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RESEARCH

Measurement of inflation in the macroeconomy

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Inflation is determined for the first time by the function of real Gross Domestic Product (GDP), the amount of money in circulation, foreign currency holdings, and the velocity of money, which are regulated by the Central Bank with an interest rate depending on consumer demand. Increasing the velocity of money through higher interest rates reduces the supply of cash and reduces inflation. Unemployment affects inflation only through the value of real GDP. An increase in real GDP reduces inflation, while an increase in unemployment reduces real GDP and increases inflation.

Keywords: economy, labor, capital, money, currency, unemployment, inflation

1 Introduction

For many years, economists around the world conducted research on the dependence of inflation on unemployment, but the results obtained could not mathematically describe the ongoing macroeconomic processes. To describe this relationship, they used the empirical curve obtained by Phillips for the decline in the rate of wage growth when the unemployment rate increases (1). The researchers converted the Phillips curve into falling inflation curves that become deflationary when the unemployment rate rises. Macroeconomic theories created after the 1930s are versions of the transformed Phillips curve (2). The fallacy of Phillips curves was proven in (3). Stagflation, which emerged in the early 1970s, rejected models based on Phillips curves (4–8). High, unpredictable inflation does not ensure a fair distribution of income, arbitrarily redistributes it from investors to debtors, slows down economic growth, and inflation expectations and mistrust reduce the country's monetary security from economic shocks. The state of the banking system with self-regulation of market equilibrium in terms of inflation within the limits established by the Central Bank and with the growth of real Gross Domestic Product (GDP) ensures the monetary security of the country. The feedback regulator of market equilibrium regarding inflation is consumer demand, which fluctuates depending on market conditions and the situation of risks and incentives. Based on the sales volume of goods and services produced in the previous time, entrepreneurs determine market conditions, which change in proportion to the situation of risks and incentives in the future, and form the situation of consumer demand for the current period (3, 4). Employment in the economy changes in proportion to demand conditions, which leads to a proportional change in the portion of available capital used in production. Fluctuations in demand conditions lead to periodic fluctuations in the number of workers and the cost of capital used in production, causing fluctuations in the value of real GDP and its nominal value through inflation (3, 4, 7, 9). Nominal consumer demand is determined and limited by the product of the quantity and speed of circulating money, set by the banking system for market self-regulation of inflation within the targeting limits. Ensuring the Central Bank's self-regulation of market equilibrium in relation to inflation requires its measurement, based on the results of which it regulates the country's macroeconomic indicators by changing the quantity and velocity of money. Inflation in macroeconomics during modeling was measured

for about sixty years by the unemployment rate function according to the erroneous Phillips curve, which is still used by central banks of highly developed countries in forecast models to determine the non-existent "optimal" combination of inflation and unemployment. Transformed Phillips curve used in DSGE models (10, 11).

The model of a modern economy with a market exchange rate is analyzed in (12), and the possibilities of banking regulation of macroeconomic processes in (7). The article defines the function of measuring inflation in the country's economy during monetary circulation during the period under review. Section 1 examines the creation of money by the banking system, which ensures the equilibrium of the economy with real consumer demand, a monetary deflator greater than one, and the velocity of money. Section 2 defines the function of inflation from real GDP, the quantity and velocity of money in circulation, and the ratio of cash to demand deposits. Section 3 proves the reason for the emergence of an erroneous Phillips curve of decreasing inflation, which turns into deflation when the unemployment rate increases.

2 Cash formation model in circulation

The creation of money by the banking system is determined by the monetary base H of the Central Bank, loans, and deposits D of commercial banks (CB). The monetary base consists of minimum reserves M_r, excess reserves O_r, and cash M_0:

$$H = M_r + O_r + M0 \tag{1}$$

CBs have demand deposits D_1, time deposits for more than one year D_2, and long-term deposits for more than four years D_3. The money supply available on the country's market during the year has three monetary aggregates: $M1 = M0 + D_1$ –the amount of cash and demand deposits; $M2 = M1 + D_2$; $M3 = M2 + D_3$. Money is created by the banking system when issuing loans, described by the equations of the existing balance ε according to (1) (3, 4, 7, 9):

$$H = M0 + M_r + O_r;\ \ \varepsilon = M3 - H - \Xi \tag{2}$$

With the coefficients established by the Central Bank: $(M_p + \Pi_p)/D_1 = \alpha$–regulatory reserves; $M0/D_1 = \beta$ – the ratio of cash to demand deposits, the creation of money by the banking system is represented according to (1) and (2) equations:

$$H = (\alpha + \beta)D_1;\ \Xi = M3 - H - \varepsilon. \tag{3}$$

Hence, the identity of the amount of circulating money is determined as the product of the credit multiplier $m = (\beta + 1)/(\alpha + \beta)$ and the monetary base H (3, 4, 7, 9):

$$M1 \equiv mH \tag{4}$$

The change in the Central Bank of the money multiplier m and the monetary base H through the change in the reserves of banks $M_r + O_r$ in accordance with (2) and (3) does not affect the amount of cash and demand deposits $M1$. The ratio of nominal GDP ω to real GDP $\mathbf{\Omega}$ is determined by the GDP deflator, i.e., change in price level in the period under review, $P = \omega/\mathbf{\Omega}$. Inflation is determined by a change in the price level relative to the price level of the previous period, taken as a unit, $p = P - 1$ (3, 4, 7–9, 12). The demand for money is determined by the desire of economic entities to have at their disposal the amount of money they need M^D. Equilibrium in the money market is ensured with a demand for money M^D equal to the supply of money M^S. During the period under review, usually a year, producers can receive for the goods sold the amount of money available to consumers, i.e., which determines the monetary demand equal to the nominal GDP,

$$\omega = P_m\bar{\mathbf{\Omega}} \tag{5}$$

where P_m is the money deflator; $\bar{\mathbf{\Omega}}$–real consumer demand [(3), p. 41].

How many times on average per year entrepreneurs $M1$ will receive an income equal to the sum of cash and demand deposits, such will be the speed of money μ circulation in the money circulation, $\mu = \omega/M1$. Hence, the demand of economic entities for money M^D for purchase and sale transactions during the year at the speed of money μ circulation is determined in accordance with (5) by the amount of cash and demand deposits:

$$M^D = M1 = P_m\bar{\mathbf{\Omega}}/\mu \tag{6}$$

Monetary equilibrium is ensured by the equality of the amount of money in the annual circulation $_{M1\mu}$ to monetary demand (5) $_m\bar{\mathbf{\Omega}}$_ with a monetary deflator not less than one (3, 4, 7, 9, 12):

$$M1\mu = P_m\mathbf{\Omega} \text{ at } P_m > 1 \tag{7}$$

With a money deflator less than one, real consumer demand cannot be satisfied without increasing the value of money, so the equilibrium in the money market will be upset. A money deflator measures the value of money in an annual cycle relative to real aggregate demand for goods $\bar{\mathbf{\Omega}}$. According to (6) and (7), the money deflator P_m, changing proportionally the amount of cash and demand deposits $M1$, does not affect the speed of money μ circulation. The real value of money is identical to the ratio of the amount of cash and demand deposits to the money deflator:

$$M^* \equiv M1/P_m \tag{8}$$

According to (6) and (7), the velocity of money in real aggregate demand for goods $\bar{\mathbf{\Omega}}$ is determined only by the real value of money M^* and does not depend on the amount of cash and demand deposits $\breve{I}1$,

$$\mu \equiv \bar{\mathbf{\Omega}}/M^* \tag{9}$$

The speed of circulation of money is regulated by the Central Bank by the interest rate i. The function of the velocity of money circulation on the interest rate is defined in (3, 4, 7, 9, 12) by the formula

$$\mu = \sqrt{2i/\bar{b}} \tag{10}$$

where $\bar{b} = b/\bar{\Omega}$–is the normalized cost of withdrawing money from a bank account, b–is the real cost of withdrawing money from a bank account. A decrease in the interest rate i and an increase in real consumer demand reduce $\bar{\Omega}$ the velocity of money.

3 The function of inflation

Non-inflationary cash $\bar{M}0$, i.e. cash at zero inflation ($p = 0, p = 1$), in the considered period is determined in (4, 12) by the function:

$$\bar{M}0 = \frac{\bar{\Omega}\beta(1-\varphi)^{1/\ln k_0}}{\mu(\beta+1)} \tag{11}$$

where φ is the level of actual unemployment, $1/\ln k_0$ is the coefficient of production technology, $k_0 = K/(\xi N_0)$ is the equilibrium capital intensity of labor, K is the cost of capital loaded in production, ξN_0 is the quantity of people working in the field of production with full employment in the economy, ξ –part of people working in production of the quantity of people working in the economy, N_0 –quantity working in the economy at full employment. The difference between full employment N_0 and the actual quantity of N workers determines the actual unemployment, $f_{\hat{o}} = N_0 - N$, and unemployment rate,

$$\varphi = (N_0 - N)/N_0 \tag{12}$$

The amount of cash $M0$ in the period t under consideration is determined by the Central Bank by regulating inflation p and actions in the foreign exchange market (12). The amount of cash due to actions in the foreign exchange market $M0_{\text{vl}}$ and cash due to the Central Bank's regulation of inflation (inflationary cash) $M0_{\text{i}}$ is equal to the difference between the available cash $M0$ and the available cash $M0_{t-1}$ in the previous $t-1$ period $M0_{\text{vl}} + M0_{\text{i}} = M0 - M0_{t-1}$. Inflationary cash is equal to the difference between available cash $M0$ and non-inflationary cash $\bar{M}0$, i.e., $M0_{\text{i}} = M0 - \bar{M}0$, and equals the difference between available cash $M0$ and available cash $M0_{t-1}$ in the previous $t-1$ period minus foreign currency cash $M0_{\text{vl}}$:

$$M0_{\text{i}} = M0 - \bar{M}0 = M0 - M0_{t-1} - M0_{\text{vl}} \tag{13}$$

If there is a difference in available cash $M0$ and available cash $M0_{t-1}$ in the previous $t-1$ period, less than foreign currency cash, we get negative inflationary cash $M0_{\text{vl}}$, the economy will go into deflation. As a result, we have the sum of foreign currency cash $M0_{\text{vl}}$ and inflation cash $M0_{\text{i}} = M0 - \bar{M}0$ equal to the difference between available cash $M0$ and cash $M0_{t-1}$ in the previous $t-1$ period, that is $M0_{\text{vl}} + M0 - \bar{M}0 = M0 - M0_{t-1}$. From here $M_{\text{vl}} = \bar{M}0 - M0_{t-1}$ and according to (11), currency cash is determined:

$$M0_{\text{vl}} = \frac{\bar{\Omega}\beta(1-\varphi)^{1/\ln k_0}}{\mu(\beta+1)} - M0_{t-1} \tag{14}$$

The functioning of the country's economy is provided by markets for goods, labor, money, and securities. Market equilibrium in the economy is ensured with equilibrium in the markets of goods and money and the presence of unemployment in the labor market (3, 4, 7–9, 12). With equilibrium in all markets, a general market equilibrium sets in. The labor market determines the quantity N of workers in the economy by the interaction of labor demand N^D and labor supply N^S. The function of the optimal labor supply can be taken equal to the quantity N_0 of workers with full employment in the economy (3, 4, 7, 9, 12):

$$N^S[w \geq 12y/(1+n)] = 0,46T \approx N_0 \tag{15}$$

where w–real wage rate, T–is the population of the country, $y = Y_{\text{hh}}/(TP)$ is the real income of households Y_{hh} from capital per one resident of the country, n is the rate of pension contributions (pension tax) on wages.

The value of real GDP produced is approximated by the function of the number of employed ξN and capital loaded in the production sector with the cost K:

$$\Omega = \sigma\, Q = \sigma\, (\xi N)^{1/\ln k_0} K^{1-1/\ln k_0} \tag{16}$$

where Q–is the real aggregate social product, σ is the coefficient of material consumption of production (3, 4, 7, 9, 12).

In the absence of unemployment, $N = N_0$, equilibrium is ensured in the labor market with an equilibrium real wage rate

$$w_0 = k_0/(e \ln k_0) \tag{17}$$

where $e = 2,71828$ is the basis of the natural logarithm. Real consumer demand is measured by real GDP at full employment, that is, according to (16),

$$\bar{\Omega} = \sigma K e^{-1} \tag{18}$$

With the equilibrium in the market of goods, the nominal aggregate consumer demand is equal to the monetary aggregate supply of goods $P\Omega$:

$$\omega = P_{\text{m}}\bar{\Omega} = P\Omega \text{ at } P \geq 1 \tag{19}$$

The ratio of real consumer demand $\bar{\Omega}$ to the real supply of goods Ω determines the production deflator $P_{\text{pr}} = \bar{\Omega}/\Omega$, whence according to (16) we get (3, 4, 7, 9, 12):

$$P_{\text{pr}} = \bar{\Omega}/\Omega = (N_0/N)^{1/\ln k_0} = (1-\varphi)^{-1/\ln k_0} \tag{20}$$

The GDP deflator according to (19) is equal to the product of money and production deflators,

$$P = P_{\mathrm{m}} P_{\mathrm{pr}} \tag{21}$$

With inflation-free consumer demand, $P = 1$, the inflation-free money deflator $\bar{P}_{\mathrm{m}}$ according to (20) and (21) is a function of the unemployment rate φ:

$$\bar{P}_{\mathrm{m}} = (1-\varphi)^{1/\ln k_0} \tag{22}$$

According to (11), (13), (20), and (21), the cash ratio in terms of non-inflationary cash is equal to the GDP deflator:

$$M0/\bar{M}0 = P_{\mathrm{m}}(1-\varphi)^{-1/\ln k_0} = P \tag{23}$$

Hence, according to (13), inflation is determined by the ratio of inflationary cash to non-inflationary cash $p = P - 1 = (M0 - \bar{M}0)/\bar{M}0 = M0_{\mathrm{i}}/\bar{M}0$, i.e. $p = \frac{M0_{\mathrm{i}}}{\bar{M}0} = \frac{(M0 - M0_{t-1} - \lambda S)(1+\beta)\mu}{\bar{\Omega}\beta(1-\varphi)^{1/\ln k_0}}$. From here, after transformation according to (20), we express the inflation function from the amount of cash in circulation, foreign currency cash, velocity of money circulation, cost of capital employed in production, coefficient of material intensity of production, and the unemployment rate:

$$p = \frac{e(M0 - M0_{t-1} - \lambda S)(1+\beta)\mu}{\beta\sigma K(1-\varphi)^{1/\ln k_0}} \tag{24}$$

Inflation is directly proportional to cash in circulation and increases with increasing unemployment, fluctuates according to the cost K capital through investments J and the conjuncture of consumer demand and the velocity of circulation of money. According to (18) and (20), we obtain $\Omega = e^{-1}\sigma(1-\varphi)^{1/\ln k_0}$ and based on (24), we express the inflation function from real GDP, the quantity and velocity of money in circulation, and the ratio of cash to demand deposits:

$$p = \frac{(M0 - M0_{t-1} - \lambda S)(1+\beta)\mu}{\beta\Omega} \tag{25}$$

Inflation decreases with the growth of real GDP, and increases with the increase in the quantity and speed of circulating money. The regulation of inflation by central banks by the interest rate will be expressed according to (25) and (10) by the function:

$$p = \frac{(M0 - M0_{t-1} - \lambda S)(1+\beta)\sqrt{2i/\bar{b}}}{\beta\Omega} \tag{26}$$

When the Central Bank increases the interest rate, according to (6) and (10), the amount of money in circulation decreases $M1 = M0(1+\beta)/\beta = P_\pi\sqrt{0.5\bar{b}/i}$ and inflation decreases.

4 The dependence of inflation on unemployment

If the monetary deflator is equal to one, that is, in the absence of monetary inflation, we obtain, according to (22), (23), the inflation function of the unemployment rate:

$$\bar{p} = (1-\varphi)^{1/\ln k_0} - 1 \text{ at } P_{\mathrm{m}} = 1 \tag{27}$$

Graphs (in percent) of the dependence of inflation $\bar{P}$ on the unemployment rate φ are shown in **Figure 1** with the values of the coefficients of production technology $1/\ln k_0 = 0,1;\ 0,075;\ 0,0666$, which correspond to the rates of real wages at full employment in the economy (17) $w_0 = k_0/(e\ln k_0) = 810;\ 19877;\ 80172$ of conventional unit (cu).

The graphs show that with increasing unemployment φ, inflation increases. With an unemployment rate of 8–10%, inflation is not more than 1.1%, and with an unemployment rate of 15–20%, inflation is not more than 2.3%. An increase in unemployment leads to a decrease in real GDP and an increase in inflation according to (24) and (27).

The change in inflation can be expressed depending on the wage rate W. The nominal wage rate W_t for the current year t can only be determined by the national accounting system as a result of accounting for the year through the GDP deflator and the real wage rate w_t, i.e. $W_t = (1+p_t)w_t$. With the coefficient z_t of changes in the salary tariff rate at the beginning of the current year t compared with the previous one, $w_{Bt} = z_t w_{Bt-1}$, the real salary rate is determined $w_t = z_t W_{t-1}$ (3, 13). This will express the existing dependence of the rate $\breve{W}_t = (W_t - W_{t-1})/W_{t-1}$ of change in the wage rate on inflation $\breve{W}_t = z_t(p_t+1) - 1$. According to (23), there is a dependence in the economy of the rate of change in the wage rate on the level of unemployment, $\breve{W} = zP_{\mathrm{m}}(1-\varphi)^{-1/\ln k_0} - 1$. When $z = 1$ and $P_{\mathrm{m}} = 1$, we obtain the dependence of the rate of change of the wage rate on the unemployment rate $\breve{W} = (1-\varphi)^{-1/\ln k_0} - 1$, the graph of which at the equilibrium wage rate $w_0 = 19877$ *y.e.* is shown in **Figure 1**. The graph shows that the growth rate of the wage rate always increases with increasing unemployment. In economic theory, the erroneous dependence of the rate of change in the wage rate on the unemployment rate, described by the empirical Phillips curve $\breve{W}_{FL} = -0,9 + 9,638\varphi^{-1,394}$, is still used to measure macroeconomic indicators. The Phillips curve $\breve{W}_{Fl}$ graph in **Figure 1** in comparison with the graph $\breve{W}$ shows the erroneous statements of Keynesian theory that entrepreneurs reduce wage rates with increasing unemployment.

The fallacy of allegations of a decrease in the wage rate with increasing unemployment has created a misconception about a decrease in inflation with increasing unemployment, as $\breve{W} = \bar{p}$ at $z = 1$ [(13), p. 141] and $p_{FL} = \breve{W}_{FL} = -0,9 + 9,638\varphi^{-1,394}$ at $z = 1$. However,

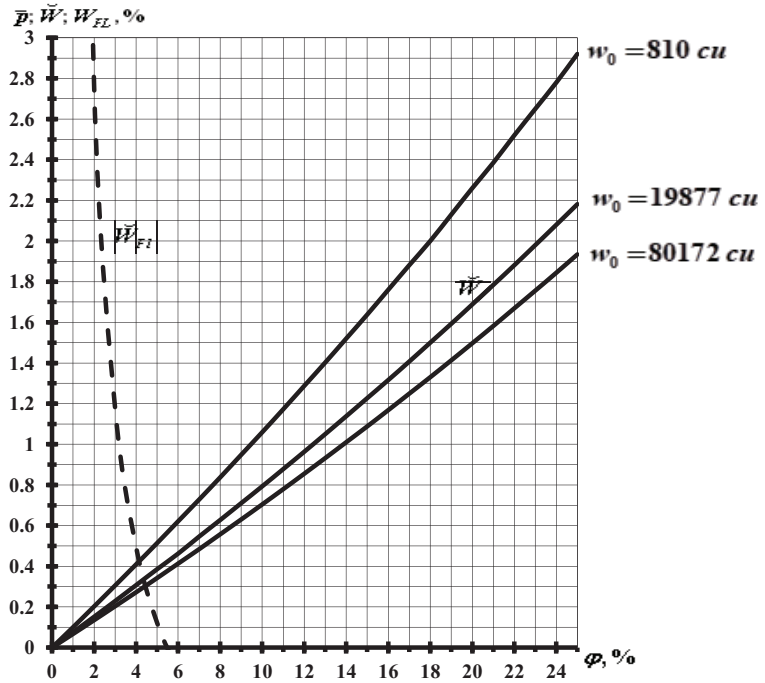

FIGURE 1 | Graphs (in percent) of the dependence of inflation on the unemployment rate.

the central banks of highly developed countries still apply forecasting macroeconomic models that use the Phillips curve to determine the nonexistent "optimal combination" of inflation and unemployment (10, 11). According to (24), (27) and the graph in **Figure 1** an increase in the unemployment rate always causes an increase in inflation.

5 Conclusion

Inflation is determined by the ratio of inflationary cash to non-inflationary cash, is directly proportional to the amount of money in circulation, decreases with the growth of real GDP, and increases with the growth of the velocity of money and unemployment. Although inflation always increases with unemployment, the impact of unemployment on inflation is small, barely exceeding one percent. The reduction of inflation by central banks by increasing the interest rate occurs due to the resulting decrease in the quantity of circulating money.

In economic theory, to measure macroeconomic indicators, the false dependence of a decrease in inflation with an increase in the unemployment rate, described by the transformed empirical Phillips curve, is still used. Central banks use macroeconomic forecasting models that use a false Phillips curve in search of a non-existent "optimal mix" of inflation and unemployment. Regulation of the amount of cash in circulation requires constant monitoring by the Central Bank of the functioning of the foreign exchange market, which determines the amount of cash in foreign currency and changes inflation. It is of interest to study inflation depending on the ratio of cash to demand deposits and the dependence of GDP growth on inflation.

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