DOI 10.1007/s10559-021-00422-1
Cybernetics and Systems Analysis, Vol. 57, No. 6, November, 2021

INFLATION TARGETING MODEL IN MACROECONOMICS

T. I. Iefymenko,[1†] B. B. Dunaev,[1‡] and A. A. Lyubich[1††] UDC 30.101.541-336.7

Abstract. *Empirical targeting by lowering inflation to the marginal level that causes monetary deflation and transition to depression is shown to increase the growth of the real GDP, while increasing inflation from the marginal level reduces the growth of the real GDP. The inflation is determined according to the theory of reproduction of the national economy by the mathematical function of the amount of money in circulation, foreign currency cash, interest rate, the cost of the utilized in production capital, the production input-output coefficient, and the unemployment rate. A model for regulating the economy by inflation targeting is developed, which allows the Central Bank of Ukraine to determine the target indicators for the period under consideration based on the statistical indicators of the previous period and through the nomogram of the inflation function of its arguments. The growth of the Ukrainian economy was modeled with an inflation target of four percent in 2021–2023 after the recession in 2020 caused by the coronavirus pandemic.*

Keywords: *macroeconomics, regulation, market, equilibrium, labor, capital, money, interest rate, exchange rate, crisis, depression, inflation, targeting.*

INTRODUCTION

Economists of many countries have been conducting research on the dependence of economic growth on inflation for many years; however, the obtained results do not allow a mathematical or adequate description of macroeconomic processes. Models constructed based on the empirical Phillips curve, which determined the decline of the salary and wage growth rate with the unemployment level increase, were used as the main tool [1]. Then, the researchers transformed the Phillips curve into an inflation decrease curve that passed into deflation with the unemployment level growth, i.e., during production decline. As stated in [2], a great number if macroeconomic theories developed after the 1930s can be interpreted as different Phillips curve versions. The inaccuracy of the Phillips curve constructed based on the Keynesian theory of the decrease of the salary and wage growth rates with the unemployment level increase was considered and proven in [3–5]. However, with the increase of the unemployment level, the salary and wage growth rate and the inflation always increase simultaneously. According to the Phillips curve, the inflation and unemployment cannot increase simultaneously. "Under these conditions, the Keynesian operations aimed at overcoming the crises were practically setting off the inflation spiral." [4, p. 81]. The macroeconomic models based on the Phillips curves did not provide a concise explanation of the stagnation phenomenon occurring in the beginning of the 1970s and was unable to predict the economic disaster of 2008 and the long-term global systematic financial crisis based on the statistic indicators of the USA for the period of 1960–2006 [3–6]. The absence of an accurate economic growth theory stipulated the search for empiric (practical) means to regulate macroeconomic processes. For example, at the end of 1970s, the rate of the Federal Reserve System was increased by 20% with the simultaneous taxation decrease in order to overcome stagnation.

[1]Academy of Financial Management, Kyiv, Ukraine, [†]*tatiefim@gmail.com*; [‡]*bbdunaev@ukr.net*; [††]*alyubich@ukr.net*.
Translated from Kibernetyka ta Systemnyi Analiz, No. 6, November–December, 2021, pp. 138–148. Original article submitted February 22, 2021.

 1060-0396/21/5706-0968

The unemployment level rose to 10.2% under the inflation of 6–8% during the two reform years. Starting from the end of the 1980s, almost ten developed countries engaged in empirical inflation targeting (IT) as a means for the central banks to regulate economic growth by changing the amount of money in circulation in order to overcome stagnation. The first ones to implement such actions were New Zealand and Canada, joined later by Great Britain, Finland, Switzerland, Australia, and Spain. The IT use became widespread after the global systematic financial crisis of 2008. The IT was used by more than 40 countries, whose share in the world gross domestic product (GDP) was around 60% [6]. Ukraine has been engaging in IT for 6 years [7].

Even more attention was payer to IT because of the economic decline in 2020 as a result of the coronavirus pandemic, which necessitated the search for tools that would renew the growth. The main IT factor is the independence of the Central Bank (CB), its authority to determine the objective inflation indicators, and its accountability in regards to reaching its goals with respect to inflation [6, 7]. The CB informing the legislative body and the national government about the determined inflation goals in the form of its quarterly report, as well as it informing the public about it through publications and mass media statements is paramount. If the inflation is lower than two percent, then it causes and preserves the economic depression, which can lead to deflation. This state can be overcome only by the deflationary spirals of the real GDP variations and the real money cost, which leads to economic and financial disaster because of the sharp decline of the production factors [8]. The high inflation unpredictability disrupts the just revenue distribution, redistributes it arbitrarily from the investors to the debtor, decreases incentives for acquiring financial assets, and hampers economic growth, while the inflation expectations and distrust decrease monetary safety. The monetary safety of a country is determined by the banking system state that causes the market equilibrium self-regulation in accordance with the inflation within the determined by the CB limits, as well as the real GDP growth under the condition of the wider reproduction of the industrial capital [4, 9, 10].

The real economy sector consists out of the production and non-production sphere. The production sphere is a combination of the production system (production), the market, and the banking systems. The market price regulator and feedback, i.e., the inflation, is the consumer demand that changes in accordance with the conjuncture, which is equal to a product of the market conjecture and the risks and stimuli conjecture. Based on the sales volume of goods and services in the previous time, businessmen determine the market conjecture that they change proportionally to the risks and stimuli conjecture for the future and form the consumer demand conjecture for the nearest time period [3, 5, 8]. They change the number of workers proportionally to the consumer demand conjecture and change the coefficient of use of the capital utilized in the capital production [3, 5, 8, 11]. The oscillation of the consumer demand conjecture causes periodic oscillations in the number of workers and the cost of the capital utilized in production. As a result, the consumer demand changes, as well as its cost through inflation [12]. The nominal consumer demand cost is determined as a product of the amount and the speed of the money in circulation determined in the economy by the banking system for the market inflation self-regulation within the given limits. The provision of the market equilibrium self-regulation by the CB necessitates its measurement, according to whose results the macroeconomic indicators of a country are regulated by changing the amount of money in circulation. For the sake of macroeconomy modeling, the inflation was measured for about sixty years by using the unemployment level function by the inaccurate Phillips curve that is still used now by the central banks of highly developed countries in the prediction models in order to determine the non-existent “optimal” combination of inflation and unemployment [13, 14]. The Phillips curve is used when constructing many big DSGE prediction models [14].

The model of the economy functioning under the market exchange rate is studied in [15] and the possibility of banks to regulate macroeconomic processes was considered in [8]. In the open national economy, the inflation is measured by the relation of the inflation cash to the inflationless cash and is a function of the real consumer demand, cash in circulation, interest rate, and unemployment level [8, 10, 15]. In what follows, a model of economic growth regulation by inflation targeting in accordance with its function arguments is described.

INFLATION FUNCTION

The relation of the nominal GDP ω to the real GDP Ω is determined by the GDP deflator $P = \omega / \Omega$. Inflation is determined by the price level change in comparison to the price level of the previous period that is taken to be one, $p = P - 1$ [3, 5, 8, 10–12, 15]. If the GDP deflator is lower than one, deflation takes place. The real GDP variable δ_t is

measured in the last period costs by the relation of the real GDP Ω_t of the period t to the nominal GDP ω_{t-1} of the previous period $t-1$ as follows:

$$\delta_t = \Omega_t / (P_{t-1}\Omega_{t-1}) - 1. \quad (1)$$

The national economic equilibrium in the period t is determined by the real GDP increase, $\delta_t > 0$. The real GDP decrease (i.e., $\delta_t < 0$) is a disturbance of the equilibrium and an economic crisis. To preserve the economy equilibrium, the real GDP in each period has to be higher than the real GDP of the previous period by the product value of the real GDP and the inflation in the previous period, $\Omega_t - \Omega_{t-1} > p_{t-1}\Omega_{t-1}$ for $\delta_t > 0$. The inflation decrease reduces the necessary economy growth level $\Omega_t - \Omega_{t-1}$ and increases the real GDP growth, while the inflation increase slows the real GDP growth. This forms the basis of the economic growth regulation performed by the central banks with the help of the empiric inflation targeting through the change in the money amount in circulation.

The amount of the income $M1$ obtained during the period under study, which is equal to the sum of cash $M0$ and on-demand deposits D_1, $M1 = M0 + D_1$, is equal to the speed of money in circulation μ, $\mu = \omega / M1$. The speed of money in circulation depends on the determined by the CB interest rate i on the demand for the money $M1$ and is determined in [3, 5, 8, 10, 12, 15] by the function

$$\mu = \sqrt{2i / \bar{b}}, \quad (2)$$

where $\bar{b} = b / \overline{\Omega}$ is the normed cost of money withdrawal from a bank account, b is the real cost of money withdrawal from a bank account, and $\overline{\Omega}$ is the real consumer demand.

If the amount of money in circulation $M1$ is present in the system, as well as the relation β of cash $M0$ to on-demand deposits D_1, then the cash in circulation in the analyzed period is determined as $M0 = M1\beta / (1+\beta)$. The cash $M0_{\text{cur}}$ (foreign currency cash) that decreases inflation is spent for foreign currency operations on the domestic market of the country in the period under study. The increase of the amount of cash $M0$ in circulation causes the inflation growth and its spending on the foreign currency cash can cause money deflation. For the exchange rate λ (UAH/USD), the foreign currency cash amount $M0_{\text{cur}}$ necessary to perform foreign currency operations depending on the foreign currency balance $S = \gamma E_e + E_{\text{CB}} + E_{\text{t}} - Z_{\text{CB}} - Z_z$ is determined in [8, 10, 15] as follows:

$$M0_{\text{cur}} = \lambda S = \lambda(\gamma E_e + E_{\text{CB}} + E_{\text{t}} - Z_{\text{CB}} - Z_z), \quad (3)$$

where E_e is the foreign currency gain of exporters, γ is the foreign currency revenue coefficient coming to the market from exporters, E_{CB} is the foreign currency revenue coming to the market from the CB, E_{t} is transfers from abroad and foreign investments, Z_{CB} is the CB foreign currency demand, and Z_z is the demand for the foreign import currency. For the sake of simplicity, we consider the demand for the foreign currency of loan payers S_z, of foreign economy investors U_z, and the population L_z as balanced by the foreign currency supply by foreign loan borrowers S_e, foreign investors U_e, and the population L_e, i.e., $S_z + U_z + L_z = S_e + U_e + L_e$.

The inflationless cash, i.e., the cash under zero inflation ($p = 0$ and $P = 1$) in the period under study is determined in [5, 8, 10, 15] by the following function:

$$\overline{M0} = \frac{\overline{\Omega}\beta(1-\varphi)^{1/\ln k_0}}{\mu(\beta+1)}, \quad (4)$$

where φ is the actual unemployment level, $1/\ln k_0$ is the production technology coefficient, $k_0 = K / \Pi_0$ is the equilibrium capital intensity, K is the cost of the capital utilized in production, $\Pi_0 = \xi N_0$ is the number of production workers under the new population employment in economy, ξ is the percentage of production workers from the number of workers in the economy, and N_0 is the number of workers in the economy under the full population employment. The difference between the full employment and the actual worker number N determines the actual unemployment $f_{\text{a}} = N_0 - N$ and the actual unemployment level

$$\varphi = (N_0 - N) / N_0. \quad (5)$$

The optimal work supply N^S can be considered as such, when it is equal to the full population employment $N_0 \approx N^S [w \geq 12\,\mathbf{и} / (1+n)] = 0.46T$ [3, 5, 8, 10, 15], where w is the real wage rate, $\mathbf{и} = И_{\text{hh}} / (TP)$ is the real household income from the capital per single citizen, T is the population number, and n is the retirement income tax rate; number 12

is determined by a graph of the function N^S / T of the argument $w(1+n)/$ **и** under the optimality condition [3, p. 53, Fig. 10]. From here, the unemployment level is determined in accordance with (5) for the known population number T and the number of workers in the economy N.

The produced real GDP is approximated by the function of the worker number Π and a capital with the cost of K involved in production as follows:

$$\Omega = \sigma Q = \sigma \Pi^{1/\ln k_0} K^{1-1/\ln k_0}, \tag{6}$$

where Q is the real aggregate product and σ is the production input-output coefficient [3, 5, 8, 10, 12 15].

The available in production capital with the cost of K_{pr} is used not completely, but depending on the consumer demand conjuncture proportionally to the utilization coefficient υ, $K = \upsilon K_{\text{pr}}$ [3, 5, 8, 11, 12, 15]. Businessmen regulate the output volumes in the period t in accordance with the sales volume in the previous periods by changing the worker number Π_t according to the worker number in the previous period Π_{t-1} according to the consumer demand conjecture $\Re_t$, $\Pi_t = \Re_t \Pi_{t-1}$ [3, 5, 8, 12, 15]. The consumer demand conjecture is determined by the product of the market conjecture $\Re_{\text{m}}$ and the risks and stimuli conjecture $\mathbb{R}_{rs}$, $\Re = \Re_{\text{m}} \mathbb{R}_{rs}$. Under the condition of free competition, as well as the presence of an unused capital, the market conjecture is determined by the function

$$\Re_{\text{m}\,t} = \delta_{t-1} - \delta_{t-2} + 1, \tag{7}$$

while the risks and stimuli conjecture is determined by the coefficient product $\mathbb{R}_{rs} = \aleph_1 \aleph_2 \aleph_3 \ldots \aleph_m$ of the available factors [3, 5, 8, 12, 15]. The change in the worker number in accordance with the consumer demand conjecture causes the proportional change in the capital utilization coefficient,

$$\upsilon_t = \Re_t \upsilon_{t-1} = \upsilon_{t-1} \Pi_t / \Pi_{t-1}. \tag{8}$$

The cost of the available industrial capital is expressed by the following function [3, 5, 8, 10, 15]:

$$K_{\text{pr}\,t} = P_{t-1} K_{\text{pr}\,t-1} + J_{\text{net}\,t-1} - \Delta_{t-1}, \tag{9}$$

where $J_{\text{net}\,t-1}$ are net investments and Δ_{t-1} is the capital underdepreciation in the $t-1$ period.

The real consumer demand is measured by the real GDP under the full population employment $N = N_0$, i.e., in accordance with (6) as follows:

$$\overline{\Omega} = \sigma K e^{-1}, \tag{10}$$

where $e = 2.71828$ is the natural logarithm base.

Under the condition of equilibrium on the goods market, the nominal consumer demand $P_{\text{mn}} \overline{\Omega}$ is equal to the monetary aggregate supply of goods and services $P\Omega$ as follows:

$$\omega = P_{\text{mn}} \overline{\Omega} = P\Omega \text{ for } P \geq 1. \tag{11}$$

The equilibrium on the monetary market is possible under the condition that the amount of money in circulation during the examined period $M1\mu$ is equal to the nominal consumer demand $P_{\text{mn}} \overline{\Omega}$, when the money deflator is no less than one [3, 5, 8, 10, 12, 15] and is as follows:

$$M\mu = P_{\text{mn}} \overline{\Omega} \text{ for } P_{\text{mn}} \geq 1. \tag{12}$$

If the money deflator is less than one, then the nominal consumer demand cannot be satisfied without increasing the money cost; thus, the equilibrium on the monetary market is disrupted and the monetary deflation takes place $p_{\text{mn}} = P_{\text{mn}} - 1 < 0$. The market equilibrium is ensured in the economy under the condition of an equilibrium on the monetary and goods and services markets, as well as the unemployment existence on the labor market [3, 5, 8, 10–12, 15–17]. The relation of the real consumer demand $\overline{\Omega}$ to the real supply of goods and services Ω determines the production deflator $P_{\text{pr}} = \overline{\Omega} / \Omega$; from there, in accordance with (6) and (5), we obtain

$$P_{\text{pr}} = \overline{\Omega} / \Omega = (N_0 / N)^{1/\ln k_0} = (1-\varphi)^{-1/\ln k_0}. \tag{13}$$

In accordance with (11), the GDP deflator is equal to the product of the monetary and production deflators

$$P = P_{\text{mn}} P_{\text{pr}}. \tag{14}$$

The real GDP variation depending on the inflation is determined by deflationary spirals [8]. The dependence of the real GDP variation on the GDP deflator in the period $t-1$ is obtained in accordance with (1), (6), (8), and (9) as follows:

$$\delta_t = \frac{\sigma_t (\Pi_{t-1} \Re_t)^{1/\ln k_{0t}}}{P_{t-1}^{1/\ln k_{0t}} \Omega_{t-1}} \{\upsilon_{t-1} \Re_t [K_{\text{pr}\,t-1} + (J_{\text{net}\,t-1} - \Delta_{t-1}) / P_{t-1}]\}^{1-1/\ln k_{0t}} - 1. \quad (15)$$

From here, it follows that the highest GDP growth for the empirical inflation targeting takes place if the GDP deflator is equal to one, i.e., the inflation in the previous period $t-1$ is equal to zero. A zero inflation cannot exist in the real economy, as it takes place in accordance with (5), (13), and (14) only in the case, when the monetary inflation and the real unemployment values are equal to zero. An inflation that is less than 2% with the ever present real unemployment stipulates a boundary monetary deflation $(1-\varphi)^{1/\ln k_0} - 1 < \overline{p}_{\text{mn}} < 0$ that causes and preserves the economic depression with the real GDP growth of no more than 2% [5, 8, 12, 15]. For example, the depression taking place in the Austrian economy could cause an economic growth by 1.6% a year in the period of 2019–2023 (1.8% growth in 2014–2018), which significantly exceeds the average indicators in the eurozone [18, p. 224]. Under the condition of the expanded reproduction of the utilized in production capital, the economic depression can be long-term if the CB upholds the boundary money deflation. The empirical inflation targeting by reducing it to the marginal level causes monetary deflation and a transition into depression, lowering the economic growth necessary for the economic growth equilibrium, thus, raising the real GDP growth that depends on the inflation in the previous period to one percent in accordance with (15). The inflation increase to the marginal level reduces the real GDP growth to one percent as well.

Given that $M1 = M0(1+\beta)/\beta$, we obtain $M0 = P_{\text{mn}} \overline{\Omega} \beta / [\mu(1+\beta)]$ in accordance with (8), while the GDP deflator in accordance with (13) and (14) is equal to the relation of the cash in circulation $M0$ to the inflationless cash $\overline{M}0$ in accordance with (4) as follows:

$$M0 / \overline{M}0 = P_{\text{mn}} (1-\varphi)^{-1/\ln k_0} = P. \quad (16)$$

The necessary cash amount $M0$ in the period under study t is determined by the CB by regulating the inflation p and the actions on the foreign currency market in accordance with (3). The sum of foreign currency cash $M0_{\text{cur}}$ and the cash obtained through inflation regulation (inflation cash) $M0_{\text{inf}}$ is equal to the difference of the available cash $M0$ and the cash $M0_{t-1}$ in the last period $t-1$, $M0_{\text{cur}} + M0_{\text{inf}} = M0 - M0_{t-1}$. The inflation cash is equal to the difference of the available cash and the cash under the condition of the inflationless consumer demand

$$M0_{\text{inf}} = M0 - \overline{M}0 = M0 - M0_{t-1} - M0_{\text{cur}}. \quad (17)$$

Taking into account (16) and (17), let us determine the inflation as follows: $p = P - 1 = (M0 - \overline{M}0) / \overline{M}0 = M0_{\text{inf}} / \overline{M}0$. Let us obtain the dependence of the inflation on cash, as well as the relation of cash to the on-demand deposits, the foreign currency cash, the interest rate, the real consumer demand, and the unemployment level in accordance with (17), (4), and (3) as follows:

$$p = \frac{M0_{\text{inf}}}{\overline{M}0} = \frac{(M0 - M0_{t-1} - \lambda S)(1+\beta)\sqrt{2i/\overline{b}}}{\overline{\Omega}\beta(1-\varphi)^{1/\ln k_0}}.$$

From here, after the respective transformation in accordance with (10), let us determine the inflation function of cash, as well as the relation of cash to the on-demand deposits, the production input-output coefficient, the foreign currency cash, the interest rate, the cost of the utilized in production capital, the production input-output coefficient, and the unemployment level as follows:

$$p = \frac{(M0 - M0_{t-1} - \lambda S)(1+\beta)\sqrt{2i/\overline{b}}}{\beta\sigma K(1-\varphi)^{1/\ln k_0}}. \quad (18)$$

ECONOMIC GROWTH REGULATION MODEL BASED ON INFLATION TARGETING

To obtain target values of (18) for a medium cycle, at the beginning of the year under study t, the statistical data of the last year $t-1$ on the population number T, the production input-output coefficient σ, the cash amount $M0_{t-1}$,

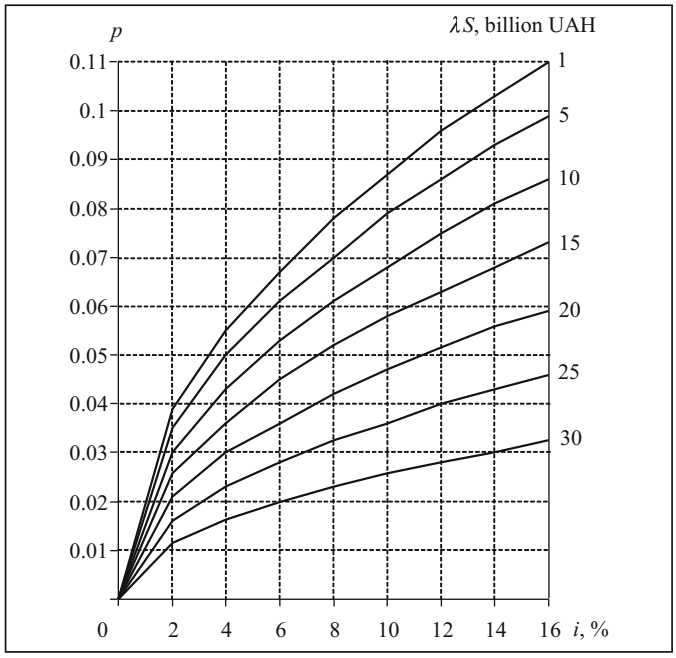

Fig. 1. The inflation function p of the interest rate i and the foreign currency cash λS in 2019.

the value of the available industrial capital $K_{\text{pr}\,t-1}$, the number of workers in production Π, and the percentage of workers in production from the number of workers in the economy ξ has to be accounted for. By determining the inflation target values for the year under study t, the Central Bank can construct a nomogram of the inflation function p in accordance with (18) depending on variations of its available regulation tools, such as the interest rate i and the foreign currency cash $M0_{\text{cur}} = \lambda S$ under the condition of the presence of the money amount in circulation $M1$, the relation of cash to the on-demand deposits β, the cost of the utilized capital K, the production input-output coefficient σ, and the production technology coefficient $1/\ln k_0$.

Figure 1 depicts a nomogram of the feasible inflation values of the Ukrainian economy with the presence of the following indicators according to the statistical data from [19] for 2019 [8, Table 1]: $T = 41.9$ million people, $N = 15.107$ million people, $M0_{2018} = 374.35$ billion UAH, $\sigma = 0.45$, $K = 22346.28$ billion UAH, $1/\ln k_0 = 0.0702$, $\varphi = 0.216$, as well as the normed cost of money withdrawal from a bank account $\bar{b} = 0.01$. With the available in 2019 values of $M1_{2019} = 832$ billion UAH and $\beta = 1.25$ and by changing the tools of the National Bank of Ukraine (NBU) to regulate the inflation, namely, the interest rate $i = 0$–16% and the foreign currency cash amount $\lambda S = 1$–30 billion UAH, we can calculate the inflation value in accordance with (18) $p = 0.000474(42.15 - \lambda S)\sqrt{200i}$ and to construct the inflation function nomogram.

From the nomogram in Fig 1, it follows that with the available $M1_{2019} = 832$ billion UAH, $\beta = 1.25$, the inflation $p = 0.082$, and the interest rate $i = 14\%$ in the banking system in 2019, $\lambda S = 9.5$ billion UAH of foreign currency cash is necessary, and with the presence of the foreign cash currency $\lambda S = 30$ billion UAH and the interest rate $i = 9\%$, the inflation decreases to $p = 0.024$. The linear interpolation of the calculated values is possible in the nomogram framework. In the case of the inflation target of 5% with the presence of the foreign currency cash of 5 billion UAH, it is necessary that the interest rate is 4%. For a different amount of the money in circulation $M1$, the CB has to construct a corresponding nomogram and make decisions concerning the target values of inflation targeting based on the analysis results.

Under the developed method of economic growth, Table 1 shows the target indicators of the inflation targeting in 2021–2023 in the case of overcoming the decline of 2020 stipulated by the coronavirus pandemic.

TABLE 1

Economic Indicators	Feasible Economic Indicators per Years				
	2019	2020	2021	2022	2023
	Output Data				
Population T, million people	41.9	41.7	41.5	41.3	41.1
Results of Modelling					
Production capital K_{pr}, billion UAH	27251.2	29777.25	33313.64	35408.71	37660.1
Market conjecture $\Re_{\text{m}}$	1.02	1	0.928	1.066	1.033
Risks and stimuli conjecture $\mathbb{R}_{rs}$	1	0.95	1.09	0.98	1
Consumer demand conjuncture $\Re$	1.02	0.95	1.012	1.044	1.033
Production workers Π, million people	11.46	10.89	11.02	11.505	11.88
Capital utilization coefficient υ	0.827	0.786	0.795	0.83	0.857
Utilized capital K, billion UAH	22438.00	23394.5	26484.34	29389.23	32274.7
Workers in economy N, million people	15.28	14.52	14.69	15.34	15.84
Equilibrium labor N_0, million people	19.274	19.182	19.09	19.00	18.906
Actual unemployment level φ	0.207	0.243	0.23	0.193	0.162
Technology coefficient $1/\ln k_0$	0.0701	0.0699	0.0693	0.0688	0.0683
Real GDP Ω, billion UAH	3659.52	3799.31	4305.38	4792.68	5280.00
Real consumer demand $\overline{\Omega}$	3714.91	3872.86	4384.37	4865.26	5342.94
Real GDP variation δ, %	3.2	-4.0	2.65	6.0	4.9
Production deflator P_{pr}	1.016	1.0196	1.0183	1.015	1.0119
Target Values Based on the Targeting Nomogram					
Circulation money $M1$, billion UAH	747.53	1050	1300	1590	1942
Relation of cash to on-demand deposits β	1.25	1.27	1.25	1.2	1.15
GDP deflator P	1.081	1.104	1.05	1.05	1.04
Interest rate i	14	8	6	5	4
Money circulation speed μ	5.292	4	3.464	3.162	2.828
Foreign currency cash $M0_{\text{cur}} = \lambda S$, billion UAH	11.383	113.58	100	104.76	131.16
Nominal GDP ω, billion UAH	3955.95	4194.1	4520.65	5032.31	5491.00
Real gross product Q, billion UAH	8795.707	9267.13	10007.11	11182.9	12202
Production input-output coefficient σ	0.45	0.45	0.45	0.45	0.45
Monetary deflator P_{mn}	1.065	1.083	1.031	1.034	1.025
Net investments J_{net}, billion UAH	431.4	556.53	561.79	628	679.2
Capital underdepreciation Δ, billion UAH	112.7	116.97	132.4	147	161.37
Available cash $M0$, billion UAH	417.67	587.44	722.22	867.27	1038.74
Inflationless cash $\overline{M}0$, billion UAH	385.73	531.25	689	826.98	998.43
Inflation cash $M0_{\text{inf}}$, billion UAH	31.94	56.19	32.22	40.29	40.31

Under the operation model of the open national economy proposed in [8, 15] and by taking account of the statistical indicators of 2019 and 2020 [19–23] in accordance with (9), the value of the available industrial capital in 2021 $K_{\text{pr}} = P_{t-1}K_{\text{pr 2020}} + J_{\text{net 2020}} - \Delta_{2020} = 33313.64$ billion UAH is determined and the market conjecture in accordance

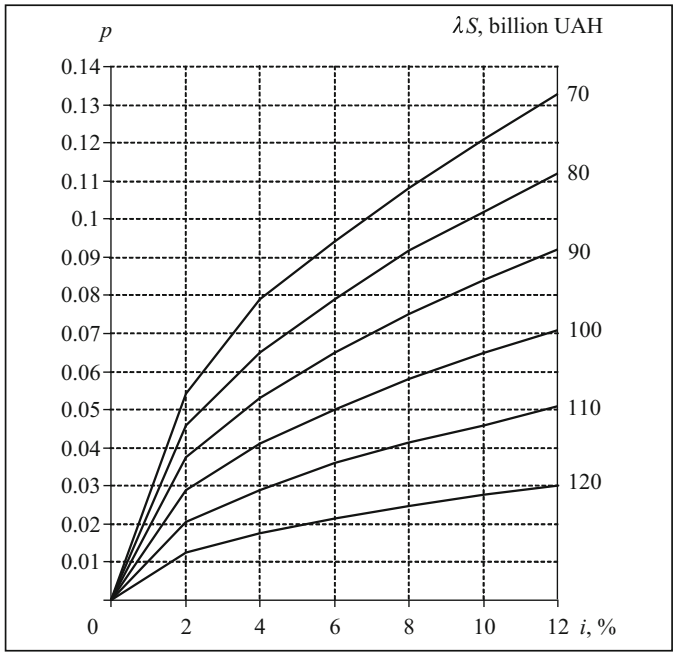

Fig. 2. The inflation function p of the interest rate i and the foreign currency cash λS in 2021.

with (7) $\Re_{\text{m}} = \delta_{2020} - \delta_{2019} + 1 = 0.928$ is determined based on the variation in the real GDP δ. The measures undertaken by the government concerning the industrial potential renewal, the revival of the defense, aviation, shipbuilding, and other industries, as well as the construction of infrastructure allows for the provision of the risks and stimuli conjecture $\mathbb{R}_{rs} = 1.09$ in 2021 and allows us to obtain the consumer demand conjecture $\Re = \Re_{\text{m}} \mathbb{R}_{rs} = 1.012$. In accordance with the statistical data of 2020, we determine by the consumer demand conjuncture of 2021 the number of workers $\Pi = \Pi_{2020} \Re = 11.02$ million people, the capital utilization coefficient $\upsilon = \upsilon_{2020} \Re = 0.795$, and the cost of the utilized capital $K = \upsilon K_{\text{pr}} = 26484.34$ billion UAH. The number of workers in the economy $N = \Pi / \xi = 14.69$ million people and the number of workers under the full population employment in the economy $N_0 = 0.46T = 19.09$ million people, the production technology coefficient $1/\ln k_0 = 1/\ln[K/(\xi N_0)] = 0.0693$, and the real unemployment level $\varphi = (N_0 - N)/N_0 = 0.23$ are determined. The real GDP is calculated in accordance with (6) $\Omega = \Pi^{1/\ln k_0} K^{1-1/\ln k_0} = 4305.38$ billion UAH, the real consumer demand is calculated in accordance with (10) $\overline{\Omega} = \sigma K e^{-1} = 4384.37$ billion UAH, and the production deflator is calculated in accordance with (13) $P_{\text{pr}} = \overline{\Omega}/\Omega = 1.0183$. The real GDP increase is determined in accordance with (1) $\delta = \Omega / \omega_{t-1} = 2.65\%$. Under the available indicators of 2021 $M1_{2020} = 1050$ billion UAH, $\sigma = 0.45$, $K = 26484.34$ billion UAH, $1/\ln k_0 = 0.0693$, $\varphi = 0.23$, $M1_{2021} = 1300$ billion UAH, $\beta = 1.25$, and $\bar{b} = 0.01$, we determine the inflation function from the interest rate and the foreign currency cash in accordance with (18) $p = 0.0004185\ (134.78 - \lambda S)\sqrt{200i}$. By changing the inflation regulation tools, i.e., the interest rate $i = 0$–12% and the foreign currency cash $M0_{\text{cur}} = \lambda S = 70$–$120$ billion UAH, the nomogram of the inflation function presented in Fig. 2 can be constructed and the target values of the inflation, the interest rate, and the foreign currency cash for 2021 can be determined.

In accordance with the nomogram (Fig. 2), let us determine based on the inflation target value $p = 0.05$ the interest rate $i = 6\,\%$ and the currency rate $M0_{\text{cur}} = \lambda S = 100$ billion UAH, as well as determine based on the inflation target value $p = 0.06$ the interest rate $i = 8\,\%$ and the currency rate $M0_{\text{cur}} = \lambda S = 98$ billion UAH. The target values are $p = 0.05$, $i = 6\%$ and $M0_{\text{cur}} = \lambda S = 100$ billion UAH. Based on the GDP deflator $P = 1 + p = 1.05$, let us determine the nominal GDP $\omega = P\Omega = 4520.65$ billion UAH and the money deflator based on (11) and (13) $P_{\text{mn}} = P / P_{\text{pr}} = 1.031$. Under the modeling conditions, the net investment regulated by the government has the value $J_{\text{net}} = 0.3(\omega - 0.1K) = 561.79$ billion

UAH and the capital underdepreciation is $\Delta = 0.005K = 132.4$ billion UAH. Let us determine the money circulation speed $\mu = 3.464$ in accordance with (2), as well as the money amount in circulation $M1 = \omega / \mu = 1305$ billion UAH and cash $M0 = M1\beta / (1+\beta) = 722.22$ billion UAH. Let us calculate the inflationless cash in accordance with (4) $\overline{M}0 = 689$ billion UAH and the inflation cash based on (17) $M0_{\text{inf}} = 32.22$ billion UAH. The precise amount of the foreign currency cash is determined for the target values $p = 0.05$ and $i = 6\%$ in accordance with (17) $M0_{\text{cur}} = \overline{M}0 - M0_{t-1} = 101.56$ billion UAH. Based on the indicators of 2021 and the available indicators of 2020, let us determine the indicators of 2022 with the inflation target of 5% and the real GDP growth of 6%, and then the indicators of 2023 with the inflation target of 4% and the real GDP growth of 4.9%.

CONCLUSIONS

The empirical inflation targeting based on target values is a widespread tool regulating the real GDP growth utilized by central banks. The inflation decreases to the marginal level, which causes monetary deflation and a transition to depression decreasing the economic growth necessary for the equilibrium, thereby, increasing the real GDP growth that depends on the inflation in the last period. The inflation increase from the marginal level decreases the real GDP growth to the boundaries of a single percent.

According to the theory of national economy reproduction, the inflation is determined by the mathematical function of the amount of cash in circulation, the relation of cash to the on-demand deposits, the foreign currency cash, the interest rate, the cost of the utilized in production capital, the production input-output coefficient, and the unemployment level.

The developed model of economic growth regulation through inflation targeting allows us to determine the target macroeconomic indicators for the period under study based on the macroeconomic indicators of the last period and an inflation function nomogram of its arguments for the medium-term in comparison to the empiric inflation targeting.

The performed modeling of the economic growth of Ukraine in 2021–2023 after the real GDP decrease in 2020 as a result of the coronavirus pandemic demonstrated the simplicity and the convenience in using an inflation function nomogram. Under the expanded reproduction of the available in production capital regulated by the government and the monetary security ensured by the NBU, the inflation target value can reach 5% in 2021 and 2022 with the real GDP growth by 2.56 % and 6 %, respectively, and the inflation target value can reach 4% with the real GDP growth by 4.9% in 2023.

REFERENCES

1. A. W. Phillips, “The relationship between unemployment and the rate of change of money wage rates in the United Kingdom, 1861–1957,” Economica, Vol. 25, Iss. 100. P. 283–299 (1958).
2. R. Barro and V. Grilli, Macroeconomics, Europaische Perspective, Munchen (1996).
3. B. B. Dunaev, Well-Being: Labor, Capital, and Money. Fundamentals of the Theory of Reproduction [in Russian], Interdruk, Kyiv (2013).
4. T. Yefymenko, Fiscal and Monetary Security of the National Economy [in Ukrainian], Kyiv: DNNU “Akad. Fin. Upravlinnya” (2016).
5. B. B. Dunaev, “Non-inflationary consumer demand,” Cybern. Syst. Analysis, Vol. 52, No. 4, 588–599 (2016). https://doi.org/10.1007/s10559-016-9861-y.
6. R. Murphy, “Explaining inflation in the aftermath of the Great Recession,” J. of Macroeconomics, Vol. 40, Iss. C, 228–244 (2014).
7. B. Danylyshyn, “Six years of inflation targeting in Ukraine: what to think about?,” URL: https://lb.ua/blog/bogdan_danylysyn/491781_shist_rokiv_inflyatsiynogo.html.
8. B. B. Dunaev, “Banking regulation of macroeconomic processes,” Cybern. Syst. Analysis, Vol. 57, No. 1, 108–123 (2021). https://doi.org/10.1007/s10559-021-00334-0.
9. T. Iefymenko, “Fiscal regulation of national economies’ sustainable growth,” Sci. Innov., Vol. 16, No. 5, 20–35 (2020). https://doi.org/10.15407/scine16.05.020.

10. B. Dunaev, “Regulation of inflation in macroeconomics,” Nauk. Pr. NDFI, No. 4, 80–94 (2020).
11. J. D. Sachs and F. B. Larrain, Macroeconomics in the Global Economy, Prentice Hall, Englewood Cliffs (1993).
12. B. B. Dunaev, “Dynamics of economic cycles,” Cybern. Syst. Analysis, Vol. 53, No. 2, 293–307 (2017). https://doi.org/10.1007/s10559-017-9929-3.
13. M.-A. Gosselin and R. Lalonde, “MUSE: The bank of Canada new projection model of the U.S. economy,” Technical Report No. 96, Bank of Canada (2005).
14. S. Nazir, S. Saeed, and A. Muhammad, “Threshold modeling for inflation and GDP growth,” MPRA Paper 79649, University Library of Munich, Germany (2017).
15. B. B. Dunaev and A. A. Lyubich, “A model of economy operation under currency market rate,” Cybern. Syst. Analysis, Vol. 56, No. 1, 126–138 (2020). https://doi.org/10.1007/s10559-020-00228-7.
16. V. M. Gorbachuk, Macroeconomic Methods [in Ukrainian], Alterpress, Kyiv (1999).
17. V. M. Gorbachuk, Macroeconomic Methods: Theories and Application [in Ukrainian], Kyi, Kyiv (2000).
18. J. Baumgartner, S. Kaniovski, and H. Pitlik, “Update der mittelfristigen Prognose der Österreichischen Wirtschaft 2019 bis 2023,” WIFO Monatsberichte, Vol. 92(4), 221–230 (2019).
19. “Monetary-credit and financial statistics,” URL: http://www.bank.gov.ua.
20. World Economic Outlook Database. October 2020 IFM. URL: https://www.imf.org/external/pubs/ft/weo/2019/02/weodata/index.aspx.
21. “Economic statistics /2019/2020, National accounts,” URL: http://ukrstat.gov.ua/operativ/menu/menu_u/nac_r.htm.
22. “The cost of fixed assets in consolidated national accounts,” URL: https://ukrstat.org/uk/operativ/operativ2007/ibd/voz/voz_u/voz06_u.htm/.
23. “Money supply M0, M1, M2, M3 in Ukraine,” URL: https://take-profit.org/statistics/money-supply-m1/ukraine/.