Interest Rates, Expected Inflation, and Supply Shocks or Why Real Interest Rates Were So Low in the 1970s

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INTEREST RATES, EXPECTED INFLATION, AND SUPPLY SHOCKS

OR

WHY REAL INTEREST RATES WERE SO LOW IN THE 1970s

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This paper investigates the relationship between interest rates, expected inflation, and aggregate supply shocks. A reduced form expression for nominal rates is derived that explains their movement by expected inflation, liquidity forces, and exogenous spending. An equilibrium model of factor employment and return shows that the demand for capital, and thus the real rate of interest, declines in response to a negative supply shock. Estimates of the model delineate an economically significant and statistically clear impact of supply shocks on real rates over the 1952-1978 period as a whole and for various subsamples. Until the early 1970s, a persistent, positive supply shock drove up real rates of interest. The estimates imply that the real rate rose by about two percentage points due to his positive shock. Since then the real rate has been driven down by adverse supply shocks as well as by higher expected rates of inflation. Incorporation of these supply forces results in a single, stable interest rate function for the entire post-Accord period and resolves two other longstanding interest rate puzzles as well. The heretofore "missing" effect of expected inflation on interest rates during the 1950s emerges and is found to be economically and statistically consistent with the impact estimated for other periods. Further, the estimates show that the expected inflation coefficient did not fall in the 1970s. In fact, point estimates of that coefficient for various subsamples mirror the path of marginal tax rates, adding empirical support to the Darby-Feldstein tax hypothesis.
1. INTRODUCTION

Over the past decade, an explosion has occurred in the amount of attention paid to the relationship between nominal interest rates and expected inflation rates. A good deal of this effort has been directed toward empirical analysis of the Fisher neutrality hypothesis that nominal rates respond one-for-one with expected inflation rates. Most empirical tests of the Fisher hypothesis have been bivariate; interest rates were regressed on a constant and on actual or expected inflation measures. The estimates of the impact of inflation on interest rates in these bivariate models tend to be unstable over time and are often weak.

Another branch of work on nominal rates has concentrated on impediments to the Fisher hypothesis occasioned by institutional frictions. Mundell (1963) and Tobin (1965) demonstrate that nominal rates may change by a smaller amount than the expected inflation rate when money pays no interest. Darby (1975) and Feldstein (1976), on the other hand, argue persuasively that the nominal rates should exhibit a greater-than-unity response to expected inflation due to the nature of U.S. income tax laws.

This paper investigates the relationship between interest rates, expected inflation, and real forces. The paper derives the reduced form for interest rates implied by a standard IS/LM model that allows for expected inflation effects. It augments that model with a model of the demand for factors of production, thereby allowing for the possibility...
of equilibrium effects on the real rate of interest due to exogenous shifts in factor supply schedules.

In particular, we address the effect of a negative shock in the supply of materials on the equilibrium rate of return to the other factor inputs in the production process, capital and labor. The factor demand model demonstrates that an exogenous decrease in the supply of one of the factors reduces the equilibrium demand for and return to each of the remaining factors. We present empirical evidence to support this claim with regard to real interest rates over the last thirty years.

The results not only strongly support the economic and statistical importance of supply shocks on real interest rates, but also resolve some longstanding puzzles in interest rate behavior. Incorporation of supply factors results in a single, stable interest rate function for the entire post-Accord period. The heretofore missing effect of expected inflation on nominal interest rates during the 1950s is found once supply forces are introduced. We also show that the apparently declining impact of expected inflation on interest rates over the postwar period, and the 1970s in particular, is shown likewise to result from failure to allow for changing aggregate supply forces. We demonstrate that, if anything, the impact rose in the 1970s, after declining into the 1960s, mirroring the pattern of marginal income tax rates and thus indirectly supporting the Darby-Feldstein tax hypothesis.

Section 2 details the interest rate and associated factor demand models. Section 3 provides the results of empirical tests of the hypotheses. Section 4 investigates the stability of the estimates. The
concluding section draws the argument and evidence together and explores the implications of each for real interest rates, measured productivity, the desired capital stock, and investment.
2. A MODEL OF INTEREST RATES

To describe the evolution of interest rates, we posit a general equilibrium model of the macroeconomy. Commodity market equilibrium is given by an IS curve (1):³

$$i = p^e + a_1 x - a_2 q$$  \hspace{1cm} (IS)

Equilibrium in the money market is characterized by an LM curve (2):

$$q = b_0 + b_1 (M - P - O) + b_2 i$$  \hspace{1cm} (LM)

Their simultaneous equilibrium is achieved by substituting (1) into (2) to generate an aggregate demand function (3):

$$q = c_0 + c_1 [M - P - O] + c_2 p^e + c_3 x$$  \hspace{1cm} (AD)

The model is closed with the addition of an aggregate supply function (4):

$$P = p^e + d_1 q$$  \hspace{1cm} (AS)

Combining (3) and (4) yields a reduced form for \( q \). Inserting that reduced form into (1) generates a reduced form for nominal interest rates, \( i \):

$$i = \beta_0 + \beta_1 p^e + \beta_2 x - \beta_3 (M - P - O).$$  \hspace{1cm} (5)

Equation (5) says that nominal interest rate movements depend upon expected inflation, on exogenous demand shifts, and on the nominal money
supply deflated by the expected price level and the natural level of output. Real rate movements then depend on the same forces.

What factors comprise exogenous demand, \( x \)? Shifts in the demand for capital that arise from exogenous forces are surely one component. Below we present a model of the demand for capital. In particular we ask how the demand for capital will respond to an exogenous decrease in the supply of another factor of production. The model considers an upward shift in the supply schedule for materials but the purpose of the model is to illustrate how the demand for capital and the profitability of capital respond to a negative oil shock.

We start with a constant-technology aggregate production function that expresses aggregate output, \( O \), as a function of capital \( (K) \), labor \( (L) \), and materials \( (M) \). For simplicity, we choose a Cobb-Douglas form that embodies constant returns to scale:

\[
(6) \quad O = L^{\alpha} K^{\beta} M^{1-\alpha-\beta}.
\]

The first-order conditions for profit maximization imply interrelated factor demands of the following form:

\[
(7) \quad \frac{\partial O}{\partial L} = \alpha L^{\alpha-1} K^{\beta} M^{1-\alpha-\beta} = W \quad (L^D)
\]

\[
(8) \quad \frac{\partial O}{\partial K} = \beta L^{\alpha} K^{\beta-1} M^{1-\alpha-\beta} = R \quad (K^D)
\]

\[
(9) \quad \frac{\partial O}{\partial M} = (1-\alpha-\beta)L^{\alpha} K^{\beta} M^{-\alpha-\beta} = \Sigma \quad (M^D)
\]
where $W$, $R$, and $\Sigma$ are the relative prices of labor, capital, and materials. The supply of these factors is assumed to be log linear and of the following form:

\begin{align*}
(10) \quad & w = l_0 + l_1 \cdot l \\
(11) \quad & r = k_0 + k_1 \cdot k \\
(12) \quad & \sigma = m_0 + m_1 \cdot m
\end{align*}

\begin{align*}
(\text{L} \Sigma) \\
(\text{K} \Sigma) \\
(\text{M} \Sigma)
\end{align*}

where $k$, $l$, $m$, $w$, $r$, and $\sigma$ are the logarithms of $K$, $L$, $M$, $W$, $R$, and $\Sigma$, respectively. The six parameters $(k_0, k_1, l_0, l_1, m_0, m_1)$ are all positive constants.

Equations (7) through (12) can be solved simultaneously for the six endogenous prices and quantities. Taking logs of (7), (8), and (9) and eliminating the price terms by equating quantities demanded to quantities supplied in each market yields (13) which can be written more compactly as (14):

\begin{equation}
(13) \quad \begin{pmatrix}
\alpha - 1 & 1 - \alpha - \beta & 1 - \alpha - \beta \\
\alpha & \beta - 1 - k_1 & 1 - \alpha - \beta \\
\alpha & \beta & - \alpha - \beta - m_1
\end{pmatrix}
\begin{pmatrix}
l_0 \\
k_0 \\
m_0
\end{pmatrix}
= 
\begin{pmatrix}
1 \\
k \\
m
\end{pmatrix}
\begin{pmatrix}
l \\
k \beta \\
m_0 - \ln (1 - \alpha - \beta)
\end{pmatrix}
\end{equation}

\begin{equation}
(14) \quad Ax = b.
\end{equation}

The intersection of the supply and demand schedules determines equilibrium factor employment and return in each market, as in figure 1.
Solving (14) for \( x \), we can assess the effect of a parametric change on equilibrium factor quantities and prices. The equilibrium capital stock falls with an exogenous leftward shift in the supply of materials, here represented by an increase in \( m_0 \):

\[
\frac{dk}{dm_0} = \left( \frac{1}{|A|} \right) (1-\alpha-\beta)(1+1_1) < 0.
\]

Conversely, a positive supply shock (a decline in \( m_0 \)) will raise the equilibrium capital stock. The negative supply shock case is shown in figure 1 as a move from \( m_0 \) to \( m_0' \). The Cobb-Douglas form implies that each remaining factor tends to be substituted for the reduced supply factor, but for each factor this gross substitution effect is more than offset by the scale or expansion effect. Each of the interrelated factor demand schedules therefore shifts downward. Less of each factor is employed while the return to capital and to labor falls relative to the price of output. In effect, this reduced supply means that there is less material for each unit of capital and labor to work with, reducing the marginal productivity of each. Capital, labor, and materials employment are each lower even after short-run adjustment to the new equilibrium is complete. The returns to capital (\( r \)) and labor (\( w \)) remain at the lowered levels so long as the adverse turn of events (here a decrease in the supply of materials) persists. The same qualitative result emerges if the parametric change involves the slope of the materials supply function.
FIGURE 1
SUPPLY AND DEMAND IN THE LABOR, CAPITAL, AND MATERIALS MARKETS
The unambiguous conclusion that real interest rates fall requires that the capital supply function not shift upward in response to an upward shift in the materials supply function. A decline in capital supply large enough to offset the decline in capital demand might arise if the response of capital supply to changes in permanent income were large enough. On the other hand, if the redistribution of wealth raised the propensity to save, the net movement of the capital supply schedule could be rightward and real interest rates would fall even further than depicted.

The Cobb-Douglas specification used here shows that even where the aggregate production function implies all inputs are competitive and not complementary, factor demand is likely to fall. The model also shows that equilibrium value added declines in response to a negative supply shock. To the extent capital and materials (like energy) are more complementary than the Cobb-Douglas function specifies, the demand for capital will fall more and the demand for labor less than indicated by our model. Using more flexible functional forms than the Cobb-Douglas specification, Berndt and Khaled (1979) and Berndt and Wood (1979) provide empirical evidence that capital and energy are gross substitutes but net complements. In that situation, the demand for capital falls more than in the Cobb-Douglas case examined here. The qualitative results are unchanged.

To date, most analyses of aggregate supply shocks have concentrated on short-run effects, with particular emphasis on inflation. Given an imperfectly flexible nominal wage, an increase in the price of
materials raises the aggregate supply schedule in price-output space. Ceteris paribus, this lowers the real money supply and thereby raises the real interest rate and lowers investment and output.

The equilibrium model of interest rates presented here focuses instead on the longer run. We grant that short-run frictions may lead to temporarily higher real interest rates and lower investment.9 Our emphasis, however, is on the effect of a change in relative factor supplies on the long-run demand for capital. The thrust of the model is that negative real supply shocks reduce the real return to capital and to labor for the longer run. The work of Gordon (1980) and Cramlich (1979) can be interpreted as demonstrating this equilibrium effect on real wages empirically for the United States during the 1970s. Our model claims equilibrium real interest rates also decline in response to negative supply shocks.

Since a permanent negative supply shock of this type will imply a permanently lower capital demand and real rate of interest, explanations of real rate movements that fail to take account of the downward shift in the demand for capital brought on by adverse material supply shifts will be misspecified. Cyclical aggregate demand measures alone, for example, will imply recovery of the real rate with recovery of output (or capacity utilization or the unemployment rate, etc.) to its equilibrium level. Cyclical measures and the real rate will likely both recover from the short-run disequilibrium levels resulting from a negative supply shock, but attaining the new (lower) equilibrium output level will not reestablish the original real interest rate. Likewise,
actual investment will tend to fall short of that predicted by flexible accelerator-type models since those models ignore the leftward capital demand shift occasioned by the materials supply shift.
3. EMPIRICAL RESULTS

To test our hypothesis that negative real supply shocks in the materials sector drive down real and, ceteris paribus, nominal interest rates, we estimate a reduced form equation based on (5) above. That model incorporates those factors that shift IS, LM, and AS functions.

Our sample extends from 1952 through 1978. The interval begins with the Federal Reserve's cessation of interest rate pegging and ends with the most recent available expected inflation data. The independent expected inflation series, PE12, is available for twelve-month horizons semiannually and is the Livingston series as modified by Carlson (1977b). Two advantages of using the Livingston data are that (1) they are not contaminated by future information as full sample, least squares estimates of expectations are and (2) they may incorporate highly nonlinear and varying parameter schemes based upon broader information sets than regression-based estimates of expected inflation can be.

The interest rate, i, is the annual nominal yield on one-year Treasury bills.\(^{10}\) Before December 1959, when the one-year bills were introduced, the rate is the yield on bills with maturities of nine to twelve months. We use Treasury bill rates, as opposed to commercial paper rates, for example, in order to minimize coefficient biases and maximize efficiency.\(^{11}\) The differential between the two series is far from constant. To the extent that the changes in the differential, presumably due to market perceptions of relative default risk and liquidity, are correlated with any of the explanatory variables, estimates
based on commercial paper rates will be biased. Even if the differential is orthogonal so that our point estimates are unbiased, the larger the variance of the differential, the less efficient our coefficient estimates will be.\textsuperscript{12}

LIQ, the liquidity proxy, is the annualized growth rate of the nominal money supply (M1A) over the last six months minus its annualized growth rate over the last three years.\textsuperscript{13} Changes in this variable correspond to LM curve shifts. This specification is chosen over a variable like real balances because real balances are endogenous and the reduced form requires exogenous regressors, to be consistent with previous work (Carlson, 1979), and because this form resulted in superior fits in spite of its exogeneity.

We capture movements of the IS curve with two variables. The first, X, is designed to pick up autonomous shifts in demand that are not related to supply shocks. Here X is the sum of real federal government defense expenditures and real exports, normalized by real potential output.\textsuperscript{14} The second variable that contributes to IS curve shifts, SUPPLY, proxies changes in the world supply of materials, broadly defined to include both materials for further processing like raw copper, and inputs consumed in production, like oil. The model in Section 2 shows that such changes alter the desired stock of capital and thereby impinge on the IS curve. Thus, this factor relocates the IS curve independently from the factors captured in defense and export demand.
SUPPLY is measured by the ratio of the implicit price deflator for imports to the GNP deflator, less the average 1972 value of one. The import deflator responds either to supply shifts or changes in the exchange rate. Exchange rate changes and real materials supply shocks may have different effects on real interest rates since the former implies an offsetting shock to foreign markets while the latter may be a positive or negative shock to all. We strip exchange rate shocks from the import deflator by multiplying it by the effective exchange rate.\(^{15}\)

The basic equation to be estimated then is (16):

\[
i = \beta_0 + \beta_1 PE12 + \beta_2 LIQ + \beta_3 X + \beta_4 SUPPLY.
\] (16)

Table 1 contains the results of estimating truncated and complete versions of (16). In each case the full sample is employed and Cochrane-Orcutt autocorrelation-corrected (CORC) estimates are presented. The first row gives the results for a skeletal Fisher equation; only expected inflation appears as an explanatory variable. The estimated expected inflation coefficient is less than 0.75 and is statistically significantly below one. Row 2 adds the liquidity variable, LIQ, and a cyclical output variable, AD, which is the ratio of real GNP to its equilibrium level. Though real output is clearly endogenous, we present estimates based on it to show that the SUPPLY effect does not depend crucially on the substitution of exogenous X for endogenous AD, to facilitate comparison with the results of Carlson (1977a, 1979), Cargill (1976), and Tanzi (1980), and to allow for the possibility that
<table>
<thead>
<tr>
<th>Estimation Method</th>
<th>Constant</th>
<th>PE12</th>
<th>LIQ</th>
<th>AD</th>
<th>X</th>
<th>SUPPLY</th>
<th>LRPOIL</th>
<th>R²</th>
<th>D.W.</th>
<th>S.E.E.</th>
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<tbody>
<tr>
<td>1. CORC $\rho = .59$</td>
<td>2.69</td>
<td>0.721</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>.8284</td>
<td>1.75</td>
<td>.822</td>
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<td></td>
<td>(6.78)</td>
<td>(6.85)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2. CORC $\rho = .57$</td>
<td>2.68</td>
<td>0.767</td>
<td>-0.144</td>
<td>24.3</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>.9045</td>
<td>2.27</td>
<td>.626</td>
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<td></td>
<td>(9.23)</td>
<td>(9.79)</td>
<td>(-3.28)</td>
<td>(4.86)</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>3. CORC $\rho = .39$</td>
<td>3.30</td>
<td>0.764</td>
<td>-0.165</td>
<td>17.7</td>
<td>---</td>
<td>-2.61</td>
<td>---</td>
<td>.9161</td>
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<td>.592</td>
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<td></td>
<td>(10.85)</td>
<td>(13.52)</td>
<td>(-3.79)</td>
<td>(3.94)</td>
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<td>4. CORC $\rho = .63$</td>
<td>2.28</td>
<td>0.728</td>
<td>-0.156</td>
<td>---</td>
<td>28.1</td>
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<td>---</td>
<td>.8638</td>
<td>2.08</td>
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<td></td>
<td>(4.26)</td>
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<td>(-3.00)</td>
<td></td>
<td>(1.30)</td>
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<td>5. CORC $\rho = .32$</td>
<td>3.12</td>
<td>0.829</td>
<td>-0.170</td>
<td>---</td>
<td>32.4</td>
<td>-4.20</td>
<td>---</td>
<td>.8999</td>
<td>2.00</td>
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<td>(8.38)</td>
<td>(11.46)</td>
<td>(-3.48)</td>
<td></td>
<td>(2.40)</td>
<td>(-5.15)</td>
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<tr>
<td>6. CORC $\rho = .40$</td>
<td>2.47</td>
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<td>-0.162</td>
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<td>24.4</td>
<td>---</td>
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<td>1.96</td>
<td>.720</td>
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<td>(9.62)</td>
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<td></td>
<td>(1.51)</td>
<td>(-3.00)</td>
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autonomous demand shifts occur in sectors other than those captured by $X$ and SUPPLY.

Both the liquidity and output variables are significant and of the anticipated sign: increased money growth relative to its recent trend depresses interest rates as does cyclically low output. The addition of these variables not only lowers the standard error of the equation but it also raises the estimated coefficient on expected inflation slightly. Somewhat surprisingly, inclusion of the highly autocorrelated output variable, $AD$, does not diminish the strong autocorrelation present in the residuals.\textsuperscript{16} Though the true errors may be positively autocorrelated, the possibility of residual autocorrelation being induced by misspecification remains. Row 3 adds the supply shock proxy. The coefficient on SUPPLY is significant ($t = -3.00$) and, as hypothesized, negative: negative supply shocks drive down real rates even after allowance for liquidity and cyclical output effects.\textsuperscript{17} Inclusion of SUPPLY reduces residual autocorrelation substantially. It also lowers the estimated coefficient on $AD$ by over one quarter. Our model implies that a specification that includes both $AD$ and SUPPLY captures the decline in investment twice—directly through $AD$ since investment is part of aggregate demand and indirectly through the effect of SUPPLY on capital demand. Thus, the decline in the estimated $AD$ coefficient brought about by the inclusion of SUPPLY adds support for our hypothesis that supply shocks in other input markets influence the demand for capital.
Since the early 1950s, the share of imports and exports in total output has risen markedly.\textsuperscript{18} A given change in SUPPLY may have a larger effect on interest rates the more extensively materials are used.\textsuperscript{19} To allow for this, we have created a variable WORLD which scales changes in SUPPLY by the percent of exports in potential output.\textsuperscript{20} The results obtained using WORLD differ negligibly from those obtained with SUPPLY. Summary statistics and individual statistics are almost identical. Since SUPPLY produces a very slightly improved fit, we retain that specification.

Concern about coefficient biases arising from the endogeneity of total output leads to its replacement by exogenous spending, X. Though AD will capture autonomous spending not picked up by X, it will also pick up endogenous spending changes. We present estimates based on each to show that the conclusions regarding SUPPLY are robust. Rows 4 through 6 substitute exogenous X for endogenous AD. Row 5 demonstrates that SUPPLY is highly significant in this specification as well (t = -5.15). Inclusion of SUPPLY raises the coefficient on expected inflation from 0.728 to 0.829. Since SUPPLY is positively correlated with expected inflation, particularly in the 1970s, and negatively correlated with the expected real rate of interest, its inclusion has reduced the downward bias in the expected inflation coefficient. Its inclusion would not be expected to alter the coefficient on X, however, since these two exogenous variables capture separate components of demand. The estimates of the effect of X are nearly identical in fact. Adding SUPPLY also reduces the standard error of the estimate and reduces the
extent of autocorrelation in the residuals greatly. Each of these factors indicates that a previously omitted, but relevant, variable has been added.21

Other forms of the proxy variable for supply shocks were considered as well. The oil and agricultural sectors are the sites of the most dramatic, recent supply shocks. To capture the exogenous shocks emanating from these sectors specifically, the relative domestic prices of energy and of food were entered separately and at the same time. In general, the relative price of food was insignificant and the relative price of energy was significant, but the overall fits were better with the broader relative price proxy. Row 6 substitutes LRPOIL, the log of the ratio of the producer price index for fuel and power to the GDP deflator, for SUPPLY. Again, this supply proxy is strongly significant (t = -3.00). To the extent that supply shocks like strikes, droughts, exhaustion of resources, or increases in the exercise of monopoly power occur in other sectors, however, single-sector-based proxies are too narrow. Because of this concern that broader measures might be more accurate proxies, and because of their slightly superior empirical performance, we have opted for the relative price of imports adjusted for exchange rate changes.

Thus, nominal interest rates respond with a coefficient of about 0.8 to expected inflation with a 95 percent confidence interval that falls a little short of 1.00 in the preferred specification of row 5. Liquidity and autonomous spending effects also drive real rates consistently. The other variable which drives expected real rates is SUPPLY, which enters significantly under each specification.
4. REAL RATE MOVEMENTS

The thrust of recent work on the interest rate-inflation relation is that a bivariate specification is incomplete, since interest rates should vary systematically with other forces. Fama (1975, 1977) argues that, nonetheless, the preponderance of market interest rate movement is due to changes in expected inflation. The $t$-statistics of table 1 support this conclusion in that the largest $t$'s are always associated with expected inflation. Further support for Fama's claim is contained in figure 2, where we plot the actual values of nominal interest rates and the component of predicted interest rates due to expected inflation ($\hat{PEI2}$) and the component due to the combined effect of $LIO$, $X$, and $SUPPLY$ over time ($\hat{SUM}$).\textsuperscript{22} Figure 2 clearly shows that expected inflation has been the prime mover of nominal rates throughout the post-Accord period. The simple correlations between nominal rates and the predicted components due to expected inflation and to the remaining factors are 0.87 and 0.10, respectively. This is consistent with semi-partial correlations as well. The declines in $R^2$ that result from deleting a variable from the full specification are as follows: omitting $PEI2$, 0.4913; omitting $LIO$, 0.0316; omitting $X$, 0.0209; and omitting $SUPPLY$, 0.1098.\textsuperscript{23}

This is not to say that changes in real rates have been inconsequential. Nor does it imply that expected inflation has had no effect on expected real rates. Mishkin (1981) argues that real rates have varied considerably over time but finds no significant relation between
FIGURE 2
THE NOMINAL INTEREST RATE AND COMPONENTS OF ITS PREDICTED VALUES
1952:6-1978:12, SEMIANNUALLY
real rates and either real or monetary forces once expected inflation is taken into account. In that circumstance, one can readily agree with his understatement that "there is something left to explain."

Taking (17) as our definition of the expected real rate, we can rewrite our estimate of (16) from row 5 in table 1 as (18):  

\[ r^e = i - p^e \]  

\[ r^e = 3.12 - 0.171 \text{ PE12} - 0.170 \text{ LIO} + 32.4 \times - 4.20 \text{ SUPPLY} \begin{pmatrix} \text{PE12} \text{ LIO} \times \text{SUPPLY} \\ \text{value} \text{value} \text{value} \end{pmatrix} \begin{pmatrix} 8.38 \ (-2.36) \ (-3.48) \\ 2.40 \ (5.15) \end{pmatrix} \]

Our estimate of the "steady-state" expected real rate of 3.12 is different from zero at well over 99 percent confidence. This steady-state rate is defined as that interest rate predicted by our estimates when expected inflation is zero, money growth proceeds at its recent trend, exogenous spending as a fraction of potential real GNP is at its 1972 value, and the supply shock variable is likewise at its 1972 value. Given the construction of our variables, this steady-state rate is estimated by the regression constant term. Since we may observe non-zero expected inflation forever, there is no presumption that this real rate will ever reign or be approached. It is the zero-expected inflation, equilibrium rate. Selection of 1972 as the base year for calculation of the equilibrium rate is arbitrary and choosing other years would generate different steady-state rates. When the 1952-1978 sample means are taken as the steady-state values for X and SUPPLY, the steady-state interest rate is 2.42.
Changes in real rates occasioned by these forces remain correctly measured regardless of the base year used for steady-state estimates. Figure 3 plots the effect on expected real rates of changing expected inflation rates and supply conditions and allows us to assess their economic significance. Each plotted series traces the impact of a variable on expected real rates and is calculated as the product of the variable and its coefficient given in (18), less the value of that product for the first observation. Thus, each measure's movement of the expected real rate is due to that factor from the 1952:6 base.

Figure 3 shows that the declining relative price of materials produced a continuing positive supply shock from 1952 until the early 1970s. This factor drove up the expected real return by over two percentage points from the 1952:6 starting point. In part this reflects the decline of the relative price of oil over this period. Saudi Arabian crude oil, for example, sold for $1.71 in 1950 but only $1.30 in 1970. Over that same period the U.S. aggregate price level went up 70.3 percent, reducing the relative price of Saudi crude by 55 percent! The steadily rising expected inflation rate has, by contrast, driven the real rate down over the sample by almost one and one-half percentage points. About half of this drop occurred by 1970 and the remainder since. Until the early 1970s, the supply effect more than offset the depressing effect of higher expected inflation. The turn in supply forces then began to reinforce the expected inflation's depressing effect on real rates. The onset of negative supply shocks during the mid-1970s led to a reduction in the real rate of nearly two points. The
FIGURE 3

THE MOVEMENT OF EXPECTED REAL INTEREST RATES DUE TO CHANGING EXPECTED INFLATION RATES AND SUPPLY CONDITIONS 1952:6-1978:12, SEMIANNually (1952:6 = 0.0)
rising expected inflation rate depressed the real rate of interest
another half point. Thus, until the early 1970s, the net effect of
these two forces was to raise real returns by a fairly small amount.
This may account for the lack of attention paid to these important
factors during this time. In the 1970s, however, the two factors each
drove down the real rate calling attention to the rate's decline, as
well as spurring the search for explanations. A result of this search
was an increased emphasis on supply-side factors that had been missing
for the previous quarter century. Higher expected inflation rates and
further increases in real world petroleum prices since 1978 would be
predicted to drive real rates lower, apart from short-run liquidity,
output, and institutional changes.
5. STABILITY OF THE INTEREST RATE RELATION OVER TIME

The introduction of supply-side effects to empirical explanations of interest rates sheds new light on two other puzzles in the interest rate literature. Cargill (1976) and Carlson (1979) both argue that the interest rate-inflation rate relation has been unstable over time. Table 2 lists the full sample results of estimating (16) again and presents the estimates obtained when the sample is split at its 1965 midpoint. F-tests of the hypothesis of joint coefficient stability were performed using ordinary least squares with $X$ as the exogenous demand variable. Tests based on the specification that includes SUPPLY cannot reject the hypothesis of stability. Nor can we reject the hypothesis of individual coefficient stability over the midsample split for any of the right-hand side variables, including the constant. When we omit SUPPLY, however, we can easily reject the hypothesis that all coefficients were stable over time, a result consistent with earlier studies. Likewise, when we carry out individual coefficient stability tests, we find that both the constant term and exogenous demand effect change significantly over the sample.

Even though we cannot reject the hypothesis of constant coefficients for equation (16), it is instructive to see how our coefficient point estimates change over time. Rows 2 and 4 in table 2 indicate that the coefficient on expected inflation has risen over time. This runs contrary to Carlson's (1979) evidence that extending the sample to include the first half of the 1970s in addition to the 1960s causes the


<table>
<thead>
<tr>
<th>Sample Period</th>
<th>Estimation Method</th>
<th>Coefficient on</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Constant</td>
</tr>
<tr>
<td>1. 1952:6-1978:12</td>
<td>CORC</td>
<td>3.12</td>
</tr>
<tr>
<td></td>
<td>$\rho = .32$</td>
<td>(8.38)</td>
</tr>
<tr>
<td></td>
<td>(2.50)</td>
<td></td>
</tr>
<tr>
<td>2. 1952:6-1965:12</td>
<td>CORC</td>
<td>3.43</td>
</tr>
<tr>
<td></td>
<td>$\rho = .42$</td>
<td>(4.05)</td>
</tr>
<tr>
<td></td>
<td>(2.34)</td>
<td></td>
</tr>
<tr>
<td>3. 1960:6-1978:12</td>
<td>CORC</td>
<td>2.78</td>
</tr>
<tr>
<td></td>
<td>$\rho = .29$</td>
<td>(6.55)</td>
</tr>
<tr>
<td></td>
<td>(1.83)</td>
<td></td>
</tr>
<tr>
<td>4. 1966:6-1978:12</td>
<td>CORC</td>
<td>1.89</td>
</tr>
<tr>
<td></td>
<td>$\rho = .01$</td>
<td>(2.85)</td>
</tr>
<tr>
<td></td>
<td>(0.05)</td>
<td></td>
</tr>
<tr>
<td>5. 1952:6-1959:12</td>
<td>CORC</td>
<td>2.51</td>
</tr>
<tr>
<td></td>
<td>$\rho = .44$</td>
<td>(5.45)</td>
</tr>
<tr>
<td></td>
<td>(1.91)</td>
<td></td>
</tr>
<tr>
<td>6. 1952:6-1959:12</td>
<td>CORC</td>
<td>2.08</td>
</tr>
<tr>
<td></td>
<td>$\rho = .71$</td>
<td>(1.89)</td>
</tr>
<tr>
<td></td>
<td>(3.95)</td>
<td></td>
</tr>
<tr>
<td>7. 1952:6-1959:12</td>
<td>CORC</td>
<td>5.75</td>
</tr>
<tr>
<td></td>
<td>$\rho = .23$</td>
<td>(4.20)</td>
</tr>
<tr>
<td></td>
<td>(0.91)</td>
<td></td>
</tr>
</tbody>
</table>
expected inflation effect to drop from about 1.3 to 1.0.\textsuperscript{25} Using Carlson's specification of omitting SUPPLY but including expected inflation, liquidity, and cyclical output measures, that same coefficient plummets from 1.01 to 0.66 over the 1952-1978 period when the sample is split in 1965.\textsuperscript{26}

Darby (1975) and Feldstein (1976) illustrate that the response of nominal interest rates to expected inflation should vary with marginal tax rates. Feldstein (1980) estimates that effective tax rates fell from the 1950s until the mid-1960s and thereafter rose above the levels of the 1950s.\textsuperscript{27} Carlson (1979) argues that the response of interest rates to expected inflation has lessened, not risen, in the 1970s, a finding difficult to square with rising marginal tax rates over this period. The estimated coefficient on PEl2 in table 2, however, mirrors the decline in Feldstein's tax series into the 1960s and its rise into the 1970s. Thus, our estimates support the Darby-Feldstein hypothesis.

Our results suggest that the expected inflation coefficient may have risen through time, though we cannot reject the hypothesis that it was constant. Again, we can explain Carlson's findings of large but declining expected inflation effects as a classic omitted variable problem. The relatively high pre-1970 estimate of the expected inflation effect results from the negative correlation (\(-0.9\)) between expected inflation and the omitted supply proxy. The positive correlation (\(+0.8\)) during the 1970-1978 period accounts for the decline when his sample period extends past 1970.
Inclusion of SUPPLY helps to explain another paradox. Cargill (1976) claims that there is no statistically discernible impact of expected inflation on nominal interest rates during the 1950s in regressions of rates on either expected inflation alone or in conjunction with liquidity and aggregate demand variables. Rows 5 and 6 in table 2 reproduce that statistically weak impact of expected inflation. The last row adds SUPPLY to that specification and reveals a much stronger impact not only of expected inflation, but also of liquidity and the demand proxies, on nominal rates when SUPPLY is included. Cargill and Meyer (1980) find a significant effect for the 1950s only by dropping the first two post-Accord years, thus starting their sample in 1954. Their estimated expected inflation coefficient then exceeds two. Taking SUPPLY to be an omitted variable, we can explain why dropping the 1952 and 1953 observations produces such a dramatic turnaround in both the economic and statistical significance of their expected inflation coefficient. Figure 3 shows that SUPPLY and PE12 were strongly positively correlated (+0.9) in 1952 and 1953. From 1954 until the end of the 1950s, they were negatively correlated (-0.6). From 1954 on, the estimate of PE12 in nominal rate regressions captures its own effect plus the effect of the positively correlated, but omitted, variable SUPPLY. This accounts for the very large coefficient on expected inflation after 1954. The positive correlation during the first two years offsets that effect for the entire 1952-1959 period, however, and produces the insignificant expected inflation effect like that in rows 5 and 6.
Other specifications than (16) were estimated to see if other omitted variables might still render our estimates biased. We found, for example, no effect of the change in aggregate demand on the level of rates. Nor did allowing for the apparently rising openness of the economy over the sample change our results. Lagging SUPPLY one period did not improve the overall fit or change point estimates. A lagged dependent variable was insignificant as were other, more flexible lag forms.
6. CONCLUSION

The model presented in Section 2 predicts that interest rates respond to expected inflation, liquidity pressures, and exogenous spending. One component of exogenous spending is the demand for capital. Our model of factor employment and return implies that the demand for capital, the return to capital, and the real interest rate each fall in response to a negative shock to the supply of another factor of production.

The empirical results support the supply shock hypothesis: changes in real supply conditions have had real effects. Supply forces drove expected real rates upward substantially during the 1950s and 1960s and downward during the 1970s. The estimated impact of supply shocks on real interest rates is economically significant and statistically robust with respect to sample period, to various specifications of the other included variables, and to various specifications of the supply proxy itself.

The model estimated here also allows us to disentangle the effects on interest rates of factor supply shifts from those of expected inflation. Consistent with the Mundell and Tobin models, as well as with the nonneutrality of existing U.S. tax laws, our estimates imply that real rates are driven down by higher expected inflation. The downward pressure exerted on real rates by rising expected inflation throughout the post-Accord period was counteracted by the uplifting effect of the positive supply shock for much of the post-Accord period.
In the early 1970s, however, supply forces reversed and began to reinforce that downward pressure on real rates. The short-run recession engendered by the negative supply shocks of the mid-1970s accentuated the short-run fall in real rates. The results also warn us that restoring expected inflation to levels observed prior to the 1970s will not restore expected real interest rates to pre-1970 levels unless supply forces revert to their previous levels as well.

Besides demonstrating the importance of supply factors in the determination of interest rates, the estimates help resolve some long-standing empirical puzzles. Addition of supply forces results in a single, stable interest rate function for the entire post-Accord period. The apparent lack of a Fisher effect for the 1950s has been reconciled as well. The expanded specification that includes supply forces delivers a statistically significant and empirically consistent response for that period. We also demonstrate that, when the sample is partitioned, the estimated response of nominal interest rates to expected inflation closely follows movements in income tax rates calculated by Feldstein (1980). This finding supports the Darby-Feldstein tax hypothesis and differs substantially from the conclusions reached by Carlson (1979).

In addition to the regression evidence presented here, which so strongly supports the role of supply shocks, several other facets of recent experience fit into the supply shock model. Investment behavior is one. Over the 1952-1978 sample, the proportion of real gross private domestic fixed investment in real GNP peaks in 1973, bottoms out in 1975, and recovers thereafter. This is precisely the pattern the supply
shock variable plotted in figure 3 would imply. Further, investment demand functions, like those of Abel (1980) and Clark (1979), cannot explain the steep decline in investment after 1972 even with flexible-accelerator-type models that include capital cost and total output as explanatory variables. Our model hints that the optimal capital-output ratio may well decline in the face of a negative materials supply shift. To the extent the equilibrium capital-output ratio falls, specifications that do not incorporate this change in the optimal factor input mix will tend to overpredict the desired capital stock and investment when a negative supply shock hits, especially during the transition to the lower desired stock. Our model predicts an endogenous fall in real rates due to the leftward IS curve shift occasioned by negative supply shocks for any given level of output. Models that explain investment as a response to changes in the real rate are doomed, for they trace out movement along an IS curve instead of capturing its leftward shift.

Recent labor market phenomena likewise fit the model. Our model predicts, in the absence of technological change, falling real wages in response to a negative supply shock. In fact, real (detrended) compensation per hour rose until the late 1960s and has fallen increasingly below its own trend since, especially in 1973-1975. This feature and the decline in measured labor productivity over the last few years are again consistent with our model. The pattern of declining (relative to trend) real wages and a sharply rising ratio of employment to population argue that the 1970s witnessed a positive labor supply shock. To the extent this is true, real rates have been buoyed and the partial effect of negative materials supply shocks underestimated.
FOOTNOTES

1See Gibson (1972), Cargill and Meyer (1980), Carlson (1979), and Pyle (1972), for example.

2Levi and Makin (1978) incorporate these and other considerations in a general macromodel and analytically derive the reduced form effect of expected inflation on nominal interest rates as a function of the structural parameters.

3The following variable definitions are used in (1) through (5):

   i = nominal interest rate

   \( p^e \) = expected inflation rate

   q = log of real output, normalized by its long-run equilibrium, or natural, rate

   \( x \) = log of real exogenous demand, normalized by natural real output

   M = log of exogenous nominal money supply

   P = log of general price level

   \( Q^n \) = log of natural real output

   \( p^e \) = expected log of general price level.

4This could be termed the inverse of expected natural velocity.

5It can be shown that \( |A| \), the determinant of \( A \) in (15), is negative for \( 0 < a, \beta, a + \beta < 1 \) and \( 1, k, m > 0 \).

6The Allen partial elasticities of substitution for the Cobb-Douglas form are each unity.

7The returns to capital and labor fall even more steeply if we assume each is supplied totally inelastically. Equilibrium output falls less, however, in that case.
8 See Gordon (1975) and Phelps (1978).

9 We can conceive of movements of aggregate output away from its equilibrium level as being generated by movements of the actual labor supply function from its equilibrium level. Recessions then result from upward shifts of the labor supply function relative to the real wage. This withdrawal of labor corresponds to the upward shift of the materials supply function and drives down the return to capital in an analogous fashion. Thus, we expect the real rate of interest to fluctuate with the business cycle. Labor supply could, of course, exogenously shift. The shifts in labor supply that generate cyclical output patterns result from misperceptions, however, which are assumed to be eliminated in the long run.

10 Since the inflation forecasts were made by early June and early December, we use June and December monthly averages for interest rates. Second and fourth quarter data are used for all other series.


12 The difference between the four-to-six month commercial paper and the six-month Treasury bill rates over the 1959-1978 portion of our sample is significantly related to the expected inflation rate for the next six months and the liquidity variable in a regression that also includes the supply proxy and cyclical output. The ratio of the variance of that difference to the variance of the six-month Treasury bill rate is 0.11.
13 This is the same specification used by Carlson (1970). Cargill and Meyer (1980) use a similar measure but do not detrend money growth. At various stages the growth rate of real balances and the inverse of expected natural velocity were substituted for detrended money growth. The results changed negligibly. In general, detrended money was associated with a slightly better overall fit.

14 The potential real output series is from Perloff and Wachter (1979) through 1977. The series is assumed to grow during 1978 at its 1977 growth rate of 3.059 percent. Our results are insensitive to the substitution of the potential output series of Tatton and Rasche (1977).

15 This allows us to enter the effective exchange rate separately and determine if offsetting exchange rate shocks affect domestic interest rates. The estimated effect turns out to be insignificant. The lack of a significant impact of exchange rate changes is consistent with integration of international capital markets. Domestic rates may be virtually immune to adverse relative shifts in input prices occasioned by exchange rate changes if capital flows toward the country experiencing the corresponding favorable shift in exchange rates. This upward shift in domestic capital supply will tend to offset the depressing effect on interest rates that operates through the demand for capital.

16 Carlson obtained the same result.

17 These results are robust with respect to the substitution of one-period-ahead predictions of SUPPLY and of AD when those values are generated as least squares predictions with current and one-period-lagged dependent variables as regressors.
From 1952 to 1978, one measure of openness, the ratio of real exports to real potential GNP, rose from .041 to .078.

See Bruno and Sachs (1978).

Our index of SUPPLY which adjusts for the scope of international trade is calculated as follows:

\[
\left( \frac{\text{WORLD}_t}{\text{WORLD}_{t-1}} \right) - 1 = \left( \frac{\text{SUPPLY}_t}{\text{SUPPLY}_{t-1}} - 1 \right) \left( \frac{\text{REAL EXPORTS} \times 100}{\text{REAL POTENTIAL GNP}} \right)
\]

The index is set equal to 1.0 for the first period and its average 1972 value is subtracted to retain consistency with SUPPLY, which is also set equal to zero in 1972.

The standard error of the estimate rises, as is to be expected when a variable correlated with the error term, due to its endogeneity, is replaced.

Each individual component is calculated as the variable times its estimated coefficient from row 5 in table 1. The actual rates differ from the sum of the four components by the constant and the autocorrelated error term.

These R^2's come from OLSQ regressions with no autocorrelation correction.

This definition ignores the impact of income taxes and will only be exact if the marginal tax rate of the marginal supplier and demander is zero.

Carlson's relatively large expected inflation effect can be attributed in part to his use of the commercial paper rate as the
dependent variable. The difference between that rate and the Treasury bill rate is significantly (and positively) related to expected inflation and supply conditions and (negatively to) liquidity. Estimates based on commercial paper rates are biased under these conditions.

26 The bivariate autocorrelation-corrected estimate declines from 0.73 to 0.57 over the same sample split.

27 Feldstein's (1980) average effective tax rates on capital income for the 1950s, 1960s, and 1970s are 0.703, 0.609, and 0.713.

28 Cargill's liquidity and output proxies, M1 growth and real GNP growth, differ somewhat from ours.

29 Figure 3 plots the product of SUPPLY and (the negative of) its negative coefficient and the product of PEL2 and its negative coefficient from (16).
REFERENCES


________. "Expected Inflation and Interest Rates." Economic Inquiry, October 1979, pp. 597-608.


