Economic Growth, Unemployment, and Inflation: A VAR Analysis of the United States

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Abstract

The following paper attempts to empirically discern the relationship between economic growth, unemployment, and inflation. Data for the US spanning a period of forty years from 1980 to 2019 has been used. First, univariate regressions are employed to find whether the Philips Curve and Okun's Law predictions have remained valid for the dataset under consideration. Next, a standard and a structural VAR are estimated using the Cholesky decomposition technique coupled with the imposition of short run and long run restrictions justified by economic theory. The impulse response functions indicate that an inflationary shock reduces unemployment while promoting economic growth while an unemployment shock reduces growth, in the short run. In the long run, the effects of the shocks on variables inevitably subside and do not have permanent impacts.

1. Introduction

In 1958, a New Zealand-born economist called G.W Lewis published a paper on the relationship between wage inflation and unemployment that later became known as the Philips Curve and has since become an integral part of macroeconomics. The curve was derived based on the analysis of British wages through a period of more than five decades preceding the First World War. Lewis found periods of high unemployment coincided with periods of low wage inflation and vice versa. The explanation he offered was when the unemployment rate is low, employers are tempted to bid wage rates up in an attempt to attract the most suitable labor from other firms and industries (Phillips, 1958). Philips' original paper had linked wage rates and not price changes with unemployment. This connection was made explicit a mere couple of years after Philips' findings were published, by Samuelson & Solow (1960) who modified the curve by replacing change in wage rates with average price rise per annum using data on the United States.

In the following years, the Philips curve was made subject to intense scrutiny. First, Friedman (1968) posited that the curve only existed in the short run because in the long run, workers will negotiate for wage contracts that increase their wages at the same rate as anticipated inflation. Then came the stagflation of the 70s when the United Kingdom experienced a period of high inflation coupled with high unemployment, a phenomenon that seemed to be the nail in the coffin of the Philips curve. Recently, the curve has undergone a resurgence of sorts when Blanchard & Gali (2005) argued in a highly influential paper that if we allow for real wage rigidities, central banks indeed face a bargain between stabilizing inflation or stabilizing the output gap.

Whether or not a tradeoff exists between inflation and unemployment is a debate that has ranged for more than half a century. The existence of a Philips curve has profound implications for policymakers; they can lower the unemployment rate by bearing high inflation, or reduce inflation if they can tolerate a high proportion of the labor force being unemployed. Since 1974, however, seven Nobel prizes have been awarded for works critical of the Philips curve (Domitrovic, 2011). Nevertheless, the relationship is still used widely by central banks all over the world to forecast inflation[1] and as a starting point for economists to untangle this complex relationship.

In addition to being affected by the rate of inflation, the unemployment rate of an economy is also perturbed by its economic growth rate (Okun, 1970). This relationship, which is now known as Okun's Law, is an empirically observed phenomenon that was first proposed by Arthur Melvin Okun in 1962. The law predicts a 1 percentage point decrease in the Unemployment Rate to be associated with a 3-percentage point increase in output pointing to the fact that economic growth is faster than the change in unemployment (Prachowny, 1993). The empirics of the relationship, however, have been found to vary across periods and different economies (Knotek, 2007).

Both these models, the Philips Curve, and Okun's Law, combine to explain that an increase in inflation will reduce unemployment while this reduction in unemployment will help promote economic growth. Wessels (2020) has estimated a VAR model using quarterly data on the United States to predict whether the US economy has entered a recessionary period owing to the coronavirus lockdowns. Blanchard & Quah (1989) run a VAR using unemployment and Gross National Product (GNP) and distinguish between two types of shocks: demand shocks that have no long run impact on the variables juxtaposed with supply shocks that permanently affect both output and unemployment. Herz & Roeger (2004) on the other hand, differentiate between the backward- and forward-looking Philips curves in their model which includes inflation, output gap, and the federal funds rate.

To examine how unemployment, inflation, and economic growth affect each other, I estimate a Vector Autoregression (VAR) model. The empirics begin with univariate regressions to test the existence of Philips Curve and Okun's Law. It is followed by the approximation of the Standard VAR which is then used to estimate the Structural VAR. The estimation is followed by the imposition of restrictions backed by theory and the depiction of the impulse response functions to evaluate the effect of external shocks on the variables.

[1] See for example Henry & Pesaran (1993) and Webb (1994).

2. Methodology

The paper uses a Vector Autoregression (VAR) to empirically estimate the relationship between the rate of inflation, the unemployment rate, and the GDP growth rate. A VAR is an *n*-equation, *n*-variable linear model in which each variable is in turn explained by its own lagged values, plus current and past values of the remaining *n*-1 variables (Stock & Watson, 2001). It is used instead of the simple regression when we are unsure about the direction of causality. In this case, we have a total of three variables, and each in turn is explained by the other two: Inflation and Unemployment are linked via the Philips Curve, and Unemployment and Economic Growth are dependent by Okun's Law.

I have used data on the US spanning a period of forty years from 1980 to 2019. The following table summarizes the three variables I have used and their respective sources.

Table 1. Dataset and Sources

Variables	Description	Data Source
Growth Rate	Generated manually using Gross Domestic Product (in constant 2015 US dollars)	World Bank and OECD national accounts data
Unemployment Rate	Unemployment, total (% of total labor force) (national estimate)	International Labor Organization (ILO) Labor Force Statistics (LFS)
Inflation Rate	Inflation, (annual percentage change in consumer prices)	International Monetary Fund (IMF), International Financial Statistics

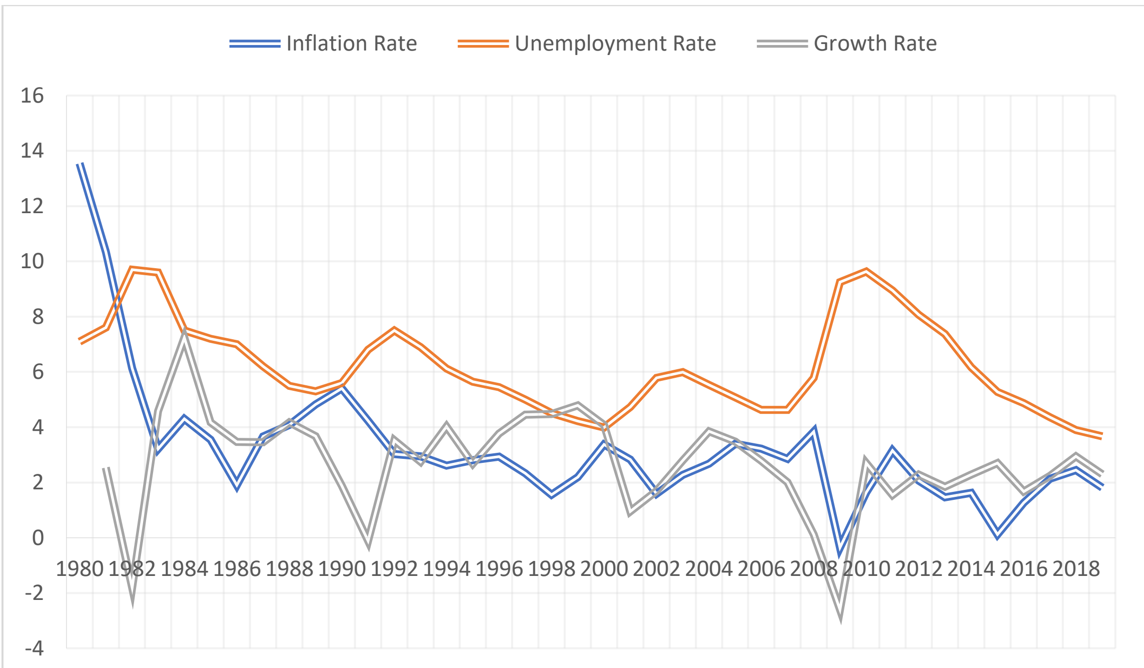
The analysis begins with the testing of the stationarity of the three series. This ensures our regression results are not spurious. It is followed by the selection of the appropriate lag length and the estimation of the standard and structural VARs. The structural form is different in the sense that it assumes the variables are contemporaneously related to each other while the reduced-form or standard version does not. The structural equations yield more unknowns than the number of equations and hence the problem of infinite solutions arises. To ensure an efficient numerical solution, we impose restrictions motivated by economic theory using Cholesky Decomposition which later helps interpret the Impulse Response Functions (IRFs). Herz & Roeger (2004), too, use the lower triangular matrix in their VAR model of Inflation, Output Gap, and the Federal Fund rate which is the result of the Cholesky Decomposition. This will be delved deeper into when the model is estimated.

3. Results and Discussion

3.1 Descriptive Results

Beginning with the descriptives, the US economy has grown at an average rate of 2.7% over the entire period under consideration. The growth has remained positive for all years except three. The average rate of inflation has been 3.2% while the mean unemployment rate has been 6.2%. The unemployment rate reached a low at the turn of the 21st century but has always remained above 4%. The graph below clearly shows the impact of the 2007-08 crisis on the macroeconomic variables used; the unemployment rate skyrocketed while the economy contracted for the first time in almost two decades.

Figure 1. Evolution of Inflation, Unemployment, and Growth Rate of the US 1980-2019

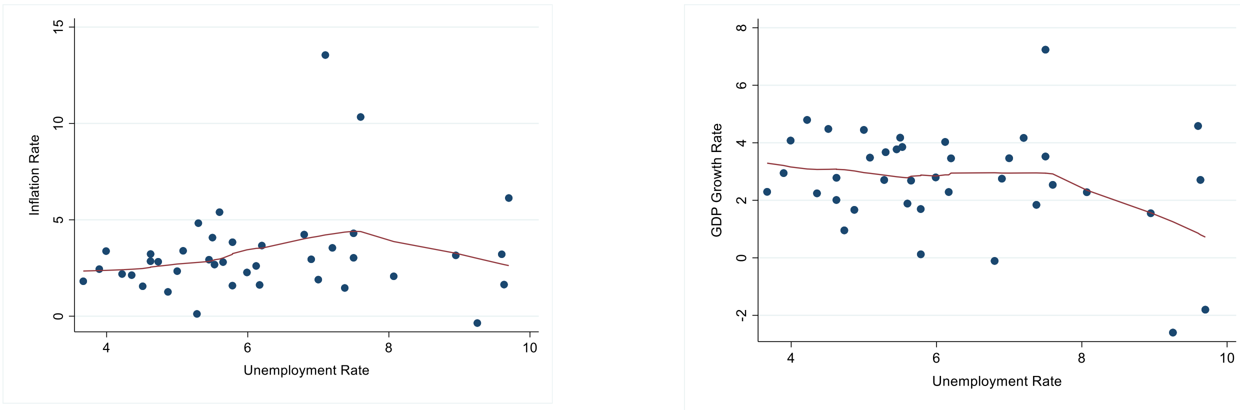


Source: Author's own illustration from the data provided by the World Bank and ILO

Does there seem to be evidence of a Philips curve in the graph above i.e., does it seem that periods of high unemployment coincide with periods of high inflation? With the exception of the last decade, this does not seem to be the case from a purely visual perspective. However, I regress Inflation on Unemployment to empirically test this hypothesis. The coefficient comes out to be statistically insignificant pointing towards the absence of the Philips curve. Next, I have plotted a curve which is a combination of a scatterplot and a graph (see next page). Each dot represents a level of inflation and unemployment in a year while the line has been plotted through the predicted values of Inflation calculated from the regression of Inflation on Unemployment.

The next step is to test whether the data satisfies Okun's Law. Are periods of high economic growth coinciding with periods of low unemployment? The relationship seems ambiguous from the graph so once again, I run a regression, this time of Growth Rate on the Rate of Unemployment. The coefficient is significant at a 10% level of significance and indicates that a 1% increase in unemployment is related to a 0.3% reduction in the growth rate, a moderate negative relationship.

Figure 2. Testing Philips Curve and Okun's Law



Source: Author's own illustration from the data provided by the World Bank and ILO

3.2 Diagnostics

3.2.1 Unit Root Tests

Before moving on to the regression analysis, it is necessary to first test the stationarity of the data. If a unit root is present, regression results are spurious. The unit root is present in an AR(1) model when,

$$y_t = \rho y_{t-1} + \epsilon_t \ ; \rho = 1$$

The Dickey-Fuller test estimates the following equation,

$$\Delta y_t = \delta y_{t-1} + \epsilon_t \ ; H_0 \colon \delta = 0$$

The null hypothesis is the series contains a unit root. Based on Figure 1, I have included a trend term (or drift) in the tests. The decision rule is to reject the null hypothesis if $t_{DF} < t_{CV}$ i.e., the series is stationary if the Dickey Fuller t-statistic is less than the critical t-value at the chosen level of significance. At the 5% level of significance, all of the three series are stationary.

Table 1. Unit Root Tests

Variables	Dickey Fuller t-values	Critical t-values
GDP Growth Rate	-4.25899	-2.94115
Inflation Rate	-5.8982	-2.93899
Unemployment Rate	-3.1108	-2.94115

Source: Author's own estimations

3.2.2 Lag Length Criteria

A test to choose the number of lags to include in the model is run and the results displayed here are for the three most commonly used criteria namely the Akaike Information criterion (AIC), Schwarz Information criterion (SC), and the Hannan-Quinn Information Criterion (HQ).

Table 2. Lag Order Selection Criteria

Lag(s)	Log Likelihood	AIC	SC	HQ
0	-172.6956	10.33505	10..46973	10.38098
1	-121.6450	7.861468	8.400183	8.0445185
2	-101.2295	7.189971*	8.132723*	7.511477*
3	-98.16611	7.539183	8.885972	7.998476

Source: Author's own estimations

The asterisk denotes the lag order selected by the criterion. All three of the criteria displayed here suggest the inclusion of up to two lags of the three variables in the VAR model.

3.2.3 Granger Causality

Granger (1969) used time-series regressions to develop a test for causality. A variable is said to Granger-cause another if it is helpful in predicting it (i.e., reducing the forecasting error).

Table 3. Granger Causality Tests

Null Hypothesis	F-stat	prob
Growth does not Granger cause Inflation	3.797	0.0332
Inflation does not Granger cause Growth	7.6628	0.0019
Unemployment does not Granger cause Inflation	0.23460	0.7922
Inflation does not Granger cause Unemployment	11.398	0.0002
Unemployment does not Granger cause Growth	3.321	0.0536
Growth does not Granger cause Unemployment	1.62352	0.2130

Source: Author's own estimations

Three of the six values have come out to be significant. The relationship between Economic Growth and Unemployment is bi-directional, both Granger Cause each other. Meanwhile, Unemployment Granger Causes Inflation but it does not seem the case the other way around.

3.3 Vector Autoregression (VAR) Analysis

3.3.1 Standard VAR

The diagnostic tests conclude the data under observation is stationary. This is the VAR model in its general form with a single lag of the dependent variables:

$$\begin{bmatrix} Inflation_t \\ Growth_t \\ Unemployment_t \end{bmatrix} = \begin{bmatrix} \alpha \\ \beta \\ \gamma \end{bmatrix} + \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \begin{bmatrix} Inflation_{t-1} \\ Growth_{t-1} \\ Unemployment_{t-1} \end{bmatrix} + \begin{bmatrix} \epsilon_t{}^{\pi} \\ \epsilon_t{}^{g} \\ \epsilon_t{}^{u} \end{bmatrix}$$

Since I concluded using two lags of the variables, my estimation of the VAR yields a total of eighteen parameters. (An asterisk denotes the coefficient being significant at a 5% level of significance.)

Table 4. Standard VAR Results

Variables	Inflation (first lag)	Growth (first lag)	Unemployment (first lag)	Inflation (second lag)	Growth (second lag)	Unemployment (second lag)
Inflation	0.425*	0.413*	0.394	0.0332	-0.103	-0.401
Growth	-0.616*	0.564*	0.139	0.617*	-0.00406	0.0777
Unemployment	0.374*	-0.117	1.369*	-0.217*	0.0817	-0.577*

Source: Author's own estimations

The results indicate that each of the variables are related significantly and positively to their past values which in terms of economics means all three of the variables change with 'inertia'. In the case of the second lag, it seems that only unemployment is related to its second lag and the relationship comes out to be negative and statistically significant. The first lag of inflation is negatively affecting growth but positively affects inflation. This means inflation is followed by lower growth and higher unemployment, both being instances policymakers tend to avoid. The first lag of growth is significantly affecting inflation which means a period of higher growth is followed by a period characterizing a higher rate of inflation. The coefficient of the second lag of inflation is significant for both the Growth and Unemployment Rate. Higher inflation is followed by increased growth and lower inflation two periods in the future.

Here, it is imperative to check the stability of the Vector Regression estimated. There are two ways to test this; the first is using a table of the roots and the second is by using a graph of roots. If the roots lie inside the unit circle or if the eigenvalues are less than one, the model satisfies the stability condition and is said to be stable. From the graph in the appendix, it is evident that all the roots lie inside the unit circle.

3.3.2 Structural VAR

The preceding VAR estimated is now known as the reduced-form model because the source of the model is found to be the structural VAR where the variables affect each other contemporaneously. Ignoring the matrix of constants, the structural VAR can be written as:

$$\begin{bmatrix} 1 & j & k \\ l & 1 & m \\ n & z & 1 \end{bmatrix} \begin{bmatrix} Inflation_t \\ Growth_t \\ Unemployment_t \end{bmatrix} = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \begin{bmatrix} Inflation_{t-1} \\ Growth_{t-1} \\ Unemployment_{t-1} \end{bmatrix} + \begin{bmatrix} v_t{}^{\pi} \\ v_t{}^{g} \\ v_t{}^{u} \end{bmatrix}$$

Using short matrix notations, this can be written as,

$$CY_t = BY_{t-1} + V_t$$

Where Y denotes the matrix of the variables, V the matrix of error terms and C and B correspond to the two matrices of constants being multiplied. To isolate the matrix of dependent variables, multiply the equation with the inverse of C.

$$C^{-1}CY_t = C^{-1}BY_{t-1} + C^{-1}V_t$$

$$Y_t = AY_{t-1} + C^{-1}V_t \qquad ; A = C^{-1}B$$

The structural parameters are recovered using the reduced-form parameters. A problem arises in the estimation:

$$C^{-1}V_t = \begin{bmatrix} 1 & j & k \\ l & 1 & m \\ n & z & 1 \end{bmatrix}^{-1} \begin{bmatrix} v_t{}^{\pi} \\ v_t{}^{g} \\ v_t{}^{u} \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} p & q & r \\ s & t & u \\ v & w & x \end{bmatrix} \begin{bmatrix} v_t{}^{\pi} \\ v_t{}^{g} \\ v_t{}^{u} \end{bmatrix}$$

It was mentioned previously that the standard VAR originates from the structural VAR. A comparison of the error components of the two models yields:

$$\begin{bmatrix} \epsilon_t{}^{\pi} \\ \epsilon_t{}^{g} \\ \epsilon_t{}^{u} \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} pv_t{}^{\pi} + qv_t{}^{g} + rv_t{}^{u} \\ sv_t{}^{\pi} + tv_t{}^{g} + uv_t{}^{u} \\ vv_t{}^{\pi} + wv_t{}^{g} + xv_t{}^{u} \end{bmatrix}$$

This equation represents what is called an 'identification problem'. Notice $\epsilon_t{}^{\pi}$, for example, that would have been labelled as an inflationary shock in the reduced-form is found to be a function of all three shocks in the structural form.

To address this, use Cholesky decomposition which essentially uses a lower-triangular matrix to provide an efficient numerical solution. In this case,

$$C = \begin{bmatrix} 1 & j & k \\ l & 1 & m \\ n & z & 1 \end{bmatrix}, \quad C_{cd} = \begin{bmatrix} 1 & 0 & 0 \\ l & 1 & 0 \\ n & z & 1 \end{bmatrix}$$

Where the subscript 'cd' denotes the Cholesky decomposition of the matrix C.

Short run Restrictions

See that if $C_{cd}$is substituted for C in the structural equation;

$$\begin{bmatrix} 1 & 0 & 0 \\ l & 1 & 0 \\ n & z & 1 \end{bmatrix} \begin{bmatrix} Inflation_t \\ Growth_t \\ Unemployment_t \end{bmatrix} = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \begin{bmatrix} Inflation_{t-1} \\ Growth_{t-1} \\ Unemployment_{t-1} \end{bmatrix} + \begin{bmatrix} {v_t}^{\pi} \\ {v_t}^{g} \\ {v_t}^{u} \end{bmatrix}$$

Three equations are obtained, the first of which states that growth and unemployment do not contemporaneously affect inflation. The Cholesky Decomposition is thus imposing a restriction on the structural VAR which must be backed by economic theory (Stock & Watson, 2001). In the short run, it seems valid that inflation will not be contemporaneously affected by growth in output or unemployment assuming price rigidity.

The second equation states that growth is not contemporaneously affected by unemployment which seems counter-intuitive to say the least. If the unemployment rate increases, as it did in 2008, it is expected that growth in the same period will be much lower. On the other hand, a lower growth rate may not instantaneously increase unemployment because most employers sign long-term contracts with employees to ensure the turn-over rate remains manageable. Based on these conjectures, the last two rows of the model are shifted:

$$\begin{bmatrix} 1 & 0 & 0 \\ l & 1 & 0 \\ n & z & 1 \end{bmatrix} \begin{bmatrix} Inflation_t \\ Unemployment_t \\ Growth_t \end{bmatrix} = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \begin{bmatrix} Inflation_{t-1} \\ Unemployment_{t-1} \\ Growth_{t-1} \end{bmatrix} + \begin{bmatrix} {v_t}^{\pi} \\ {v_t}^{u} \\ {v_t}^{g} \end{bmatrix}$$

Again, using matrix notations,

$$C_{cd} Y_t = B' Y_{t-1} + V_t$$

$$Y_t = A' Y_{t-1} + {C_{cd}}^{-1} V_t \quad ; \; A' = C_{cd} B'$$

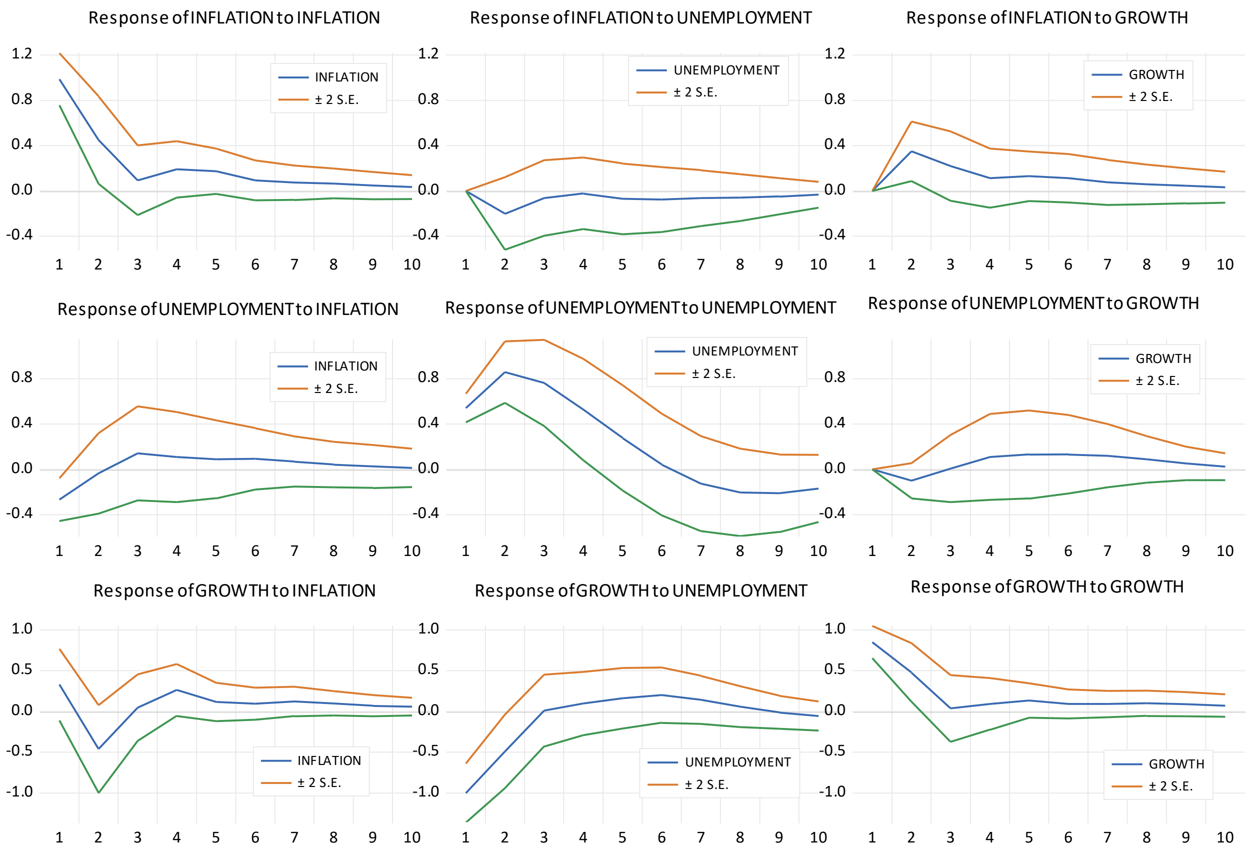
Estimating this model gives the following matrix:

$${C_{cd}}^{-1} = \begin{bmatrix} 0.988 & 0 & 0 \\ -0.266 & 0.542 & 0 \\ 0.329 & -0.999 & 0.849 \end{bmatrix}$$

All the elements of this matrix are significant at the 1% level of significance with the exception of $n = 0.329$. See that this appears in the equation of growth and links it with inflation. The parameter being statistically insignificant means inflation does not contemporaneously affect economic growth.

See graph on the next page for the short run impulse response functions. The upper triangular matrix used yields the three corresponding impulse responses zero. The three diagonal responses are all positive, an intuitive finding pointing to the fact that a shock in the three variables positively impacts their values in the short run. An inflationary shock it seems reduces unemployment while promoting economic growth, albeit both very moderately. Lastly, a shock to unemployment reduces growth in the short run, another reasonable deduction. An example of this phenomenon could be the post-coronavirus labor supply shock also known as the Great Resignation when many workers voluntarily resigned *en masse* which led to a low growth rate.

Figure 3. Short run Impulse Response Functions



Source: Author's own illustration from the data provided by the World Bank and ILO

Long run Restrictions

It is first necessary to discern the intuition behind the long run restrictions. Consider a simple AR(1) model:

$$y_t = \rho y_{t-1} + \epsilon_t \ ; |\rho| < 1$$

Through recursive substitution,

$$y_t = \rho^t y_0 + \epsilon_t$$

Since ρ is a fraction, as $t \to \infty, \rho^t \to 0$. Hence, the dependent variable is solely a function of the error term in the long run. Applying to the Vector Autoregression,

$$\begin{bmatrix} Growth_{t\to\infty} \\ Inflation_{t\to\infty} \\ Unemployment_{t\to\infty} \end{bmatrix} = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \begin{bmatrix} v_t{}^{\pi} \\ v_t{}^{u} \\ v_t{}^{g} \end{bmatrix}$$

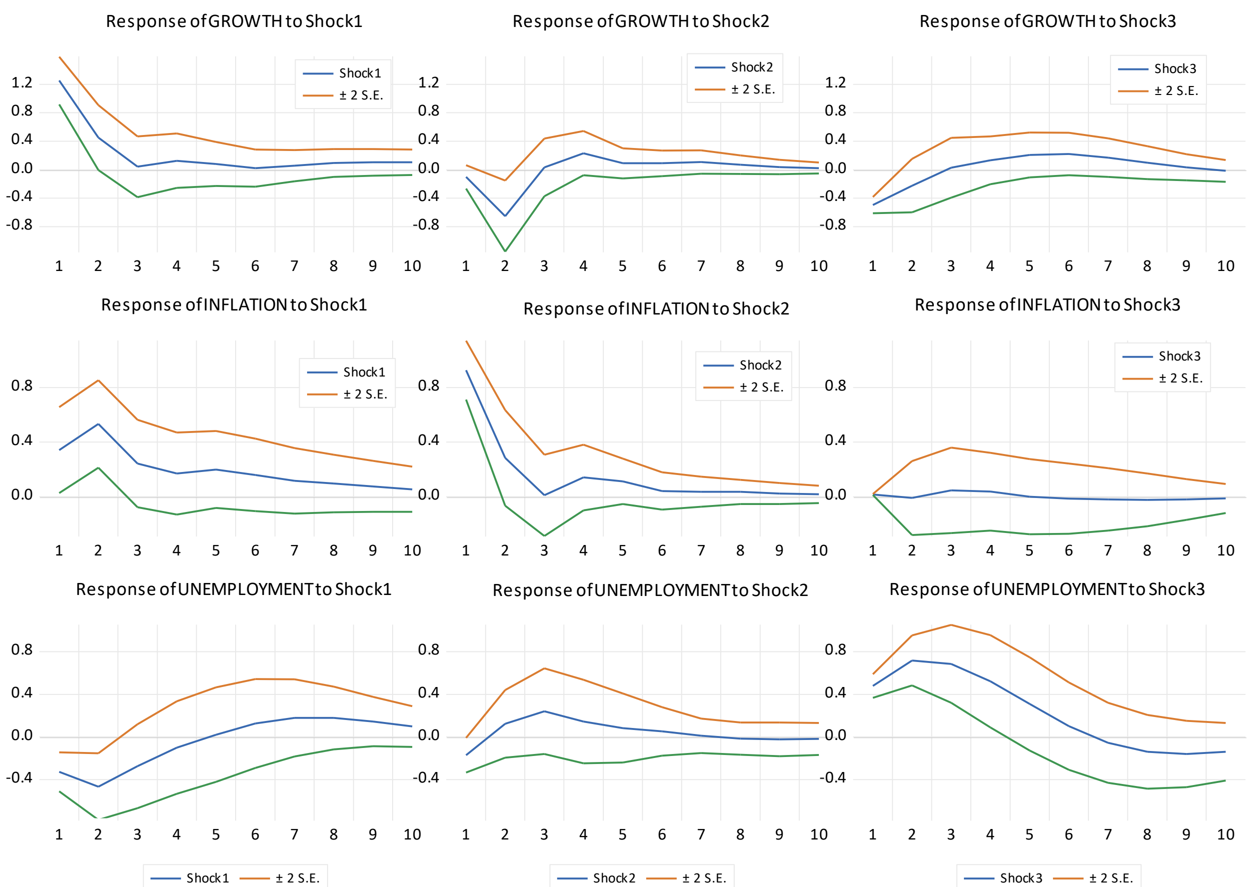
Again, the order has been changed to account for the restrictions to be imposed later on. The theory I use stems from the difference in short run and long run validity of the Classical and Keynesian Schools of Thought. In the long run, the Aggregate Supply (AS) curve is more vertical owing to price flexibility. Hence, I do not expect a shock in inflation or unemployment to permanently change the output and thus the growth rate. These comprise the first two restrictions. The third restriction is backed by the vertical long run Philips Curve using which I assume an unemployment shock will not permanently impact inflation.

Cholesky decomposing the matrix of constants and estimating the long run model yields the following matrix:

$$\begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} = \begin{bmatrix} 2.66 & 0 & 0 \\ 2.1559 & 1.705 & 0 \\ -0.395 & 0.461 & 2.296 \end{bmatrix}$$

Both g and h are insignificant depicting the fact that growth and inflationary shocks do not permanently affect unemployment.

Figure 3. Long run Impulse Response Functions



Source: Author's own illustration from the data provided by the World Bank and ILO

Here, shock1 represents a shock to growth, shock2 to inflation, and shock3 to unemployment. A growth shock positively impacts growth and inflation in the long run while negatively impacting unemployment. An inflationary shock in the long run moderately impacts both inflation and unemployment negatively. A shock to unemployment on the other hand does not impact inflation, however, it does negatively impact economic growth. With increasing time periods, the impact of all the shocks on all the variables dissipates (the lines converge to zero), a fact pointing toward the stability of the model.

4. Conclusion

This paper began with an introduction to the Philips Curve and Okun's Law, one arguably more influential than the other but both representing an inter-relationship of immense significance. In order to better analyze the causal link between variables without imposing *a priori* restrictions, Stock & Watson (2001) suggest the use of the Vector Autoregression model which has been employed here. The findings obtained imply a Philips Curve was not followed by the US in the past four decades suggesting the absence of a tradeoff between unemployment and inflation in the long run. Moreover, the results point to the fact that the long hold belief of the curve represents a stable relationship between the two variables is indeed a fallacy, a conclusion similar to the one drawn by numerous other studies (see for example Friedman (1968) and Blanchard & Gali (2005)).

In the case of Okun's Law, on the other hand, the univariate regression yielded a statistically significant albeit modest in size negative coefficient that satisfied the proposed relationship in the law. Blanchard & Quah (1989) posit a tight relationship between output and unemployment in the case of demand disturbances, but no such link when it comes to supply disturbances. This, the reason, is because as output increases, unemployment may fall in the short run but return to its initial value in the long run (ibid). Furthermore, with the long run restriction imposed, the impulse response of unemployment to a growth shock was negative and persisted for almost four years. Blanchard & Quah (1989) have explained this using wage and price rigidities. Herz & Roeger (2004) use their New Keynesian Phillips Curve to offer explanations for two contradictory outcomes of a demand shock. In their backward-looking model, for example, the demand shock leads to a negative output effect, a decline in inflation in the current period, and a downward adjustment of inflation expectations in the next period, when the negative demand shock has already disappeared, and actual inflation adjusts upwards. This positive inflation surprise leads to an increase in output above its potential (and thus reduced unemployment) during the adjustment process.

To summarize, the relationships analyzed in this paper depend crucially on the economy under study, the time frame considered, and whether the relationship is being evaluated in the short run or the long run. It is worth noting that it is the nature and not the existence of the inter-relationship between unemployment, economic growth, and inflation that remains ambiguous. This study aims to serve as a foundation for future works attempting to understand this sophisticated link between these key macroeconomic variables.

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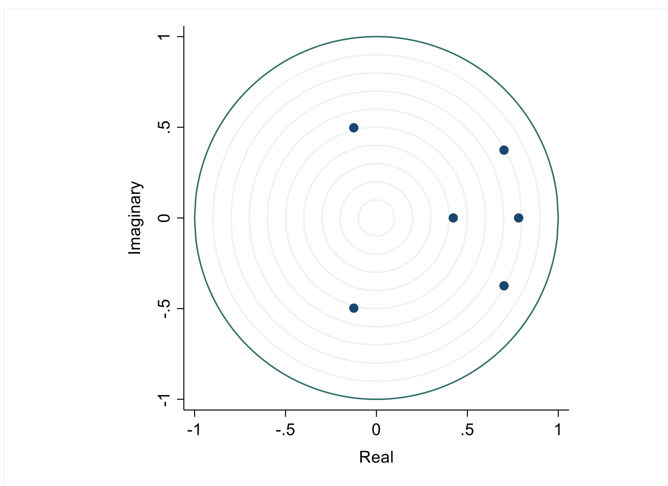
Appendix

Table 1/A. Summary Statistics of the Dataset

Variables	Observations	Mean	Std. Dev.	Min	Max
Growth Rate	39	2.704	1.782	-2.5999	7.237
Unemployment Rate	40	6.203	1.669	3.669	9.7
Inflation Rate	40	3.225	2.415	-3.556	13.55

Source: Author's calculations from the data provided by the World Bank and ILO

Figure 1/A. Graphing the Roots



Source: Author's own illustration from the data provided by the World Bank and ILO