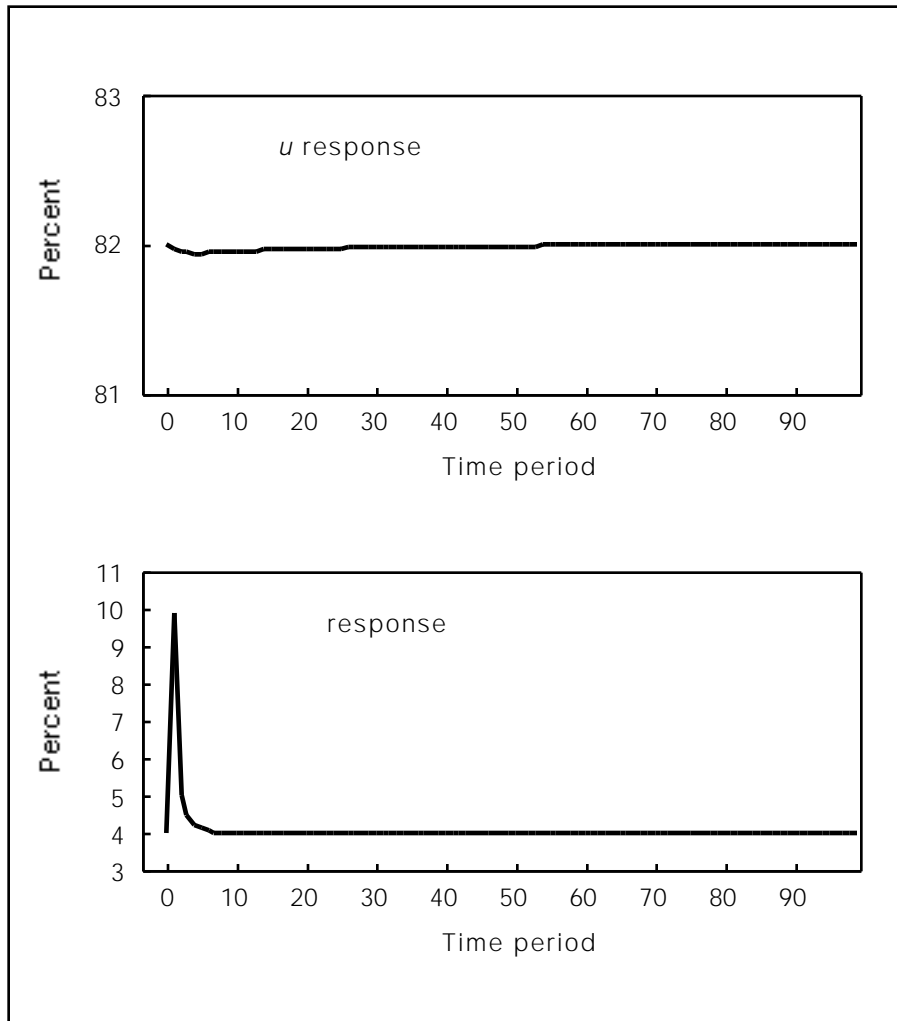
Note:  $\pi$  is expressed at annual percentage rates.

**Figure 3** Response of  $u$  and  $\pi$  to a 50 Percent Rise in  $p^e$



Note:  $\pi$  is expressed at annual percentage rates.

**Figure 4 Response of  $u$  and  $\pi$  to a 1 Percent Rise in  $x$**



Note:  $\pi$  is expressed at annual percentage rates.



### Simulation Results

Table 2 presents the model's correlations between  $u$  and  $\pi$  for various values of  $\theta$ . When  $g$  does not respond to  $z$  shocks, i.e., when  $\theta = 0$ , the correlation between  $u$  and  $\pi$  is negative. The reason, as explained in more detail before, is in this case all three exogenous shocks cause opposite movements of  $u$  and  $\pi$ . But when the endogenous response of  $g$  to  $z$  is sufficiently strong, specifically when  $\theta$  is at least 0.25, movements in  $z$  give rise to positive comovement of  $u$  and  $\pi$ . It turns out that  $z$  shocks are so important relative to shocks to  $p^e$  and  $x$  that for values of  $\theta$  at least as high as 0.25, the correlation between  $u$  and  $\pi$  becomes positive. Moreover, the  $u, \pi$  correlation is increasing in  $\theta$  because the effect of  $z$  on  $\pi$  is directly related to  $\theta$ .

The model's positive  $u, \pi$  correlations are within close range of the 0.09 value of the correlation between  $u$  and  $\pi$  manifest in the U.S. data. Thus, once a significant endogenous response of  $g$  to  $z$  is accounted for, the model captures quite well the average U.S. historical relationship between  $u$  and  $\pi$ .

**Table 2 Correlations between  $u$  and  $\pi$**

| $\theta$ | Corr ( $u, \pi$ ) |
|----------|-------------------|
| 0        | -0.11             |
| 0.25     | 0.01              |
| 0.30     | 0.04              |
| 0.35     | 0.06              |
| 0.40     | 0.09              |
| 0.48     | 0.17              |

Note: Corr ( ) denotes correlation between the variables in parentheses.

## 4. CONCLUDING COMMENTS

Sometimes in the U.S. economy capacity utilization and inflation move together, a fact that is much emphasized in the popular press. Less noticed is the fact that U.S. capacity utilization and inflation sometimes change in different directions too. Historically, the opposite movements in inflation and utilization have been small in size, with two notable exceptions being the large negative comovements during the energy price crises of 1973/1974 and 1979. On average for the U.S. economy (1953–1995), the instances of positive connections between inflation and utilization slightly dominate those of negative relations because the correlation between inflation and utilization is 0.09. Why do inflation and utilization exhibit such a variable relationship?

This article develops a neoclassical theory to offer an explanation of the utilization/inflation relationship. The causal role of technology shocks, coupled with endogenous monetary responses to economic activity, of energy price

variations, and of changes in money growth are emphasized. The theory shows how technology shocks that are directly accommodated by money growth are an important source of positive comovement between utilization and inflation. On the other hand, according to the theory, substantive shocks to energy prices, in the same order of magnitude as those that occurred in 1973/1974 and 1979, cause dramatically opposite movements in inflation and utilization. Furthermore, the theory explains that changes in money growth cause a small degree of negative covariation of utilization and inflation. The theory's explanation not only works in principle but also meets with *quantitative* success. In particular, it well captures the average correlation between utilization and inflation manifested in the U.S. data.

Because of the neoclassical theory's success in explaining the average utilization/inflation correlation, it would be interesting to use this theory as the basis of further empirical investigations of the utilization/inflation relationship. Specifically, the theory suggests that, underlying the highly variable bivariate relationship between utilization and inflation shown in Figure 1, there is a more stable multivariate empirical relationship between utilization, inflation, technology, energy prices, and money growth. Therefore, working within such a multivariate empirical model might prove useful both in explaining the historical path of inflation and utilization and in forecasting future inflation.

The neoclassical theory developed here incorporates only one source of monetary nonneutrality, the inflation tax. Because of the inflation tax, expansions in money growth cause decreases in utilization while inflation increases. It may be that other channels of monetary nonneutrality, such as sticky prices, are more important for the utilization/inflation relationship because they allow increases in money growth to instead increase *both* utilization and inflation. But the present theory's success in explaining the positive linkages between utilization and inflation *without* such channels creates a strong case that technology shocks and endogenous monetary responses are responsible for much of the utilization/inflation relationship. In so doing, it supports a growing body of theory that stresses the role of technology and endogenous monetary policy in explaining more general relationships between real and nominal economic activity (see, e.g., Gavin and Kydland [1995] and Finn [1996]).

### Data Appendix

The data are quarterly and seasonally adjusted for the United States over the period 1953:1 to 1995:4. DRI's database is the source. A detailed description of the data follows.

*Capacity Utilization Rate:* Total industry (consisting of manufacturing, mining, and utilities) utilization rate for the period 1967:1 to 1995:4. Manufacturing industry utilization rate for the period 1953:1 to 1966:4.

*Inflation Rate:* CPI annualized quarter-to-quarter inflation.

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