A simultaneous equation model to determine the rate of inflation

Mary Elizabeth Rieder
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A simultaneous equation model to determine the rate of inflation

by

Mary Elizabeth Rieder

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of The Requirements for the Degree of DOCTOR OF PHILOSOPHY

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DEDICATION

To "Chris"

Who took the time and had the patience to make me an economist
I. INTRODUCTION

In contrast with earlier periods in the development of economic theory, the basic problem now facing economists is not one of insufficient aggregate demand and unemployment, but inflation. Inflation is generally considered to be a problem associated with full employment and excess aggregate demand, rather than with unemployment and insufficient aggregate demand.

Inflation is also essentially a monetary rather than a real phenomenon. The Classical economists clearly realized this. Postulating the exchange identity, $MV = PY$, where $M$ is the money supply, $V$ is income velocity, $P$ is the price level, and $Y$ is the level of real output, they argued if the economy is at full employment and $V$ is constant, prices would rise in proportion to increases in the money supply. Even if $Y$ and $V$ are not held constant, but are allowed to vary within reasonable limits consistent with the concept of full employment and the institutional framework of the economy, the relationship between the money supply and the price level, while no longer proportional, is still very strong.

It would seem that the money supply would be the key variable in determining the price level in macroeconometric models. However, in the major quarterly econometric models
of the United States, this is not the case. David Fand (40) points out that the price level in many of these current econometric models depends on such variables as wages, unit labor costs, variable markup, capacity utilization, unfilled orders, shipments, and farm and import prices. These variables take into account changes in costs, shifts in demand, productivity trends, tax changes etc., but do not explicitly take into account the effect on prices of changes in the money supply. Fand argues these models use basically the microeconomic approach of supply and demand analysis to explain a macroeconomic price variable. This approach poses two problems. First, movements in an aggregate index cannot be adequately explained using a theory of relative prices. And second "...this demand-supply theory suggests that changes in the cost of production (an autonomous rise in the money wage rates, in the markup factor, or in profits) will cause general commodity prices to rise without specification of the monetary requirements necessary to generate rising prices or validate the higher price level" (Fand 40, p. 451). The current macroeconometric models do not have a monetary theory of the price level.

In these models the main reason for the non-monetary
approach to inflation lies in their basic structure. These models are built in the Keynesian tradition where the problems of recession, insufficient demand, and unemployment are of primary interest. Assuming that aggregate supply will rise to meet aggregate demand, the emphasis in these models is on aggregate demand and its components: consumption, investment, and government spending, if a closed economy is assumed. In order to highlight aggregate demand, these models subdivide into a consumption sector, an investment sector, and a fiscal sector. The level of output and the level of employment depend on the level of aggregate demand as determined in the various sub-sectors of the model.

Changes in policy variables are translated first into changes in demand, thus indirectly affecting the level of output and employment.

To determine the effect of changes in the money supply, for example, on the level of prices, output, and employment, changes in the money supply must first be translated into changes in consumption, investment, or government spending. Typically changes in the money supply are translated into changes in demand through changes in the interest rate. The interest rate mechanism operates in the manner to be described. The money supply change causes interest rates to change. The interest rate changes will lead to changes in consumption and investment. For example, the FRB-MIT-Penn
model postulates first a change in the money supply which affects interest rates. The changes in the interest rates change the various investment variables through the cost of capital variables. Consumption is directly influenced by changes in interest rates and is also affected by the interest rate effect on wealth. Housing expenditures are directly affected by interest rate changes as well as credit rationing variables, (25). Autonomous changes in the money supply in general will not affect the level of government spending.¹

The effect of changes in the money supply on prices, output and employment is obscured in these models, because the effect of monetary changes is not direct, but must operate through the interest rate mechanism. The interest rate is, however, a price. And, like any price, it is determined by the interplay of the forces of supply and demand. A

¹The converse, however, is not necessarily true. If there is an increase in government spending, government can obtain its spending power in three ways. The first is to increase taxes, causing declines in consumption and investment to offset the increase in government spending. The second is deficit financing through the issue and sale of bonds to the public. The public trades present consumption and investment for future consumption and investment, freeing current goods and services for government use. The third is deficit financing through the issue and sale of government bonds to the Federal Reserve. This increases the money supply to the extent that the Federal Reserve does not offset this purchase of bonds by open market operations. Therefore, although the autonomous shifts in the money supply do not affect the level of government spending, the method used to finance government spending may change the money supply.
change in supply or demand will affect the interest rate. We can isolate the effect of monetary actions on the interest rate only if we hold demand constant as well as the other factors that influence supply. And this is impossible in a model built to explain actual economic phenomena. The full implications of using an interest rate to reflect monetary actions is discussed more fully by Starleaf and Stephenson (107), and in other literature on the monetary indicator problem (14, 15).

Further, in an inflationary period the money supply effect in changing interest rates becomes impossible to isolate. The reason for this is seen in Irving Fisher's distinction between real and nominal rates of interest. The nominal or market rate of interest measures the rate of exchange between present and future dollars. The real rate of interest measures the rate of exchange between present and future goods and services. The difference between them is the expected rate of inflation. In equation form: $R_n = R_r + E(\dot{P})$, where $R_n$ is the nominal rate of interest, $R_r$ is the real rate, and $E(\dot{P})$ is the expected rate of inflation. Clearly if $E(\dot{P})$ is zero, the nominal and real interest rates are identical. But if the rate of price increase is not zero, nominal interest rates, $R_n$, will change as inflationary expectations change. Hypothetically, during an inflationary period because of expected continued inflation, nominal
interest rates could rise although the money supply was also increasing during the same period. If a monetary rather than an inflationary interpretation is made of the increasing interest rates, the conclusion would be that the money supply is declining and should perhaps be increased to keep interest rates from rising even further.

The interest rate mechanism gives potentially false information about the direction and impact of money supply changes. This is especially true in an inflation. It is, therefore, an unacceptable mechanism in models developed to explain the inflationary process in monetary terms.

It is the purpose of this dissertation to formulate an econometric macroeconomic model that will assess directly the effect of changes in the money supply on prices as well as output and employment.

Once this is accomplished, it should be possible in such a model to discern a rate of growth of the money supply consistent with the widely sought economic goals of either price stability, full employment, or economic growth.

Much has been written on an optimum rate of growth in the money supply, particularly within the context of growth models. Milton Friedman (48) has recently estimated that the optimum rate of growth of the money stock for price stability in the U.S. is about 2%. His estimate is not derived from a fully specified interdependent system of equa-
tions estimated simultaneously, but from single equation reduced form models of the demand for money.

It is the second objective of this dissertation to evaluate this suggested rate of monetary growth within the context of a simultaneous system of equations and to determine if the result generated from such a system of equations is consistent with that suggested by Dr. Friedman.
II. THE MODEL AND THE ESTIMATION OF THE STRUCTURAL EQUATIONS

A. The Model

In order to develop a model that directly accounts for changes in the money supply on prices, we begin by looking first at the formulation of a traditional Keynesian model. In such a model, aggregate demand for goods and services is defined as the sum of consumption, gross investment, and government spending on goods and services, assuming a closed economy. As an identity this can be expressed as the familiar $PY = C + I + G$, where $PY$ is nominal aggregate demand broken down into its constituent parts: $C$, consumption; $I$ gross investment; and $G$, government spending. Making the basic Keynesian assumption that aggregate supply will rise to meet aggregate demand, the definition becomes a statement of supply and demand equilibrium. If aggregate demand in real terms just equals aggregate supply in real terms, the economy will be in equilibrium. If aggregate demand is greater than aggregate supply, disequilibrium exists, setting into motion forces in the economy that will return the economy to equilibrium by increasing either prices and/or output.

This same aggregate supply and demand relationship can also be constructed from the quantity theory of money. In terms of this theory, over a specified time period, the supply of money times income velocity must equal the average
price of goods and services sold during the period mul-
plied by the amount of real output sold. In equation form
this relationship is defined by the familiar equation of
exchange: MV = PY. PY is aggregate supply, while the
interaction of M and V can be interpreted to represent aggre-
gate demand. Actual velocity times the money supply must
equal the nominal value of the goods and services sold. In
this formulation, the equation is an identity.

If desired money balances are substituted for the money
supply, the equation then represents an equilibrium condition
which states that aggregate demand and aggregate supply
will be equal if, and only if, actual money balances are
equal to desired money balances. If the actual and desired
values deviate, it is possible to have either excess demand
or supply in the aggregate economy. If the supply of money
is greater than the amount of money that people desire to
hold, it is assumed that people attempt to spend away their
excess money balances. It follows that either C or I or G
has to increase. This increase in aggregate demand has the
effect of calling forth increases in either prices or real
output or a combination of the two, depending upon the
availability of unutilized productive capacity.

Employing the above analysis, the model we have speci-
fied is developed in two sectors. One sector is formulated
to represent aggregate demand. The other sector is formu-
lated to embody the forces pertinent to aggregate supply. Price increases, or inflation, are then viewed within the context of the model as resulting from the difference between aggregate supply and demand.

The model consists of eight equations: a price equation, a velocity equation, an output equation, an employment equation, and a wage equation, plus three definitional identities to close the model. The model is specified in log-linear form since four of the five basic equations: prices, velocity, output, and employment are theoretically multiplicative, and the wage equation is multiplicative in the demand for labor and no a priori reason exists to reject a multiplicative formulation for the supply of labor as well.

The estimates of each of the structural equations are based on quarterly observations from 1952 to 1969. Each of the equations is estimated by ordinary least squares or generalized least squares. Two stage least squares estimation was attempted, but in terms of the predictive accuracy in the reduced form of the model, the ordinary least squares estimates proved to be superior.

The Model:

The model consists of eight equations, specified as follows:

(1) \( \ln P_t = \ln M_t + \ln V_t - \ln Y_t \)
(2) \[ \ln V_t = \alpha_{21} \ln P_t + \alpha_{22} \ln Y_t + \alpha_{23} \ln P_t - \alpha_{24} \ln P_{t-1} \]

(3) \[ \ln \left[ \frac{Y}{E} \right]_t = \ln A_t + \beta_1 \ln \left[ \frac{K}{E} \right]_t \]

(4) \[ \ln E_t = \alpha_{41} \ln \beta_2 - \alpha_{42} \ln A_t + \alpha_{43} \ln Y_t - \alpha_{44} \ln \left[ \frac{W}{E} \right]_t + \alpha_{45} \ln P_t \]

(5) \[ \ln W_t = \alpha_{51} \ln \beta_2 + \alpha_{52} \ln Y_t + \alpha_{53} \ln P_t + \alpha_{54} \ln N_t + \alpha_{55} \ln E_t \]

(6) \[ \ln Y_t = \ln \left[ \frac{Y}{E} \right]_t + \ln E_t \]

(7) \[ \ln \left[ \frac{W}{E} \right]_t = \ln W_t - \ln E_t \]

(8) \[ \ln \left[ \frac{K}{E} \right]_t = \ln K_t - \ln E_t \]

Where \( P \) is the price level, \( P_{t-1} \) is the price level lagged 1 quarter; \( M \) is the money supply; \( V \) is velocity; \( Y \) is real income; \( E \) is the number of men and women employed; \( Y/E \) is real income divided by the number employed; \( A \) is the level of technology; \( K \) is the capital stock; \( K/E \) is the capital stock divided by employment; and \( N \) is the size of the population between the ages of 14 and 64. All variables are measured in the current period, except for \( P_{t-1} \), which is prices lagged one quarter. The \( \alpha \)'s represent the coefficients on the variables. If there is no \( \alpha \), the coefficient is one. The source of the data used in the estimation of the model can be found in Appendix A.
B. The Price Equation

The price equation is quickly recognizable as a simple variant of the equation of exchange, \( MV = PY \). To derive this equation, the natural log is taken of the equation of exchange and the price variable is algebraically isolated:

\[
(1) \quad \ln P_t = \ln M_t + \ln V_t - \ln Y_t
\]

Prices change when there is disequilibrium between aggregate demand and aggregate supply. Aggregate demand in the model is embodied in \( \ln M + \ln V \). Aggregate supply is represented by \( \ln Y \). In this model, it is clear that the money supply itself is the crucial variable. As the money supply and/or velocity increase relative to aggregate output, prices will rise.

As discussed in the introduction, we do not employ an interest rate to determine the effect of monetary policy on the macro level of prices, wages, employment, and output. In this model we are able to obtain the direct effect of monetary changes. This is desirable for three reasons. First, we are interested in the use of the money supply rather than the interest rate as the monetary policy variable. Second, the interest rate in a simultaneous equation system should really be an endogenous rather than an exogenous variable if it is used, and at this point in the development of the
model we are not ready to include a financial sector to determine interest rates. Finally, the interest rate in an inflation model is a difficult variable to interpret and link directly with changes in the money supply because of the strong relationship between the rate of inflation and the nominal interest rate.

Changes in demand are seen in the price equation through the direct interaction of changes in the money supply and changes in velocity. In this formulation of the model the money supply is exogenous, while velocity and output are endogenously determined in later equations.

C. The Demand Sector

Because of the exogeneity of the money supply, the only behavioral equation on the demand side of this model is the velocity equation. The velocity equation is derived in the following manner. We begin again with the equation of exchange:

\[(2a) \quad MV = PY\]

and velocity is isolated by dividing both sides by \(M\):

\[(2b) \quad V = \frac{PY}{M}\]

then the numerator and denominator are both divided by \(P\):
(2c) \( V = \frac{Y}{M/P} \)

In this form of the equation, it is easily seen that velocity is defined as the ratio of real income to real money balances. To make it a behavioral equation we specify that desired velocity is the ratio of real income to desired money balances. The literature of the demand for money typically specifies the following money demand relationship:

(2d) \( \frac{M}{P} = \beta_0 \gamma Y^\delta r^{-\gamma} \)

where the demand for money balances depends positively on the level of income representing a transactions balance effect, and negatively on the interest rate representing the opportunity cost effect.

It can be argued that the rate of change of prices is superior to the interest rate as a determinant of money demand for the rate of change of prices picks up two different elements of opportunity cost. First, there should be a decrease in desired money balances as a response to inflation itself. Inflation erodes the purchasing power of idle money balances, and, in fact, acts as a tax on money balances. Second, the rate of inflation picks up the opportunity cost element embodied in the rate of interest. Given the relationship between the market rate of interest and the rate of inflation discussed in the introduction it follows that the higher the rate of inflation, the higher the nominal rate of
interest, and the higher the opportunity cost of holding money.

We replace the interest rate in the money demand function with an argument for the rate of inflation:

\[ M_t/P_t = \beta_0 Y_t^{\delta_1} (P_t/P_{t-1})^{-\delta_2} \]

The negative coefficient, \(-\delta_2\), can be rationalized along the same lines as the negative coefficient for the rate of interest. The higher the opportunity cost of holding money balances, the lower the money balances held, yielding, the negative coefficient.

The velocity function is derived by substituting Equation (2e) for the denominator of (2c):

\[ V = Y_t/\beta_0 Y_t^{\delta_1} (P_t/P_{t-1})^{-\delta_2} \]

Taking the natural log of both sides, we obtain:

\[ \ln V_t = -\ln \beta_0 + (1-\delta_1)\ln Y_t + \delta_2 \ln P_t - \delta_2 \ln P_{t-1} \]

The empirical estimate of this equation, based on the period 1952 to 1969, is as follows: ("t" values are in parentheses)

\[ \ln V_t = -1.9385 + .5139 \ln Y_t - 3.106 \ln P_t + 3.817 \ln P_{t-1} \]

\[ (5.56) \quad (9.131) \quad (3.898) \quad (4.878) \]

\[ R^2 = .9829 \]

\[ DW = .3998 \]
The sign and size of the coefficient on real income is consistent with theoretical expectations. Disentangling the coefficient on Y to obtain \( \delta_1 \), the income elasticity of money demand, yields a value of .4861. This estimate is consistent with those of other studies relating real money balances, measured as demand deposits plus currency, to real income and interest rates. For example, Dickson and Starleaf in their forthcoming paper (30) relate the demand for real money balances to real income, a market rate of interest, the yield on commercial bank time deposits, and the aggregate price index. They estimated the equation with the Almon lag structure, and report a coefficient on \( \ln y^* \) of .526.

The reversed signs on prices is puzzling. The net effect is, negative \((-3.106 \left( P_t - P_{t-1} \right) + .7 P_{t-1})\) which is opposite of what the theory would lead us to expect.

The low Durbin-Watson is, of course, of concern. An attempt was made to estimate this equation by generalized least squares. The generalized least squares (GLS) was performed by using a first order auto-regressive scheme on the residuals from the OLS equation. The original data were transformed on the basis of the parameter from the residual regression. The function was then re-estimated using the transformed variables in place of the original variables. The transformed variables took the form of \( Y_t' = Y_t - \rho Y_{t-1} \). The
first "pass" using GLS resulted in the loss of significance on \( P_t \), unrealistic regression coefficients, and an even lower Durbin-Watson. The equation was subjected to a second round of GLS and similar results were obtained in terms of significance and coefficient size, but the Durbin-Watson moved from positive serial correlation to negative serial correlation. We decided to acknowledge the presence of serial correlation in the estimated equation and proceed.

D. The Supply Sector

1. The production function

The supply sector is dominated by the aggregate production function. Following Valavanis (113), the aggregate supply function employed is the well known and widely used Cobb-Douglas production function. For our model we require that the Cobb-Douglas be homogenous of degree one, that is, \( \beta_1 + \beta_2 = 1 \):

\[
Y = AK^{\beta_1}E^{\beta_2}
\]

Ideally we would like to have \( K \) represent the flow of capital services. We would also like an employment measure purged of underemployment and overtime qualifications. It would also be most desirable to have an independent measure of \( A \), like the one constructed by Solow (104) using Goldsmith's data for the period 1909 to 1943. In all cases, data limitations forced the use of less than ideal measures.
of these variables. Capital is entered as a stock. A, the
level of technology, is proxied by a measure of output per
man hour. And E, employment, is the number of persons
employed.

There are several different ways of expressing a Cobb-
Douglas production function for estimation. The one we chose
was the one that performed the best, that is, the one that
gave the most consistent predictions in the reduced form
of the model. This form of the Cobb-Douglas is derived as
follows: First divide both sides of (3a) by E:

\[ Y/E = A(K/E)^{\beta_1} E^{\beta_2-1} \]

By the assumption of 1st degree homogeneity, $\beta_2-1 = \beta_1$, and
(3b) becomes:

\[ Y/E = A(K/E)^{\beta_1} \]

Taking the natural logs, we obtain:

\[ \ln Y/E = \ln A + \beta_1 \ln K/E \]

The estimated equation is as follows:

\[ \ln Y/E = 0.6617 \ln A + 0.832 \ln K/E \]
\[ (6.972) \quad (58.233) \]
\[ R^2 = 0.9997 \quad DW = 0.946 \quad \rho = 0.93 \]

It is noted that despite using generalized least squares,
the Durbin-Watson remains low. It is also noted that the
coefficient on K/E is rather high for the exponent for the capital input in production, although it is of the same order of magnitude (.7) obtained by Valavanis\(^2\) (113).

The capital stock in this formulation of the model is taken as exogenous, even though it logically should be endogenous. To endogenize the capital stock would require the specification of an investment function as well as an accumulation function. This would involve the introduction of a series of linear equations and identities yielding a mixed system of linear and nonlinear equations. While procedures are currently available for handling mixed systems of equations, the model would have become substantially more complicated. It was decided at this stage in the development of the model to enter the capital stock as an exogenous variable.

\^2\text{Because of our concern over the size of this coefficient, a different form of the equation was estimated. This formulation took the form of:}

\[(3e) \quad \ln \frac{Y}{E} = c + \beta_1 \ln \frac{K}{E}\]

and the estimate of this equation is:

\[(3f) \quad \ln \frac{Y}{E} = 5.753 + .401 \ln \frac{K}{E} \quad \bar{R}^2 = .999 \]

\[\text{DW} = 1.066 \]

\[\rho = .949\]

\(\beta_1\) in this form of the equation is equal to .401, which would seem more reasonable and is also close to Solow's (104) estimate of .353 for annual data from 1909-1943. This form of the equation when used in place of (3d) in the simultaneous model, proved inferior in generating the reduced form predictions, so the presented equation (3d) was chosen.
2. The employment function

There has existed for quite some time a debate in the literature over the role of the real wage in the economy. The marginal productivity theory of distribution assigns to the real wage the role of clearing the labor markets. By contrast, the Cambridge school argues that the main function of the real wage is to create enough income for workers to clear the commodity market. The marginal productivity argument focuses on aggregate supply, while the Cambridge school emphasizes the demand side.

Solow and Stiglitz (105) have constructed a theoretical model which incorporates both these theories of the real wage. Their main arguments will be briefly summarized here because we draw on them in the development of the employment equation.

Their model first specifies an aggregate production function. In the short run, aggregate supply is postulated as a function of the labor input only: $Y^S = F(N), F'(N) > 0, F''(N) < 0$. Under more or less competitive conditions, aggregate supply will be near the profit maximizing level of output where price is equal to marginal cost. Because labor is the only input, this is tantamount to arguing that to be on the aggregate supply curve labor will be hired up to

---

3. So named, because this explanation of the role of the real wage has been discussed at various times by Nicholas, Kaldor, Joan Robinson, and Luigi Pasinetti.
the point where the real wage rate paid equals the marginal product of labor. Further, because of decreasing marginal productivity, aggregate output can be seen as an inverse function of the real wage. Thus, \( Y^s = F^{-1}(W/P) = G(W/P) \), where \( G' < 0 \).

On the demand side, aggregate demand is seen as an increasing or constant function of the real wage. The higher the real wage, the more purchasing power wage earners have. Aggregate demand is specified as: \( Y^d = H(W/P), H' > 0 \).

There then exists some real wage, \( W/P^* \), such that aggregate supply and aggregate demand are equal. If the actual real wage is below \( W/P^* \), aggregate supply will be greater than aggregate demand. In this case actual output will be limited to the level of aggregate demand. Producers will produce what they can sell. When the level of output is determined by the level of aggregate demand, which is less than the desired level of aggregate supply at the going real wage, producers are forced to move away from their profit maximizing level of output and employment. The marginal product of labor employed is greater than the real wage, or price is greater than marginal cost. It would seem that each competitive producer would increase his profits by increasing output and employment, but all producers together can sell no more than \( Y^d \), the level of aggregate demand. Therefore, excess supply is incompatible with perfect compe-
tition. Arrow (2), suggests that a way to solve this theoretical problem is to postulate that when there is excess supply, markets become imperfectly competitive. Each producer now views himself as facing a falling, rather than a horizontal demand curve for his products. Hence, if aggregate demand is less than aggregate supply at the going real wage, the level of aggregate demand dominates the production decisions of suppliers who remain off their desired supply schedules until demand rises to the equilibrium level of output. When the real wage is greater than \((W/P)^*\), there is excess demand in the economy and producers will produce along their aggregate supply function.

In terms of an illustration:

![Diagram](https://via.placeholder.com/150)

Aggregate demand, \(Y^d\), is seen as a positive function of the real wage, \((W/P)\). Aggregate supply, because of diminishing marginal returns to labor, exhibits a negative slope. \((W/P)^*\) and \(Y^*\) are that real wage and output level required to equate aggregate demand and supply. The relevant portion
of the graph is the inverted "v", whose zenith is \( Y^* \). Using this illustration, it can be seen that if the real wage lies to the left of \( (W/P)^* \), say \( (W/P)_1 \), producers wish to supply \( S \), which is greater than the amount of aggregate demand, \( Y^d \), generated at the real wage \( (W/P)_1 \). In this case, the level of aggregate demand prevails and actual output equals \( Y^d \). Anywhere on the left leg of the inverted "v", producers are producing at an output level below the optimal level. At this level of production, price is greater than marginal cost, or the marginal product of labor is greater than the real wage. As the real wage rises toward \( (W/P)^* \), output will increase in response to the increase in demand which is the result of the increase in the real wage. This allows producers to move toward their desired level of output which is represented by the supply curve.

Once the real wage rises to \( (W/P)^* \), the argument becomes asymmetrical as output no longer responds to changes in demand, but is now controlled by the conditions affecting the aggregate supply function. As the real wage is forced above the equilibrium level, to the right of \( (W/P)^* \), producers will now produce along the downsloping right leg of the inverted "v", which is the relevant portion of the aggregate supply function. Every point on this curve represents a price equal to the marginal cost condition. As the real wage continues to move to the right of \( (W/P)^* \),
output and employment will decrease, leaving the economy in a period of excess demand. To require that production be equal to aggregate demand at a real wage greater than \((W/P)^*\) would force production to an output level where price was less than marginal cost causing profits to fall. This is an untenable position in a free enterprise economy where each producer makes his own production decisions. A producer finding himself at a level of production where profits are falling would either reduce production by laying off workers until he was back at his profit maximizing level of production, given the real wage, or he would raise his price causing the real wage to fall back toward equilibrium.

The implications of this analysis for employment are interesting. Because \(Y = F(N)\), it can be seen that as the economy moves from \((W/P)_1\) toward equilibrium at \((W/P)^*\), the effect of the higher wage rate will increase aggregate demand, and employment will increase as output rises to meet the increase in demand. In this situation, employment can be seen as an increasing function of the real wage. This finding helps explain the phenomenon of increasing real wages and increasing employment at the beginning of the business cycle. This positive functional relationship continues until \((W/P)^*\) is reached. As mentioned previously, the argument becomes asymmetrical at this point. If the real wage is pushed beyond \((W/P)^*\), employment will fall as producers move
down along the aggregate supply curve. In this portion of the inverted "v", employment is seen as an inverse function of the real wage.

From this model a possible explanation of a period characterized by both inflation and unemployment can be attempted. Given large wage increases during a boom, the real wage will be pushed beyond \((W/P)^*\) if prices do not keep pace. Because the new real wage is now greater than the equilibrium real wage, employment and output will fall as producers adjust their output to a level where the marginal physical product of labor is equal to the real wage. At the same time high wages for those who remain working keep aggregate demand from falling in proportion to employment cuts. Hence, inflation occurs as aggregate demand exceeds aggregate supply, although there is unemployment in the economy. If wages are held fairly constant as prices rise in this situation, the real wage will fall and the economy will move back toward equilibrium at the lower equilibrium wage with higher output and employment.

It should be noted here that this analysis does not insure full employment at equilibrium. It is not necessary in this formulation for \((W/P)^*\) to be equal to the real wage that will clear the labor market. An equality between aggregate supply and demand could occur at a level of output requiring less than full employment of the labor force.
With this model of the relationship between employment and the real wage, we derive the employment function used in our model. We begin with the specification of the limiting case of the marginal productivity determination of the real wage-employment relationship. We will then modify the function by incorporating a correction factor for periods when employment depends not on the equality of productivity and the real wage, but on the level of aggregate demand. When aggregate demand dominates production decisions, the real wage will be less than the marginal product of labor.

First the aggregate production function is again postulated. Because this model is to be estimated from 1952 to 1969 it would be inconsistent to specify a short run production function where output is a function of labor only. What immediately follows is essentially a short run argument, but the function is corrected to incorporate long term elements later in the development.

Again we postulate the Cobb-Douglas production function:

\[ Y = AK^{\beta_1}E^{\beta_2} \]  

and taking the first derivative with respect to employment:

\[ \frac{\partial Y}{\partial E} = A\beta_2 K^{\beta_1} E^{\beta_2-1} \]

which can be rewritten as:
Noting the expression in parentheses is equal to $Y$, we substitute and obtain the following:

\[(4d) \quad \frac{\partial Y}{\partial E} = \beta_2 \frac{Y}{E}\]

Then assuming more or less competitive conditions, we can assume that to be on the profit maximizing aggregate supply curve labor will be paid a real wage rate, $(W/EP)^4$, equal to its marginal product:

\[(4e) \quad \frac{\partial Y}{\partial E} = (W/EP)^\phi_1\]

If the equality holds exactly, such that we are always on the aggregate supply curve, price will be equal to marginal cost and $\phi_1$ will equal 1, and should estimate so empirically. We anticipate that during certain quarters over which the function is estimated, we will not be on the aggregate supply function. We allow for this by using the power of $\phi_1$ on $(W/EP)$, and allowing for a less than unity coefficient empirically. It should be noted that we would not expect $\phi_1$ to estimate greater than one as this would imply that producers were paying labor more than its marginal product, causing profits to fall.

Equating (4d) and (4e), taking the natural log of both sides, and solving for $E$, we obtain:

\[\text{Because elsewhere in the model the symbol } W \text{ represents the wage bill and not the wage rate, the real wage rate will be expressed as } W/EP \text{ throughout the rest of the paper.}\]
\[ (4f) \ln E_t = \ln \beta_2 + \ln Y_t - \phi_1 \ln \frac{W_t}{E_t} + \phi_1 \ln P_t \]

In this formulation we expect a unit coefficient on \( Y \) and the size of \( \phi_1 \) tells us how close we are to the real wage equating marginal product condition. This form of the employment equation takes account only of the negative sloping portion of the inverted "v" where employment is a negative function of the real wage. We must also attempt to incorporate a variable in the employment equation that will account for the positively sloped portion.

We do this by noting that if the economy is at a position to the left of \( (W/P)^* \), aggregate demand determines the level of output and the level of employment. At this level of output the real wage is less than productivity, or \( W/EP - MPP_e < 0 \). To account for this in our function we add productivity to the employment equation as a corrective factor. In the region on the left leg of the inverted "v", employment and the real wage increase together while productivity decreases as the economy moves toward equilibrium in the commodity market. In the region on the right leg of the inverted "v", employment and the real wage move in opposite directions while employment moves with productivity. We would hope to get a negative empirical relationship between employment and productivity if we are in fact picking up some of the influence of the positive relationship between the
real wage and employment during periods where aggregate demand controls the productive decisions.

Adding the productivity variable does something else for the employment equation. It allows it to shift over time in response to shifts in the production function. The employment function takes on the desired long run characteristics by allowing for shifts in the function over time. In this type of a formulation we are implicitly assuming disembodied or neutral technical change. A negative sign on productivity in this context would suggest capital-labor substitution.

Since we can find no \textit{a priori} reason prohibiting the inclusion of productivity as additive in the logs, we modify (4f) as follows:

\begin{equation}
(4g) \quad \ln E_t = \pi_1 \ln \beta_2 + \pi_2 \ln Y_t - \pi_3 \ln \frac{W_t}{E_t} + \pi_4 \ln P_t
\end{equation}

- \pi_5 \ln A_t

The reader will note the change in coefficients between Equation (4f) and (4g). Because of the interdependence of wages, output, and productivity, we could not expect the coefficients to remain the same after the inclusion of productivity in the equation. In the empirical estimation of this equation we would no longer expect unitary coefficients on $\ln \beta_2$, and $\ln Y$, nor would we expect identical
coefficients on wages and prices.

The estimated equation is as follows:

\[
\ln E_t = -3.713 + .833 \ln Y_t - .424 \ln \frac{W_t}{E_t} + .743 \ln P_t
\]

\[
(11.32) \quad (18.93) \quad (6.51) \quad (9.48)
\]

\[-.478 \ln A_t \]

\[
(13.78)
\]

\[R^2 = .999\]

\[DW = 1.56 \quad \rho = .54\]

The equation was estimated using generalized least squares. The equation coefficients come with the expected signs. There is a strong relationship between output and employment as would be expected. The coefficients on \(W/E\) and \(P\) are different from each other suggesting that productivity has a different relationship with wages and with prices. The negative sign on \(A\) is difficult to interpret because of the dual function of \(A\) in the equation. The negative sign supports a capital-labor substitution effect, as well as the argument of productivity decrease and employment increase as the economy moves from a position of insufficient aggregate demand toward equilibrium.

3. The wage function

Since A. W. Phillips (89) established an empirical relationship between wages and unemployment for the U. K., attempts to improve and broaden his simple specification of the wage function have been prevalent in the literature.
Beginning with the simple Phillips relationship, further study has produced considerable conflicting evidence. In an attempt to derive a Phillips Curve for the United States, Samuelson and Solow (94) published a scatter diagram for aggregate data indicating no relationship between wages and unemployment. In a later study, Rees and Hamilton (92) found an unstable Phillips curve, and offered the possibility of the existence of a family of Phillips curves.

In an attempt to discover a more stable relationship between wages and unemployment, Lipsey and Steuer (74) added profits to the function as an explanatory variable. Using annual data they found the addition of the profit variable did improve the explanatory ability of the function, and also found that profits and unemployment have about equal explanatory power.

Following this study, Perry (86) published an extensive study relating wages, lagged prices, unemployment, and various profit variables and was able to explain an impressive amount of variation in changes in wages in the manufacturing sector. His reported $R^2$ is .87. The inclusion of lagged prices in a model containing profits and unemployment to explain wage changes, and the use of quarterly data to estimate the model, improve the explanation of wage changes in U.S. manufacturing.

What these and similar studies have in common is that they are mainly empirical investigations into wage determination without theoretical underpinnings. In fact Perry (86)
Edwin Kuh (67) attacks the Perry profit hypothesis in a theoretical and empirical work that offers productivity as the key determinant of changes in the wage rate, arguing that profits, in fact, are merely a proxy for productivity. The amount of variation in wage changes that Kuh is able to explain using his formulation is only about half that explained by Perry.

Christian (22), in formulating his wage equation to determine the effectiveness of the wage-price guideposts, incorporates a productivity variable along with prices and unemployment. In the manufacturing sector he is able to generate an $R^2$ of .93, which exceeds that of Perry (86). In this paper, Christian compares the average forecast error in a model using a profit variant with the average forecast error using the productivity variant. He reports a forecast error in the profit variant models one and one-half times as large as the errors in the productivity variant formulation.

In our development of the wage equation, wages are seen

as a factor price. Because they are a price, wages are deter-
mined by the interplay of the forces of supply and demand.
First, a demand for labor function is specified, then a supply
of labor function is derived. Then the two are set equal
and wages are isolated, giving us the wage function used in
this model.

The demand for labor formulation follows the ideas
presented by Kuh (67), in that productivity is the major
determinant in the demand for labor. Following the same
derivation as the employment equation, the Cobb-Douglas
production function is again postulated:

\begin{align}
\text{(5a)} \quad Y &= \beta_1 \frac{\beta_2}{E} \\
\end{align}

the marginal product of labor is derived from this function
and equated to the real wage:

\begin{align}
\text{(5b)} \quad \beta_2 \frac{Y}{E} &= (W/EP)^{\phi_1} \\
\end{align}

natural logs are taken and the employment variable is again
algebraically isolated:

\begin{align}
\text{(5c)} \quad \ln E^D &= \ln \beta_2 + \ln Y - \phi_1 \ln \frac{W}{E} + \phi_1 \ln P \\
\end{align}

and treated as the employer's demand for labor.

A supply of labor function is specified as follows:

\begin{align}
\text{(5d)} \quad E^S &= (W/EP)^{\gamma_1(N)}^{\gamma_2(U)}^{\gamma_3(U)} \\
\end{align}
W/EP is again the real wage, N is the size of the population between the ages of 14 and 64, and U is the level of unemployment. It is hypothesized that $\gamma_1$ will be positive, as one would expect a higher real wage to attract a larger supply of labor. $\gamma_2$ is also postulated as positive. As the size of the potential labor force grows, the supply of labor should also increase. However, the postulated sign of $\gamma_3$ is unclear. As U increases this may have the effect of either increasing or decreasing the supply of labor, depending on whether the "additional worker" or "discouraged worker" effect is dominant. The "discouraged worker" effect, as presented by Strand and Dernberg (109), derives from the case in which as unemployment rises and output falls, some workers are discouraged by not being able to find work and drop out of the labor force. As unemployment rises the supply of labor falls. Conversely, as unemployment falls, the supply of labor will rise as these workers are now encouraged to re-join the labor market. The "additional worker" effect is defined as the case in which as unemployment increases, secondary workers are drawn into the labor force by economic need. Thus, an increase in unemployment fosters an increase in the labor force. There remains the possibility that no relationship exists between the level of unemployment and the size of the labor force if the two effects cancel each other.
The current literature has no definitive evidence for either conclusion. The current state of opinion is that there is a differential effect present at different times depending on the intensity and length of recession or boom.

The unemployment variable may also have the effect, in addition to shifting the supply of labor curve, of changing its elasticity. In periods of low unemployment the curve may become very inelastic. During periods of low unemployment, the result of the increase in the demand for labor is an increase in the real wage. Conversely, when unemployment is high, the supply of labor curve becomes increasingly elastic, and any increase in the demand for labor can be met without large increases in the real wage. In terms of an illustration:

Figure 1. Low U

Figure 2. High U
In Figure 1, low unemployment has caused the supply of labor function to become very inelastic. Any increase in the demand for labor, for example from $E_1^d$ to $E_2^d$, will cause a large rise in the real wage to increase employment. In Figure 2, higher unemployment causes the supply of labor curve to become more elastic. In response to an increase in demand from $E_1^d$ to $E_2^d$, more labor can be employed with little change in the real wage. It is in this manner that unemployment can change the elasticity of the supply of labor function.

Therefore, using the supply of labor function specified in Equation (5d) and taking the natural log of this equation we obtain:

\[(5e) \quad \ln E^s = \gamma_1 \ln \frac{W}{E} - \gamma_1 \ln P + \gamma_2 \ln N + \gamma_3 \ln U\]

Setting the demand for labor (5c) equal to the supply of labor (5e), and solving for $\ln W/E$, the wage equation is obtained:

\[(5f) \quad \ln \frac{W}{E} = \frac{1}{\gamma_1 + \phi_1} \ln \beta_2 + \frac{1}{\gamma_1 + \phi_1} \ln \gamma + \ln P - \frac{\gamma_2}{\gamma_1 + \phi_1} \ln N - \frac{\gamma_3}{\gamma_1 + \phi_1} \ln U\]

Because this is a simultaneous system of equations, it would be unrealistic to take the unemployment level as an exogenous variable. We therefore endogenize unemployment in the following manner. First we specify the following
identity:

(5g) \( U = L - E \)

where \( U \), the level of unemployment, is defined as the difference between the labor force \( L \), and the level of employment, \( E \). Then dividing both sides of the equation by \( L \) we obtain:

(5h) \( \frac{U}{L} = 1 - \frac{E}{L} \)

Now define another identity:

(5i) \( (1 - \frac{E}{L}) = (\frac{E}{L})^\sigma \)

where \( \sigma \) is that number that makes this an identity. For example if \( \frac{E}{L} = 0.5 \) then \( \sigma \) would equal 1.00. As \( \frac{E}{L} \) increases, \( \sigma \) remains positive and becomes greater than one.

Now, substituting the right hand side of (5i) into (5h), the following is obtained:

(5j) \( \frac{U}{L} = (\frac{E}{L})^\sigma \)

Taking the natural log of both sides and solving for \( \ln U \):

(5k) \( \ln U = \sigma \ln E + (1 - \sigma) \ln L \)

We now specify that:

(5l) \( L = N^U \)
where ν is the elasticity of the labor force with respect to population. Again taking the natural log of this equation:

\[(5m) \quad \ln L = \nu \ln N\]

Making the proper substitution of \(\ln L\) into (5k), we obtain our expression for unemployment:

\[(5n) \quad \ln U = \sigma \ln E + (1-\sigma)\nu \ln N\]

Substituting this equation for unemployment into the wage equation, we obtain:

\[(5o) \quad \ln \frac{W}{E} = \frac{1}{\gamma_1+\phi_1} \ln \beta_2 + \frac{1}{\gamma_1+\phi_1} \ln Y \]

\[+ \ln P - \frac{\{\gamma_2+\gamma_3\nu(1-\sigma)\}}{\gamma_1+\phi_1} \ln N - \frac{\gamma_3\sigma}{\gamma_1+\phi_1} \ln E\]

Because many policy discussions focus on the wage income rather than an aggregate wage rate, we express this equation in terms of the wage bill. Noting that: \(\ln W/E = \ln W - \ln E\), we add \(\ln E\) to both sides of (5o), obtaining the wage equation included in the model:

\[(5p) \quad \ln W_t = \frac{1}{\gamma_1+\phi_1} \ln \beta_2 + \frac{1}{\gamma_1+\phi_1} \ln Y_t \]

\[+ \ln P_t - \frac{\{\gamma_2-\gamma_3\nu(1-\sigma)\}}{\gamma_1+\phi_1} \ln N_t + \{1 - \frac{\gamma_3\sigma}{\gamma_1+\phi_1}\} \ln E_t\]
The estimated equation is as follows:

\[
\ln W_t = 2.871 + .714 \ln Y_t + 1.202 \ln P_t - .0032 \ln N_t + .609 \ln E_t
\]

\[
(2.634) (9.476) (18.082) (.066)
\]

\[
R^2 = .999
\]

\[
DW = 1.821 \quad \rho = .69
\]

Because of the low Durbin-Watson using ordinary least squares, the equation was estimated using generalized least squares. The signs of the variables in the estimated equation are as predicted for output, prices, and population. The positive sign on employment indicates that the sign of \( \gamma_3 \), the elasticity of the supply of labor with respect to unemployment must be positive, since the denominator, \((\gamma_1 + \phi_1)\), is known to be positive from the positive coefficient on \( \ln Y \), and since \( \sigma \) must also be positive and greater than 1. In order for the expression \([1 - \frac{\gamma_3^\sigma}{\gamma_1 + \phi_1}]\) to be positive and less than 1, \( \gamma_3 \) must be positive. This evidence supports the "additional worker" hypothesis. To generate further confirmation on the sign of \( \gamma_3 \), the equation was reestimated using \( W/E \) as the dependent variable. In this formulation the coefficient on employment becomes \(-\frac{\gamma_3^\sigma}{\gamma_1 + \phi_1} \ln E \). The sign of the estimated coefficient of \( \ln E \) in this form of the equation is negative further supporting the positive sign of \( \gamma_3 \).

The coefficient on prices is greater than unity, the theoretical size of this coefficient. We are, perhaps,
picking up the "over-reaction" by labor to inflation in the latter part of the 1960's. Given an inflationary period and the expiration of labor contracts, labor attempts to make up for past losses as well as projected future losses in purchasing power. Therefore, the coefficient on prices would be greater than unity. To support this interpretation, we estimated the wage equation for the first 36 quarters of the sample period using generalized least squares. This estimation of the wage equation covers the period from 1952 to 1960, which is a period of relative price stability. For this period the coefficient on prices falls to .998. The hypothesis of the over-reaction of wages to price increases during inflationary periods is empirically supported. The entire estimated equation for wages from 1952-1960 is presented in Appendix B.

It is impossible to disentangle the coefficient on \( Y \). It is readily determined that the value of \( (\phi_1 + \gamma_1) \) is 1.4. Given that \( \phi_1 \) is the indicator of the extent to which labor receives its marginal product, we know that its value must be positive and, in all likelihood, cannot, exceed unity. Thus, if \( \phi_1 \) is equal to, or very close to, unity, \( \gamma_1 \), the elasticity of the supply of labor with respect to the real wage would be equal to, or very close to .4. Without independent information, we can only conclude that this is a reasonable estimate.
We attribute the non-significance of the coefficient of population to the small variance in the series compared with changes in the wage bill.

Expectations by labor about the future rate of inflation plays a pivotal role in the wage-price nexus. Thus it would be most desirable to incorporate a measure of expectations into the model. An initial attempt to incorporate expectations into the wage equation is presented and discussed in Appendix C.

E. The Complete Model

Before proceeding to the derivation of the reduced form, it will be useful to summarize the complete theoretical model and the estimates of its structural equations:

**Theoretical Model:**

1. \( \ln P_t = \ln M_t + \ln V_t - \ln Y_t \)

2. \( \ln V_t = \alpha_{21} \ln \beta_0 + \alpha_{22} \ln Y_t + \alpha_{23} \ln P_t - \alpha_{24} \ln P_{t-1} \)

3. \( \ln [Y/E]_t = \ln A_t + \beta_1 \ln [K/E]_t \)

4. \( \ln E_t = \alpha_{41} \ln \beta_2 - \alpha_{42} \ln A_t + \alpha_{43} \ln Y_t - \alpha_{44} \ln [W/E]_t + \alpha_{45} \ln P_t \)
(5) \[ \ln W_t = \alpha_{51} \ln \beta_2 + \alpha_{52} \ln Y_t + \alpha_{53} \ln P_t \]
\[ + \alpha_{54} \ln N_t + \alpha_{55} \ln E_t \]

(6) \[ \ln Y_t = \ln [Y/E]_t + \ln E_t \]

(7) \[ \ln [W/E]_t = \ln W_t - \ln E_t \]

(8) \[ \ln [K/E]_t = \ln K_t - \ln E_t \]

**Structural Estimates:**

(2) \[ \ln V_t = -1.9385 + .5139 \ln Y_t - 3.106 \ln P_t \]
\[ + 3.817 \ln P_{t-1} \]

(3) \[ \ln Y/E_t = 5.6617 \ln A_t + .832 \ln [K/E]_t \]

(4) \[ \ln E_t = -3.713 + .833 \ln Y_t - .424 \ln [W/E]_t \]
\[ + .743 \ln P_t - .478 \ln A_t \]

(5) \[ \ln W_t = 2.878 + .714 \ln Y_t + 1.202 \ln P_t - .0032 \ln N_t \]
\[ + .609 \ln E_t \]

The output equation, the employment equation and the wage equation are all estimated using generalized least squares. The general form of an equation estimated by GLS is:

\[ Y_t = \alpha_0 + \alpha_i X_{it} + \rho u_{t-1} + e_t \]

The structural equations to be used in the computation of the reduced form coefficients must be of this form. We, therefore, solve for \( u_{t-1} \) from the original equation:

\[ U_{t-1} = Y_{t-1} - \alpha_0 - \alpha_i X_{i_{t-1}} \]
and substitute this into the above expression:

$$Y_t = \alpha_0 (1-\rho) + \alpha_i X_{i_t} + \rho Y_{t-1} - \rho \alpha_i X_{i_{t-1}} + e_t$$

Each structural equation estimated by GLS now contains not only the current values of the relevant variables, but $\rho$ times the lagged values of the independent and dependent variables as well.

Also before proceeding to the reduced form of the model and the policy implications that can be generated, several comments about the model seem in order. This is a very small, very aggregative, and very interdependent model. It lacks a financial sector, and endogenous capital stock, an indicator for government fiscal policy, and in independent foreign sector. With this in mind, the following discussion of the reduced form, its coefficients, and the policy implications derived from it should be understood as an indication of the true relationship existing among the variables discussed.
III. THE DERIVED REDUCED FORM OF THE MODEL, ITS RELIABILITY, AND THE POLICY IMPLICATIONS

A. The Derived Reduced Form of the Model

Once we have estimated each of the structural equations, getting the individual effect of each of the independent variables on each of the dependent variables, the next step is to take the model into its reduced form. The inter-dependence of the entire system is then taken into account and the effect of each exogenous variable on each endogenous variable is isolated.

In matrix notation, we begin with:

\[ \Gamma Y = -\beta X \]

where \( Y \) is the vector of jointly determined variables, \( X \) the vector of exogenous variables, \( \Gamma \) the matrix of coefficients of the jointly determined variables, and \( \beta \) the matrix of coefficients of the exogenous variables.

We then calculate \( \Gamma^{-1} \), and premultiply both sides of the matrix equation by \( \Gamma^{-1} \), giving us the derived reduced form:

\[ Y = \pi X \]

Table 1 presents the \( \pi \) matrix of reduced form coefficients. The endogenous and exogenous variables are so labeled.
Table 1. Matrix of reduced form coefficients

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<th>Exogenous variables</th>
<th>P</th>
<th>V</th>
<th>Y/E</th>
<th>E</th>
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<td>-.6269</td>
<td>-.3317</td>
<td>.0683</td>
</tr>
<tr>
<td>E-1</td>
<td>-.0191</td>
<td>.1419</td>
<td>-.7969</td>
<td>.9579</td>
<td>.2551</td>
<td>.1609</td>
<td>-.7027</td>
<td>-.9579</td>
</tr>
<tr>
<td>N-1</td>
<td>.00002</td>
<td>-.0002</td>
<td>.0010</td>
<td>-.0012</td>
<td>.0013</td>
<td>-.0002</td>
<td>.0026</td>
<td>.0012</td>
</tr>
<tr>
<td>W/E-1</td>
<td>-.0061</td>
<td>.0452</td>
<td>-.2541</td>
<td>.3054</td>
<td>.2153</td>
<td>.0513</td>
<td>-.0901</td>
<td>-.3054</td>
</tr>
<tr>
<td>Y/E-1</td>
<td>-.1225</td>
<td>.9122</td>
<td>.4113</td>
<td>.6235</td>
<td>.9712</td>
<td>1.0347</td>
<td>.3478</td>
<td>-.6235</td>
</tr>
<tr>
<td>K/E-1</td>
<td>.1019</td>
<td>-.7590</td>
<td>-.3422</td>
<td>-.5187</td>
<td>-.8081</td>
<td>-.8609</td>
<td>-.2894</td>
<td>.5187</td>
</tr>
</tbody>
</table>
in the table. Each coefficient in the \( \pi \) matrix represents, *ceteris paribus*, the change in an endogenous variable given a unit change in an exogenous variable. For example, if the money supply increases by 1%, prices would increase by .24205%, etc.

In this model, our basic idea was to isolate the money supply as a policy variable in order to determine the effect of changes in the money supply on prices, wages, employment, and output. Looking at the reduced form coefficients indicates first that a unit increase in the money supply will increase prices and the wage rate by an almost equal amount (.27 for the wage rate vs .24 for prices). Money supply changes have their strongest effect on current velocity (-.75). The strong negative effect suggests the existence of a lag in the effect of changes in the money supply as reported by Friedman and others. What we cannot discern from the model in its current specification, is the effect on the real variables of the system that will take place as actual money balances are brought into equilibrium with the desired level of money balances. Lags aside, if these estimates are at all indicative of the true relationships, the small impact of changes in the money supply on output (.012) and employment (.08) over the period studied is rather striking. A possible explanation of these small coefficients is that the rapid rate of growth in the money supply during
the latter part of the 1960's coincided with a period of full employment, and full production. The coefficients during this period may well dominate the full period relationship, giving the result that changes in the money supply really affect only prices and wages and do not affect output and employment significantly. To check this possibility the model should be reestimated over a period of relative price stability, and the coefficients compared. Alternatively, the estimates provide support for the proposition that money is neutral. This is not necessarily surprising. These estimates represent an 18 year average of the quarterly effect of changes in the money supply on output and employment, and we may be picking up the long run neutrality of money.

The reduced form further reveals that a unit increase in productivity has a small (-.075) negative effect on prices and a moderately negative (-.19) effect on employment, while increasing the wage bill (.24), output (.63), and the wage rate (.45). The signs and magnitudes of these relationships are as expected. The small effect on prices is disappointing, but may be explained by the fact that increases in productivity more often go into increases in wages rather than decreases in prices. The coefficient on employment (-.19) suggests capital-labor substitution, and/or that the relationship between increases in productivity and employment during the upward movement on the cycle are overpowered by the in-
creases in productivity gained as marginal workers using older capital equipment are laid off as a recession begins. The strong effect (.61) on output indicates the importance of productivity gains for noninflationary expansion.

Changes in population show little effect on any of the endogenous variables.

Capital formation, as expected, is clearly a key variable. A unit increase in the capital stock has a moderate effect on decreasing prices (-.11), increasing employment (.56), and increasing the wage rate (.31), and a strong effect on increasing the wage bill (.87), output (.92), and velocity (.81).

Turning now to the lagged coefficients, the interplay of lagged prices and lagged wages is interesting. Initially it appears that price increases last quarter will increase employment (.22), or inflation is beneficial to employment. This view ignores the relationship between wages and prices. Although increasing prices last quarter do have a positive effect on employment, increasing wages last quarter will cause a decline (-.39) in current employment. From the structural equation for the determination of the wage bill, we note that current wage increases are 1.2 times as large as current price increases. This suggests that a 1% increase in prices this quarter, and a 1.2% increase in wages this quarter should lead to a net decline in employment next quarter, if we con-
sider only the wage-price effects on employment, of \(-.24\%\). Isolating the wage-price effect on future employment indicates that inflation really does not increase employment, but has the opposite effect. As would be expected given the above discussion of the employment effect, the net effect of increasing wages and prices on the next quarter's real output is also negative, but the net effect is small \((-0.08\%)\). Combining the wage and price lags with the money supply, it is noted that real output is unresponsive to changes in the monetary variables of the system.

The effect of lagged prices on the monetary variables of the system is very strong, affecting current prices with a coefficient of .92, velocity with a coefficient of .96, and the current wage bill with a coefficient of .45. The strong response of velocity to lagged price increases suggests that although the monetary authorities control the money supply in an attempt to control inflation, increases in velocity during an inflationary spiral can lead to still further inflationary pressures on the economy. The rate of growth of the money supply may have to be slowed even more than originally thought to halt inflation.

Considering the coefficients on lagged wages, we find little evidence to verify a wage push element in the inflationary spiral, as the effect of lagged wages on current prices is very small (.008).
The lagged output coefficients suggest that the higher output last quarter, the lower (-.32) employment in the current period. The employment effect could explain the negative coefficient between lagged output and the wage bill (-.72) and the wage rate (-.40).

The coefficients on lagged productivity are very puzzling. An increase in productivity this quarter leads to price decreases (-.07) in the current period, but price increases (.07) in the following quarter. As would be expected, lagged productivity leads to further decreases in employment (-.07). It also leads to decreases in the wage bill (-.40), output (-.63) and the wage rate (-.33). Again we may be picking up the employment effect on productivity increases that could account for these rather odd results.

B. The Reliability of the Model

In order to determine the reliability of the model, the data were tracked over the sample period using the derived reduced form equations. These estimates were compared with the actual values of the data used in the estimation of the model. The methodology of this test is as follows. We begin with the reduced form of the model where each endogenous variable is specified as a function of all the exogenous variables multiplied by the proper reduced form
coefficient. In matrix notation this becomes: $Y = \pi X$.

Using these reduced form equations, we generate 72 quarterly predictions for each of the endogenous variables in the model, $\hat{Y}_{ij}$, where "i" subscripts the year and "j" subscripts the quarter of the forecast variable. To generate the forecasts, $\hat{Y}_{ij}$, the values of the exogenous variables that were used to estimate the model are read in, and multiplied by the appropriate reduced form coefficient. For example:

$$\hat{Y}_{52:1} = \text{con} + \pi_{1,2} M_{52:1} + \pi_{1,3} A_{52:1} + \pi_{1,4} N_{52:1} + \pi_{1,5} K_{52:1}$$

$$+ \pi_{1,6} P_{51:IV} + \pi_{1,7} W_{51:IV} + \pi_{1,8} Y_{51:IV} + \pi_{1,9} A_{51:IV}$$

$$+ \pi_{1,10} E_{51:IV} + \pi_{1,11} N_{51:IV} + \pi_{1,12} W/E_{51:IV}$$

$$+ \pi_{1,k3} V/E_{51:IV} + \pi_{1,14} K/E_{51:IV} \cdot$$

or

$$\hat{Y}_{52:1} = -.41376 + .2420 M_{52:1} - .0745 A_{52:1} - .00004 N_{52:1}$$

$$- .1096 K_{52:1} + .9251 P_{51:IV} + .0078 W_{51:IV}$$

$$+ .0064 Y_{51:IV} + .0742 A_{51:IV} - .0191 E_{51:IV}$$

$$+ .00002 N_{51:IV} - .0061 W/E_{51:IV} - .1225 Y/E_{51:IV}$$

$$+ .1020 K/E_{51:IV}$$

A vector of $\hat{Y}_{ij}$ is computed for each of the endogenous variables. The next step is to run a correlation on $Y$ and $\hat{Y}$, using the formulation:
\[ Y = a + b \hat{Y} \]

to compare the forecast values with the actual values. Finally, we test the hypothesis that \( a = 0 \) and \( b = 1 \) from the correlation analysis. If \( a \) does not significantly differ from 0, and \( b \) does not significantly differ from 1, the model tracks the data very well over the sample period.

The results of this test are presented in Table 2. At the .01 level of significance we are able to accept the null hypothesis of \( a = 0 \) or \( b = 1 \) for 10 of the 16 correlations. This evidence suggests the model tracks the data reasonably well over the sample period.

C. The Policy Implications from the Reduced Form

In order to derive the full policy implications of the model, a dynamic simulation of the model needs to be computed and the long run or dynamic policy multipliers derived. From this type of analysis the optimum rate of growth of the money supply could be ascertained, given the policy objectives.

This extension of the analysis is beyond the scope of the current work. We can, however, arrive at a general idea of the implications for employment and real output that a rate of growth of the money supply consistent with price stability would imply. This type of analysis is not
Table 2. OLS reduced form "forecast" analysis

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>( &quot;t) value H: ( a \neq 0 )</th>
<th>( b )</th>
<th>( &quot;t) value H: ( b-1 \neq 0 )</th>
<th>( R^2 )</th>
<th>D.W.</th>
<th>S.E.E.</th>
<th>C.V.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P )</td>
<td>0.0032 ( (.00069)^a )</td>
<td>0.464</td>
<td>1.0015 ( (.0061) )</td>
<td>0.246</td>
<td>0.997</td>
<td>0.418</td>
<td>0.0056</td>
</tr>
<tr>
<td>( V )</td>
<td>0.0200 ( (.008) )</td>
<td>2.5</td>
<td>0.9852 ( (.0062) )</td>
<td>2.258</td>
<td>0.997</td>
<td>0.785</td>
<td>0.0092</td>
</tr>
<tr>
<td>( Y/E )</td>
<td>0.1143 ( (.0574) )</td>
<td>1.99</td>
<td>0.9871 ( (.0064) )</td>
<td>2.08</td>
<td>0.997</td>
<td>1.546</td>
<td>0.0064</td>
</tr>
<tr>
<td>( E )</td>
<td>-0.0619 ( (.0209) )</td>
<td>2.96</td>
<td>0.9761 ( (.0077) )</td>
<td>3.10</td>
<td>0.996</td>
<td>1.134</td>
<td>0.0052</td>
</tr>
<tr>
<td>( W )</td>
<td>0.0647 ( (.0202) )</td>
<td>3.2</td>
<td>0.9895 ( (.0035) )</td>
<td>3.00</td>
<td>0.999</td>
<td>0.7002</td>
<td>0.0095</td>
</tr>
<tr>
<td>( Y )</td>
<td>0.1010 ( (.0321) )</td>
<td>3.14</td>
<td>0.9841 ( (.0051) )</td>
<td>3.11</td>
<td>0.998</td>
<td>0.942</td>
<td>0.0086</td>
</tr>
<tr>
<td>( W/E )</td>
<td>0.0563 ( (.0306) )</td>
<td>1.83</td>
<td>0.9935 ( (.0036) )</td>
<td>1.81</td>
<td>0.999</td>
<td>1.409</td>
<td>0.0073</td>
</tr>
<tr>
<td>( K/E )</td>
<td>-0.1315 ( (.0579) )</td>
<td>2.27</td>
<td>1.0134 ( (.0060) )</td>
<td>2.23</td>
<td>0.997</td>
<td>1.102</td>
<td>0.0054</td>
</tr>
</tbody>
</table>

\(^a\)Standard errors in parentheses.
definitive, but is merely suggestive of the kind of policy implications this model is capable of generating.

We begin this analysis by computing a trade-off matrix which is presented in Table 3.\footnote{This type of a trade-off approach was employed by DeWald and Johnson (29) to provide an analysis of Federal Reserve policy making.} The coefficients in this table represent the compensating change in the money supply required to hold an endogenous variable constant, given a 1\% change in an exogenous variable in one time period. For example, if there is a 1\% increase in productivity, the money supply must increase by .3076\% in order to hold prices constant, by .7443\% to hold velocity constant, by 12.9188\% to keep the output-employment ratio constant, etc. The method used to compute this table is presented in Appendix D.

Among the more interesting coefficients in the table, are the changes in the money supply necessary to compensate for changes in certain exogenous variables in order to keep real output constant. For example, if the capital stock declines by 1\%, the table indicates that it would take a .72718\% increase in the money supply to maintain real output at its original level in one time period. This coefficient reflects the large response of real output to changes in the capital stock (.93), and the minimal response of real output to changes in the money supply (.013). This minimal response of output to money supply changes supports an argument for the
Table 3. Tradeoff matrix (this table represents the change in the money supply needed to hold an endogenous variable constant given a unit change in $A$, $K$, $N$, or $P_{t-1}$)

<table>
<thead>
<tr>
<th></th>
<th>$P$</th>
<th>$V$</th>
<th>$Y/E$</th>
<th>$W$</th>
<th>$E$</th>
<th>$Y$</th>
<th>$K/E$</th>
<th>$W/E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A$</td>
<td>.3076</td>
<td>.7443</td>
<td>12.9188</td>
<td>-.6977</td>
<td>2.5584</td>
<td>-49.421</td>
<td>2.5584</td>
<td>-1.6106</td>
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<tr>
<td>$K$</td>
<td>.4528</td>
<td>1.095</td>
<td>5.834</td>
<td>-2.5098</td>
<td>-7.3583</td>
<td>-72.718</td>
<td>5.343</td>
<td>-1.1506</td>
</tr>
<tr>
<td>$N$</td>
<td>.0002</td>
<td>.0004</td>
<td>-.0239</td>
<td>.0055</td>
<td>-.0239</td>
<td>-.0236</td>
<td>-.0239</td>
<td>.0138</td>
</tr>
<tr>
<td>$P_{t-1}$</td>
<td>-3.822</td>
<td>1.2917</td>
<td>-2.9445</td>
<td>-1.2864</td>
<td>-2.9446</td>
<td>-2.946</td>
<td>-2.9446</td>
<td>-1.2266</td>
</tr>
<tr>
<td>$W_{-1}$</td>
<td>-.0321</td>
<td>-.0775</td>
<td>5.1473</td>
<td>-1.1984</td>
<td>5.1478</td>
<td>5.1493</td>
<td>5.1478</td>
<td>-1.1506</td>
</tr>
<tr>
<td>$Y_{-1}$</td>
<td>-.0266</td>
<td>-.0639</td>
<td>4.2389</td>
<td>2.0775</td>
<td>4.2393</td>
<td>4.241</td>
<td>4.2393</td>
<td>1.4715</td>
</tr>
<tr>
<td>$A_{-1}$</td>
<td>-.3066</td>
<td>-.7416</td>
<td>-8.8564</td>
<td>1.1553</td>
<td>.9008</td>
<td>49.242</td>
<td>.9008</td>
<td>1.2266</td>
</tr>
<tr>
<td>$E_{-1}$</td>
<td>.0793</td>
<td>.1904</td>
<td>-7.6356</td>
<td>-.7369</td>
<td>-7.6365</td>
<td>-12.6410</td>
<td>-7.6365</td>
<td>2.5989</td>
</tr>
<tr>
<td>$N_{-1}$</td>
<td>-.0001</td>
<td>-.0002</td>
<td>.0165</td>
<td>-.0038</td>
<td>.0164</td>
<td>.016</td>
<td>.0164</td>
<td>-.0095</td>
</tr>
<tr>
<td>$W/E_{-1}$</td>
<td>.0251</td>
<td>.0607</td>
<td>-4.0284</td>
<td>-.6219</td>
<td>-4.6286</td>
<td>-4.030</td>
<td>-4.0028</td>
<td>.3331</td>
</tr>
<tr>
<td>$K/E_{-1}$</td>
<td>-.4211</td>
<td>-1.0185</td>
<td>-5.4256</td>
<td>2.3342</td>
<td>6.8433</td>
<td>-67.628</td>
<td>6.8433</td>
<td>1.0701</td>
</tr>
</tbody>
</table>
neutrality of money, or an argument for significant lags in the effect of monetary policy.

Now, combining Table 3 and the reduced form coefficients in Table 1, we find that if we know the quarterly growth rates of productivity and the capital stock, inflation last quarter, (because population effects are so minute they will be omitted from the discussion) the rate of growth in wages last quarter, output last quarter, productivity last quarter, employment last quarter, the wage rate last quarter, output per man last quarter and capital per man last quarter, we can determine the rate of growth in the money supply required to maintain price stability. If we assume as a starting point a period of price stability, then the rate of growth of the money supply needed to maintain price stability can be determined from the following relationship:

(a) \[ \Delta M = .3078 \Delta A + .453 \Delta K - .032 \Delta W_{t-1} - .027 \Delta Y_{t-1} \]
\[ - .307 \Delta A_{t-1} + .079 \Delta E_{t-1} + .025 \Delta W/E_{t-1} \]
\[ + .506 \Delta Y/E_{t-1} - .421 \Delta K/E_{t-1} \]

Once we have determined the change in the money supply in this fashion, we can then turn to the reduced form coefficients in Table 1 to ascertain the rate of growth in employment and output implied by the growth rates in the relevant variables using the following relationships:
(b) \[ \Delta E = 0.0759 \Delta M - 0.1936 \Delta A + 0.558 \Delta K - 0.390 \Delta W_{t-1} \]
\[ - 0.321 \Delta Y_{t-1} - 0.068 \Delta A_{t-1} + 0.958 \Delta E_{t-1} \]
\[ + 0.305 \Delta W/E_{t-1} + 0.6230 \Delta Y/E_{t-1} - 0.519 \Delta K/E_{t-1} \]

(c) \[ \Delta Y = 0.0127 \Delta M + 0.6293 \Delta A + 0.926 \Delta K - 0.066 \Delta W_{t-1} \]
\[ - 0.054 \Delta Y_{t-1} - 0.627 \Delta A_{t-1} + 0.161 \Delta E_{t-1} + 0.051 \Delta W/E_{t-1} \]
\[ + 1.035 \Delta Y/E_{t-1} - 0.861 \Delta K/E_{t-1} \]

To illustrate, assume that the exogenous and lagged endogenous variables take the following values: \( A \) grows at .75% per quarter, \( K \) at .75% per quarter, \( Y_{t-1} \) at 1% per quarter, \( A_{t-1} \) at .5% per quarter, \( E_{t-1} \) at .5% per quarter, \( W_{t-1} \) at 1% per quarter, \( W/E_{t-1} \) at .8% per quarter, \( Y/E_{t-1} \) at .5% per quarter, and \( K/E_{t-1} \) at .4% per quarter. We then compute from relationship (a) that the rate of growth of the money supply consistent with price stability is .53% per quarter, or an annual rate of 2.1% per year. We note that this growth rate is close to the 2% annual growth rate proposed by Milton Friedman (48), and we, therefore, feel that the model tends to generate reasonable values for policy purposes.

Using the rate of growth of the money supply calculated in (a) to be consistent with price stability, we turn to
relationships (b) and (c) to determine the rates of growth of employment and real output that would also occur. We find that employment will grow at about .4% per quarter or at an annual rate of 1.6%, and will slightly exceed the average annual rate of growth of the labor force of 1.56%. Real output will grow at about 1.1% per quarter or 4.4% per year.

If a faster rate of growth in real output or employment is sought, the reduced form coefficients point to the capital stock as the key variable. Capital stock increases should also lead to productivity increases which would further increase output, but lead to declines in employment. The net effect on employment will still be positive unless productivity increases by 3% for every 1% increase in the capital stock. The data we have on the capital stock and productivity do not suggest such a relationship.

In concluding this section, we note that from the reasonable coefficients obtained from this feasibility exercise, that the model is well worth continued effort, and that simulations and dynamic multipliers would be worthwhile calculating for their more realistic policy implications.
In the present paper, we have specified and estimated a quarterly macroeconometric model in a way that would allow the effect of changes in the money supply to directly influence prices, employment, wages, and output, without forcing the money mechanism to work through an interest rate.

The formulated model is divided into two subsectors, the demand subsector and the supply subsector. The demand sector consists of the exogenous money stock and the velocity equation. The supply sector consists of the aggregate production function, an employment function and a wage function. The model is closed by three definitional identities. Each of the structural equations was estimated by either ordinary least squares or generalized least squares over the period 1952-1969 using quarterly observations.

The major conclusions of the model were drawn from the derived reduced form of the model. Changes in the money supply over the 18 year estimation period were observed to have their most significant effect on velocity. This finding strongly suggests a substantial lag in the effect of monetary changes on the economic variables of the system. Changes in the money supply had a quantitatively similar
effect on wage rates and prices, suggesting a weak response of the real wage to monetary changes. Finally, changes in the money supply had little impact on output and employment, supporting the proposition of long run money neutrality.

In the area of policy implications it was noted that to extract the real policy implications from the model simulations should be done, and the long run as dynamic multipliers computed. A feasibility example was presented to test the quality of the model in generating reasonable policy recommendations. From this simple example employing a trade-off matrix and the reduced form coefficients we computed that the rate of growth of the money supply consistent with price stability was 2.1% annually. This estimate compares favorably with that rate of growth presented by Milton Friedman, and therefore seems reasonable. We also computed that the growth in employment would slightly exceed the growth rate of the labor force, and the growth in output would be about 4% annually. Both are reasonable values also. Further, from the reduced form it was easily seen that the rate capital formation is the key variable in increasing growth rates for both real output and employment while maintaining price stability.

In terms of future theoretical development, much can be done to improve the present model. A framework to incorporate monetary lags would be desirable as would a full financial
sector. The capital stock should be endogenized and expectations should be added.

In terms of future empirical work, the model should be extended into the future to test its predictive accuracy from 1970 to 1972. It would also be most interesting to reestimated the model for periods characterized by unutilized resources to determine if in these periods the neutrality of money is maintained. Also in the interest of determining monetary neutrality, a short term cyclical analysis might also be attempted. It has not escaped our notice, that a refined version of this model might be used to separate the income and price effects of monetary changes.
V. BIBLIOGRAPHY


VI. ACKNOWLEDGMENTS

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I would also like to express my appreciation for the three year NDEA Fellowship and the one year NSF Fellowship I was awarded. These Fellowships financed my graduate studies for the four years I attended Iowa State.

And thanks too, to Shu Huang and Charlotte Latta for cheerful computational assistance in the estimation of the model, and to Ray Michaelski for computer advice.

Finally, thank you to my husband, Ed Rieder, whose continued encouragement and cooperation was essential.
The data to estimate this model are drawn from several sources. The primary source of data was Data Resources Incorporated (DRI). The price level, $P$, is the GNP deflator and its retrieval code from DRI is PGNP. Velocity is computed as the ratio of Gross National Product to the money supply. The retrieval code for Gross National Product is GNP. Money supply is defined as currency plus demand deposits. Its retrieval code is MONEY1. This is a monthly series on DRI, and was made quarterly using averages. Real output, $Y$, is measured as Gross National Product in constant dollars. Its retrieval code is GNP58. The price level lagged one quarter, $P_{t-1}$, is the GNP deflator lagged one quarter. The wage bill, $W$, is measured as total compensation to employees. Its retrieval code is WSS. Employment, $E$, is the number of men and women employed. Its retrieval code is EHH.

A second source of data is that used to estimate the FRB-MIT-Penn quarterly macroeconomic model of the United States economy. Our series for capital, $K$, is drawn from these data. To get an aggregate measure for capital, we summed the series for capital in producer's structures, 18; capital in producer durables, 30; capital owned by state and local governments, 102; the capital measure of single family
dwellings, #294; and the capital measure of multiple family dwellings, #296. The measure for the level of technology is proxied by an output per man-hour variable. The data to compute this proxy also comes from the FRB-MIT-Penn model. The series for real output, #3, was first adjusted from an annual rate to a quarterly rate. Then this adjusted series for output was divided by the series for the average number of hours worked per man per quarter, #142 times the series on the number of persons employed, #147.

A third source of data is needed to estimate population, N. The data on population between the ages of 14 and 64 were obtained from the Department of Commerce, Bureau of the Census, Current Population Reports, Series P-25, 1970. Census figures are annual, and reported as of April first each year. To make this series quarterly, a linear growth path of population was assumed, and the values calculated with the following formula:

\[ X_{ij} = X_{ij-1} + \frac{1}{4}(X_i - X_{i-1}) \]

where i is the index for the year and takes the values of 1951, 52, ... 70, and where j is the quarter index and takes the values 2, 3, and 4. When j = 1, \( X_{ij} \) is the reported value in the year it represents.

Annual figures on the size of the labor force were obtained from the Federal Reserve Bulletin.
VIII. APPENDIX B

The full wage equation estimated for the first thirty-six quarters is as follows:

\[
\ln W_t = 3.046 + .7691 \ln Y_t + .9988 \ln P_t + .4880 \ln N_t + .3985 \ln E_t
\]

\[
\text{with coefficients: } (1.338) (6.4168) (4.171) (7.61) (2.188)
\]

\[
\bar{R}^2 = .999
\]

\[
\text{DW} = 1.8660
\]

\[
\rho = .63
\]
To incorporate expectations into the wage equation, we begin with the wage Equation (5p), and modify it by replacing ln P, by ln P**, which makes wages a function of expected prices, rather than actual prices:

\[
\ln W = \frac{1}{\phi_1 + \gamma_1} \ln \rho_2 + \frac{1}{\phi_1 + \gamma_1} \ln Y_t \\
+ \ln P^{**} - \frac{\gamma_2 + \gamma_3 v(1-\sigma)}{\phi_1 + \gamma_1} \ln N_{t+1} - \frac{\gamma_3}{\phi_1 + \gamma_1} \ln E_t
\]

We next define:

\[
\ln P^{**}_t = \lambda \ln P_t + (1-\lambda) \ln P^{**}_{t-1}
\]

where ln P** is seen as price expectations formulated as a decaying weighted average of past price levels which is condensed into the above expression by the application of the Koyck transformation on the decaying weighted average. This is, of course, a naive and only first approximation to price expectations for the wage equation. This formulation implicitly assumes in the coefficient of \(\lambda\) that the expectations of the suppliers and demanders of labor are identical. Further work, both theoretical and empirical are needed to build expectations properly into the wage equation. However as a first approximation, we built in expectations...
using the previously discussed simplifications as follows:

\( \ln W_t = \frac{1}{\phi_1 + \gamma_1} \ln \rho_2 + \frac{1}{\phi_1 + \gamma_1} \ln \gamma_t \)

\[ + \ln \phi_{**} - \frac{\gamma_2 + \gamma_3 \nu (1-\sigma)}{\phi_1 + \gamma_1} \ln N_t + \left[ 1 - \frac{\gamma_3 \sigma}{\phi_1 + \gamma_1} \right] \ln E_t \]

where:

\( \ln \phi_{**} = \lambda \ln \phi_t + (1-\lambda) \ln \phi_{t-1} \)

Then lagging wages by one period:

\( \ln W_{t-1} = \frac{1}{\phi_1 + \gamma_1} \ln \rho_2 + \frac{1}{\phi_1 + \gamma_1} \ln \gamma_{t-1} \)

\[ + \ln \phi_{**} - \frac{\gamma_2 + \gamma_3 \nu (1-\sigma)}{\phi_1 + \gamma_1} \ln N_{t-1} \]

\[ + \left[ 1 - \frac{\gamma_3 \sigma}{\phi_1 + \gamma_1} \right] \ln E_{t-1} \]

and solving for \( \ln \phi_{**} \):

\( \ln \phi_{**} = \ln W_{t-1} - \frac{1}{\phi_1 + \gamma_1} \ln \rho_2 - \frac{1}{\phi_1 + \gamma_1} \ln \gamma_{t-1} \)

\[ + \frac{\gamma_2 + \gamma_3 \nu (1-\sigma)}{\phi_1 + \gamma_1} \ln N_{t-1} - \left[ 1 - \frac{\gamma_3 \sigma}{\phi_1 + \gamma_1} \right] \ln E_{t-1} \]

and subbing this into (5u):
\[(5x) \quad \ln P_{t}^{**} = \lambda \ln P_{t} + (1-\lambda) \ln W_{t-1} - \frac{(1-\lambda)}{\phi_{1}+\gamma_{1}} \ln \rho_{2}
- \frac{(1-\lambda)}{\phi_{1}+\gamma_{1}} \ln Y_{t-1} + \frac{\{\gamma_{2}+\gamma_{3}v(l-\sigma)\}}{\phi_{1}+\gamma_{1}}(1-\gamma) \ln N_{t-1}
+ (1-\gamma)[1 - \frac{\gamma_{3}^{\sigma}}{\phi_{1}+\gamma_{1}}] \ln E_{t-1}\]

and finally subbing this into (5t), the wage equation with expectations is derived:

\[(5y) \quad \ln W_{t} = \frac{\lambda}{\phi_{1}+\gamma_{1}} \ln \rho_{2} + \frac{1}{\phi_{1}+\gamma_{1}} \ln Y_{t} + \lambda \ln P_{t}
- \frac{\gamma_{2}+\gamma_{3}v(l-\sigma)}{\phi_{1}+\gamma_{1}} \ln N_{t} + [1 - \frac{\gamma_{3}^{\sigma}}{\phi_{1}+\gamma_{1}}] \ln E_{t}
+ (1-\lambda) \ln W_{t-1} - \frac{(1-\lambda)}{\phi_{1}+\gamma_{1}} \ln Y_{t-1}
+ (1-\lambda) \frac{\{\gamma_{2}+\gamma_{3}v(l-\sigma)\}}{\phi_{1}+\gamma_{1}} \ln N_{t-1}
- (1-\lambda)[1 - \frac{\gamma_{3}^{\sigma}}{\phi_{1}+\gamma_{1}}] \ln E_{t-1}\]

\[
\ln W_{t} = .7141 + .7238 \ln Y_{t} + .5618 \ln P_{t} + .2145 \ln E_{t}
(1.04) \quad (12.03) \quad (6.224) \quad (1.813)
- .8565 \ln N_{t} - .3274 \ln Y_{t-1} + .1895 \ln E_{t-1}
(1.98) \quad (3.88) \quad (1.67)
+ .5914 \ln N_{t-1} + .532 \ln W_{t-1}
(1.33) \quad (7.78)
\]

\[R^2 = .999 \quad DW = 1.9 \quad \rho = .97\]
The table used to present the trade-offs in changes in the money supply to hold an endogenous variable constant, given a unit change in an exogenous variable, was computed in the following manner. Each coefficient in the table represents the negative of the ratio of reduced form coefficients, \(-R_y^b/R_a^y\). \(R_y^b\) is the reduced form coefficient of the exogenous variable experiencing the unit change in the reduced form equation of the relevant endogenous variable whose constancy is required. \(R_a^y\) is the reduced form coefficient of the money supply in the reduced form equation of the relevant endogenous variable whose constancy is required.

For example, if we wish to compute the compensating change in the money supply required to keep prices constant given a unit change in productivity, we take the coefficient of productivity in the reduced form price equation, \(-.0745\), as \(R_y^b\). This is divided by the reduced form coefficient of the money supply in the price equation, \(.2420\), or \(R_a^y\). The negative of this ratio is then the first element in Table 4. The remaining elements are computed in a similar manner.