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The Importance of Calculating the Potential Gross Domestic Product in the Context of the Taylor Rule

A b s t r a c t. Taylor stated humorously that his rule was so easy that it could be written down on the back of a business card. The reality shows that the practical use of this type of rule implies accepting many assumptions about its final shape. The article mentions only the matter of influence of calculating the potential GDP and output gap on the empirical relevance of the Taylor rule. Two ways of calculating potential GDP were presented, i.e. the HP filter and linear trend of the current and the real GDP both seasonally adjusted (an additive model with seasonal dummies; TRAMO/SEATS procedure).

K e y w o r d s: Taylor rule, output gap.

1. Introduction

While the opinion that the central bank's actions can influence both inflation and the economy's real sphere is common, the economic reality shows, however, that precise specification of their effects is difficult for decision-makers. There is not one specific answer to the question how to run the monetary policy. The decision-makers should take into account the fact that good monetary policy must be more transparent, coherent and understandable for participants of the economic life. That is the reason why a possibility of basing the monetary policy on a certain rule has been recently often considered. It does not mean, however, that calculation of the interest rate should be carried out in the mechanical way. It is rather generally about outlining certain frames which could acquaint economic subjects with the essence of the interest rate policy.

Enhancing the monetary policy lies in taking into account the complementary elements of so called Taylor's triangle, consisting of the direct inflation targeting strategy, the floating rate of exchange and the rule of the monetary policy understood as some plan of action (Wojtyna, 2004).

The Taylor rule, which is most popular among researchers, belongs to the category of instrument rules[1], which means that it determines the interest rate considering only current values of variables: the output gap and the difference between inflation and the inflationary target (Żyżyński, 2006). The rule of the monetary policy considered in this paper is a classic Taylor rule represented by the formula (Taylor, 1993)[2]:

$$i_t = \alpha + \beta_1 \pi_t + \beta_2 y_t + \varepsilon_t,$$
$$\alpha = r^* - 0{,}5\pi^*, \tag{1}$$

where: i – interest rate, π - the rate of inflation, π^* – the predetermined rate of inflation (inflation target), r^* – the real interest rate responding to the level of full employment, y – the output gap as the percentage deviation of real GDP (Y) from potential GDP (Y^*), hence:

$$y = \left(\frac{Y - Y^*}{Y^*} \right) \cdot 100. \tag{2}$$

Parameters β_1 and β_2 should be positive, what more the parameter β_1 should be higher than one ($\beta_1 > 1$) in order to treat the Taylor rule as a nominal anchor for inflation and expectations. In other words, the nominal interest rate should rise more than one-for-one with an increase in inflation above inflation target. Only in that case, real interest rate is positive, when inflation is above the target.

2. Seeking the Optimal Taylor Rule

Generally, it is assumed that a good rule should characterize itself by its simplicity, be commonly comprehensible, durable and valid. It is also important to announce a rule in advance, in order to inform about it the highest possible number of economic subjects. According to J. B. Taylor (2000) a monetary policy rule is just "some emergency plan defining in the most coherent way the circumstances in which the central bank should make changes in the monetary policy instrument".

The rule suggested by Taylor has a specific form which has been modified for years. At present, there is no agreement among researchers on applied measures of inflation and output gap, types of data, degree of rule complexity or even weights attributed to inflation and the gap. Thereby, the differences occur-ring in empirical studies make impossible to compare the results. The types of

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[1] Basically, the rules of the monetary policy are divided into instrument rules and targeting rules which characterize decision makers' aim in more general categories.

[2] Taylor has suggested a function of reaction which describes well the FED monetary policy in 1987-92, in which federal funds' rate is lifted or lowered according to inflation's deflection from the aim of inflation and the size of the output gap. The β_1 and β_2 parameters amounted to 1.5 and 0.5, respectively.

problems with empirical verification of the Taylor rule and some of its modifications are shown in Figure 1.
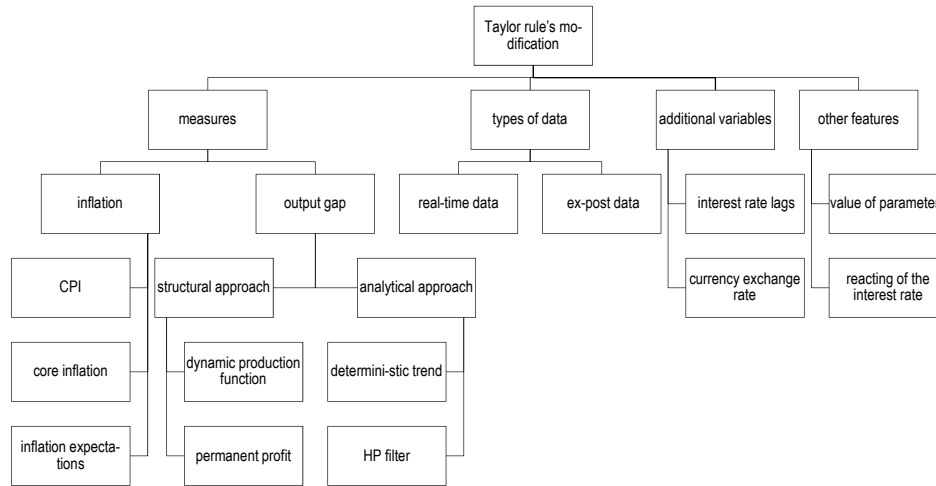

Figure 1.   Types of the Taylor rule's modification

It is important to mention that not all of the variants of the monetary policy rules were shown here. The chart was limited only to the most often estimated types of the Taylor rule. There are researches, who consider different interest rate measures. Economists use both the official interest rates of central banks and short-term market rates[3].

Many different combinations regarding the performance of monetary policy rule exist. This paper is restricted only to the selected measure of output gap, taking the consumer price index, CPI, as a measure of inflation, and the central bank reference rate – as a measure of interest rate.

In practice, the measuring of the level and growth rate of potential GDP can be inaccurate. There is no one recommendation how to estimate the potential GDP because of its unobservability. Taking into account the unobservability of the potential GDP, there is no fixed and recommended measuring method. The evidence of that may be the numerous works on calculating the output gap for Poland, in which the results vary greatly (compare: Gradzewicz, Kolasa, 2004; Petru, Mrowiec, 2005; Białkowski, Rosiak-Lada, Zwiernik, Żochowski, 2007). The HP filter beside the trend function is one of the most used empirical techniques by researches who deal with the calculation of potential GDP in the context of the Taylor rule. The Hodrick-Prescott filter and the deterministic trend are easier in comparison with structural methods, but they do not take into ac-

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[3] While the rate of open market's short-term operations influences mostly market interest rates short term maturity. Long-term instruments are shaped under the market participants' expectations.

count structural changes occurring in the economy. However, the use of the Cobb-Douglas dynamic function requires availability of quarterly data on the real level of fixed assets which are not published by Central Statistical Office (CSO) and accepting many assumptions referring to data calculation, that may deform the final result (see: Gradzewicz, Kolasa, 2004).

The aim of this paper is to evaluate the influence of different methods of calculating the potential GDP on estimation of the parameters of Taylor rule. Methods of estimating the potential GDP resting on the smoothing of the real GDP using Hodrick-Prescott filter and the linear trend are presented. Author tests the hypothesis that Poland's Monetary Policy Council sets the interest rate according to the Taylor rule.

3. Empirical Analysis for Poland

In the study the following data were used: quarterly GDP data, CPI – the indicator of goods' prices and consumer services (corresponding period of previous year=100) published by CSO and the level of the NBP reference rate (from the end of a quarter). Two not seasonally adjusted GDP series were based: current GDP (current prices in billions PLN) and real GDP – nominal GDP corrected by the change in prices, expressed in annual average fixed prices from the previous year. The GDP deflator is utilized as a measure of the proportional change in prices of all goods and services and is published annually by CSO. Using this procedure presented in the paper *CSO information on quarterly Gross Domestic Product estimate*[4] enabled to calculate the price deflators for the period I quarter of 1998 – IV quarter 2007, where:

$$\begin{array}{l} GDP\ delator \\ ith\ quarter\ 1998 \end{array} = \dfrac{\begin{array}{l} GDP\ nominal\ dynamics\ ith\ quarter\ 1998 \\ (current\ prices) \end{array}}{\begin{array}{l} GDP\ real\ dynamics\ ith\ quarter\ 1998 \\ (annual\ average\ prices\ from\ the\ previous\ year) \end{array}}$$

Quarterly data consist of 40 observations. The sample covers the period from I quarter of 1998 to IV quarter 2007. Data are presented in Figure 2.

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[4] http://www.stat.gov.pl/gus/45_1437_PLK_HTML.htm (18. 01. 09). It is important to notice that CSO publishes the annual GDP deflator. The way of calculating the quarterly GDP price indicators presented in the work is correct because the geometric average from the quarterly GDP price indicators for following years is equal to the annual GDP price indicators published by CSO.
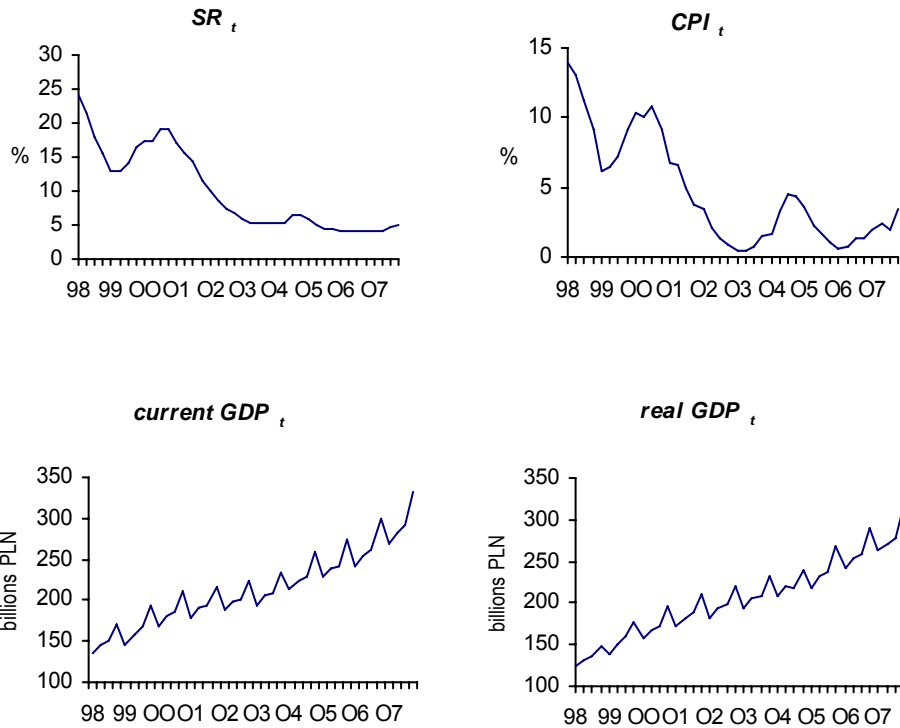
Figure 2. Reference rate SR_t and CPI_t, current GDP_t, real GDP_t in Poland over the period 1998–2007

Behavior of current and real GDP in Figure 2 indicates the occurrence of seasonal fluctuations. There is no one recommended method of eliminating seasonal fluctuations. For seasonal adjustment of time series, the CSO uses the TRAMO/SEATS method. In this paper the procedure recommended by CSO as well as the method including seasonal dummies (the additive model with seasonal dummies, where $Q_{it}^* = Q_{it} - Q_{mt}$) are used. Only for the real GDP process slightly difference between the methods of seasonal adjustment in IV quarter of 1998 is observed (see Figure 3). It is assumed that this difference will influence substantially the GDP gap series obtained at a later stage. Seasonally adjusted real GDP time series are presented in Figure 3.
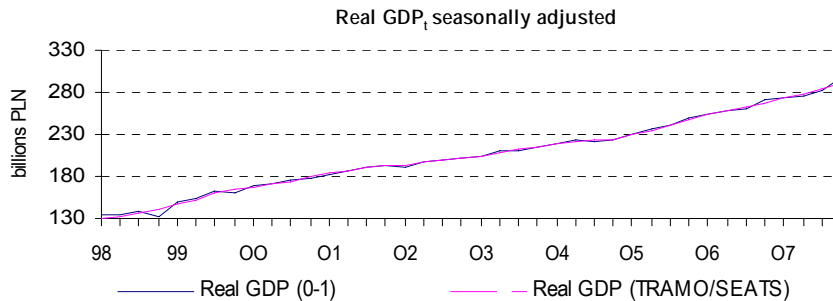
Real GDP_t seasonally adjusted

Figure 3. Real GDP_t seasonally adjusted in Poland over the period 1998–2007

In order to apply the Taylor rule, the assumptions concerning the real interest rate r^*, the inflationary target and the method of estimating the output gap should be taken.

The real interest rate is treated as fixed, i.e. during the period 1998–2007 it took the value from the interval (3%–6.6%) (Brzoza-Brzezina, 2003)[5]. The inflationary target in 1998 was equal to 9.5%. Since 1999 an obligatory long-term target at 4 percent level was applied which was supposed to be reached by the end of 2003. Since 2004 the inflationary target was equal to 2.5%.

For calculating potential GDP the Hodrick-Prescott filter was used as well as the linear trend model for current and real GDP (seasonally adjusted using TRAMO/SEATS procedure and seasonal dummies). In the case of the HP filter the standard value of parameter λ was taken at the basic level for quarterly data, i.e. (Hodrick, Prescott, 1980). After obtaining the potential GDP the output gap (GDP gap) can be calculated. It is the rate of deviation of real GDP from potential GDP, showed in a formula (2), i.e.:

$$gap_{GDP} = \frac{GDP - hpt\_GDP}{hpt\_GDP} \quad \text{or} \quad gap_{GDP} = \frac{GDP - trend\_GDP}{trend\_GDP},$$

where: hpt_GDP – potential GDP estimated using the Hodrick-Prescott filter; $trend\_GDP$ – potential GDP estimated using the linear trend model.

The output gap informs about the inequality existing in the real economy and is treated as a factor influencing the inflationary processes. Inflation usually decreases when real GDP is below potential GDP (negative output gap) and increases when real GDP is above potential GDP – positive output gap (Solow,

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[5] According to the author there exists a way of determining the real rate which does not require using intricate econometric techniques when time series of a moderately long period of stable inflation is observed. It is assumed that the beginning of the stabilization period in Poland have begun in 2002.

Taylor, 2002)[6]. Behavior of the output gap is presented in Figure 4 and 5. The following notations are used:

> *gap_n (method of seasonal adjustment; method of calculating potential GDP; the initial time series).*

output gap - current GDP
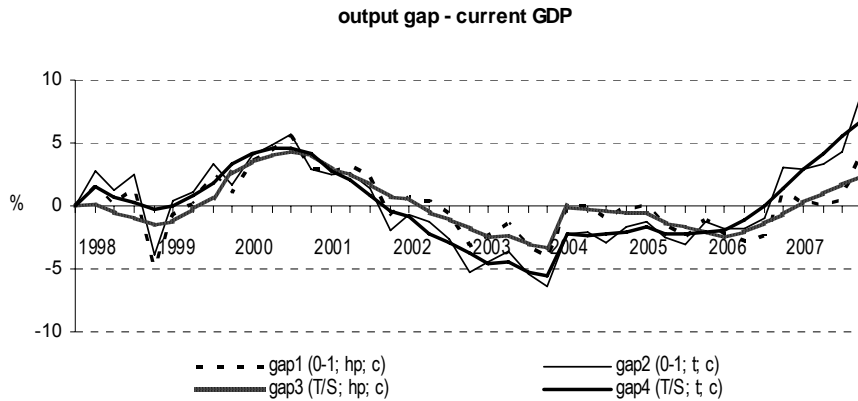
Figure 4. The GDP gap in Poland over the period 1998–2007 (current GDP)
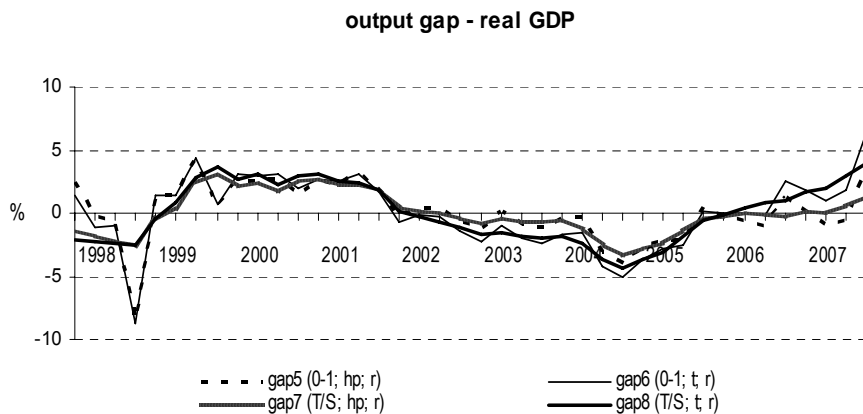
output gap - real GDP

Figure 5. The GDP gap in Poland over the period 1998–2007 (real GDP)

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[6] Taylor suggests that this relation is rather short-term, nonetheless, he stresses that there is a necessity of choice between the size of inflation's fluctuations and the size of deviation of real GDP from potential GDP.

gap 1 (0-1; hp; c)	the GDP gap as a percent deviation of nominal GDP seasonally adjusted (the model with dummy variables (0-1)) from potential GDP calculated by the HP filter (hp), used for series GDP in current prices (c);
	the GDP gap which is based on the GDP in current prices series takes the same value as the gap based on the GDP in constant prices series (average 1998=100);
gap 2 (0-1; t; c)	the GDP gap as a percent deviation of nominal GDP seasonally adjusted (the model with dummy variables (0-1)) from potential GDP calculated as a trend of GDP (t) in current prices (c) seasonally adjusted (the model with dummy variables (0-1));
gap 3 (T/S;hp; c)	the GDP gap as a percent deviation of nominal GDP seasonally adjusted (T/S analysis) from potential GDP calculated by the HP filter (hp), used for the GDP series in current prices (c);
gap 4 (T/S; t; c)	the GDP gap as a percent deviation of nominal GDP seasonally adjusted (T/S analysis) from potential GDP calculated as a GDP trend (t) in current prices (c) seasonally adjusted (T/S analysis);
gap 5 (0-1; hp; r)	the GDP gap as a percent deviation of real GDP seasonally adjusted (the model with dummy variables (0-1)) from potential GDP calculated by the HP filter (hp) used for the real GDP series (r);
gap 6 (0-1; t; r)	the GDP gap as a percent deviation of real GDP seasonally adjusted (the model with dummy variables (0-1)) from potential GDP calculated as a trend (t) of real GDP (r) seasonally adjusted (the model with dummy variables);
gap 7 (T/S; hp; r)	the GDP gap as a percent deviation of real GDP seasonally adjusted (T/S analysis) from potential GDP calculated by the HP filter (hp) used for the real GDP series (r);
gap 8 (T/S; t; r)	the GDP gap as a percent deviation of GDP seasonally adjusted (T/S analysis) from potential GDP calculated as the trend (t) of real GDP (r) seasonally adjusted (T/S analysis).

Figure 4 and 5 shows that in 2002 the GDP fell below the potential level. When real GDP is placed below potential GDP the inflationary pressure does not exist. Negative output gap was observed in 2003, 2004 and 2005, respectively. The situation where GDP was above the potential GDP occurred at the beginning of 1998 year and is maintained more or less until the beginning of 2002 with a certain exception at the turn of 1998 and 1999. The differences between the GDP gap based on the current GDP (gap 1, 2, 3 and 4) and the gap based on the real GDP are observed. The greatest distance between gap 7 (T/S;hp;r), gap 8 (T/S,t;r), which take negative values is noticed in 1998. The output gap based on the real GDP was closed in 2006 (gap 5, 6, 7 and 8). In the case of GDP gap based on the current (gap 1, 2, 3 and 4) the closing output gap was observed year later, in the second half of 2006 (compare Figure 4 and 5)[7].

Alternative methods of estimating the potential product lead to various calculations of the GDP gap. A much bigger fluctuations are observed, when the gap is calculating using the linear trend than the HP filter. It is especially relevant to observations of the end of year 2007. Also the choice of methods elimi-

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[7] The closure of the output gap means not only balance between real and potential GDP, but also the situation where real GDP grows faster than potential one.

nating the seasonal fluctuations from the original GDP series impacts on the final results. In the case of output gaps calculated for series seasonally adjusted using dummies variables 0-1 (gaps 1, 2, 5, 6) the outlier values were observed, which are not likely from the point of view of economic reality (IV quarter of 1998).

Using the obtained series of the GDP gap, an estimation (OLS) of the original Taylor rule was carried out. Its results were presented in Table 1.

Table 1. The results of the original Taylor rule's estimation – types of output gap

variable	$gap1_t$ (0-1;hp;c)	$gap2_t$ (0-1;t;c)	$gap3_t$ (T/S;hp;c)	$gap4_t$ (T/S;t;c)	$gap5_t$ (0-1;hp;r)	$gap6_t$ (0-1;t;r)	$gap7_t$ (T/S;hp;r)	$gap8_t$ (T/S;t;r)
	coeff.	coeff.	coeff.	coeff.	coeff.	coeff.	coeff.	coeff.
const	3.27***	2.90***	3.38***	2.90***	3.37***	3.27***	3.42***	3.28***
CPI_t	1.44***	1.52***	1.42***	1.52***	1.41***	1.44***	1.41***	1.44***
gap_t	0.08	-0.12	0.16	-0.13	0.37***	0.19*	0.64***	0.27*
Summary								
R^2	89.42	89.71	89.56	89.67	91.23	90.13	92.53	90.41
S(u)	2.01	1.98	2.00	1.99	1.83	1.94	1.69	1.92
DW	0.27	0.3	0.27	0.29	0.45	0.28	0.29	0.25
ρ_{11}	0.89	0.86	0.90	0.87	0.83	0.92	0.91	0.93

Note: ***, **, * denotes significance at 1%, 5%, 10%. R^2 is the determination coefficient, S(u) is standard error of residuals, DW is the Durbin-Watson statistic and ρ_{11} the partial autocorrelation coefficient of first order.

The coefficients of inflation impact are significant in all variants, positive and higher than 1 $(\beta_1 > 1)$ and what is more, close to the value pointed by Taylor – 1.5. The choice of type of series like real GDP is crucial for estimation results. The impact of the gap turned out irrelevant in the models where the initial series for estimating the gap was GDP in current prices. In the models where the gap was based on the real GDP series significant parameters were received, however, for gap 6 and 8 (potential GDP calculated as real GDP's trend) significance was at the 10% level. The coefficients of gap 5, 6, 7 and 8 have positive sign, as expected. However, these models do not meet the statistic requirements. Low values of the DW statistics for all models show first order autocorrelation for residual process. Coefficients of the first order autocorrelation turned out to be significant ($\hat{\rho}_{11} > 0.35$ autocorrelation coefficient is distinctly higher that the corresponding critical value of the Quenouille test ($2/\sqrt{n}$). The high, positive autocorrelation of a residual process may give evidence about the omission of important variables or the elements of internal structure for given process. Additionally, the relation between R^2 and DW indicates a spurious relationship. The correct statistical inference requires taking into account the information about the internal structure of the processes being modeled (trend, autoregression).

4. Detecting the Internal Structure of Processes

Assuming the nonstationarity in mean, the level of a trend, occurrence of seasonality and order of autoregression were detected. The results of detecting the internal structure of the analyzed processes are presented in Table 2.

Table 2. The results of the study of the internal structure of particular processes

structure	SR_t	CPI_t	$gap1_t$ (0-1;hp;cb)	$gap2_t$ (0-1;t;cb)	$gap3_t$ (T/S;hp;cb)	$gap4_t$ (T/S;t;cb)	$gap5_t$ (0-1;hp;r)	$gap6_t$ (0-1;t;r)	$gap7_t$ (T/S;hp;r)	$gap8_t$ (T/S;t;r)
r	1	1	-	-	-	-	-	-	-	-
S	no	no	no	no	no	no	no	no	no	no
AR(q)	4	5	5	5	4	4	5	5	1	2

Note: r – degree of polynomial trend, S – occurrence of seasonality, Ar(q) – order of autoregression for given processes.

The choice of trend degree was made using the F-test. This test is most often used when comparing linear trend models and testing significant differences in the variances.

In all estimated trend and seasonality models the seasonal coefficients turned out to be insignificant, hence the lack of seasonality in the analyzed time series was found.

The third stage of studying the internal structure of processes is the identification of lag length of particular processes; therefore the Akaike information criterion (AIC) was used. Because of the small sample size, the corrected AIC was used, in the form:

$$AIC_C = AIC + \frac{2K(K+1)}{n-K-1},$$

where K stands for the number of estimated parameters, including the constant and variance (Burnham, Anderson, 2004)[8]. The models with the lowest value of AIC_C were chosen.

Accepting the assumption of nonstationarity in mean, linear models of reference rate were built, in which the specification of an equation describing the monetary policy rule was broadened by information of the internal structure of processes. The inclusion of internal structure of given processes is the basis of congruent modelling, formulated by professor Zieliński. The concept of congruent modelling is understood as the congruence of the harmonic structure of an endogenous process with the joint harmonic structure of explanatory processes and residual process which is independent from explanatory processes (Talaga, Zieliński, 1986). Hence, the estimated equations have the form:

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[8] The authors point that there is too much usage of AIC in research, while the requirement that n/k>40 instead of AIC_C. Thus, AIC_C should be used regardless of the sample size because with the growth observations' number, AIC_C converges to AIC.

$$SR_t = \alpha_0 + \alpha_1 t + \sum_{k=1}^{4} \beta_{ik} SR_{t-k} + \sum_{k=0}^{5} \beta_{\pi k} CPI_{t-k} + \sum_{k=0}^{q} \beta_{yk} gap_{t-k} + \varepsilon_t,$$

where q denotes the lag length depending on the method of estimating the output gap.

Table 3. The reduced dynamic congruent models for the reference rate depending on different GDP gap's variants

variable	gap1$_t$ (0-1;hp;c)	gap2$_t$ (0-1;t;c)	gap3$_t$ (T/S;hp;c)	gap4$_t$ (T/S;t;c)	gap5$_t$ (0-1;hp;r)	gap6$_t$ (0-1;t;r)	gap7$_t$ (T/S;hp;r)	gap8$_t$ (T/S;t;r)
	coeff.	coeff.	coeff.	coeff.	coeff.	coeff.	coeff.	coeff.
const	0.15	4.09**	0.15	5.59***	11.61`***	7.70***	9.45***	7.71***
t		-0.08**		-0.12**	-0.20***	-0.16***	-0.17***	-0.16***
CPI $_t$	0.59***	0.42***	0.59***	0.38***		0.35***		0.35***
CPI $_{t-1}$					0.73***		0.60***	
CPI $_{t-2}$	-0.41***	-0.48***	-0.41***	-0.50***				
CPI $_{t-3}$	0.19*	0.30**	0.19*	0.32***	0.37***	0.40***	0.49***	0.44***
CPI $_{t-4}$								
CPI $_{t-5}$						-0.15**	-0.22***	-0.17**
gap $_t$					0.27***	0.12**		
gap $_{t-1}$					0.24***		0.79***	0.32***
gap$_{t-2}$		0.12**		0.18***	0.34***	0.21***		
SR $_{t-1}$	0.80***	0.83***	0.80***	0.81***		0.47***	0.34*	0.65***
SR $_{t-2}$							-0.36**	-0.37***
SR $_{t-3}$						-0.19*		
SR $_{t-4}$		-0.18**		-0.22***	-0.23***			
Sumary								
R^2	99.38	99.54	99.38	99.56	99.65	99.57	99.61	99.60
S(u)	0.43	0.40	0.43	0.38	0.35	0.39	0.36	0.37
DW	1.55	1.96	1.55	2.08	1.85	1.97	2.28	2.31
ρ_{11}	0.21	-0.01	0.21	-0.08	0.06	-0.04	-0.14	-0.23

Note: ***, **, * denotes significance at 1%, 5%, 10% level. R^2 is the determination coefficient, S(u) is standard error of residuals, DW is the Durbin-Watson statistic and ρ_{11} the partial autocorrelation coefficient of first order.

After estimation of the starting version of congruent models the insignificant variables were eliminated using a posteriori selection method. The estimation results are presented in Table 3. The reduced congruent models contain significant parameters at 10% significance level (except the constant in models 1 and 3) and have the desired properties of residual process. In all estimated equations the inflation's influence is significant. In models 1 and 3 (gap1 (0-1;hp;c), gap3 (T/S;hp;c)) the impact of gap was not significant, and what is more, the reduced model has the same form in both cases. The impact of current inflation and output gap is observed only in model 6 (gap6 (0-1;t;r)), but the coefficient of the impact of inflation on the reference rate is smaller than one. Taking into consideration the lagged influence of inflation (its accumulated impact is equal to 0.6 percentage point) the model does not satisfy the stability condition called the

Taylor principle. In model 5 (gap5 (0-1;hp;r)), the accumulated impact of inflation and output gap amounted to 1.1 and 0.85 percentage point, respectively.

Moreover, in each variant of model the lagged reference rate is significant, what means that changes of reference rate are autoregressive distributed (the interest rates' smoothing effect). It shows the partial reaction of Monetary Policy Council on changes in the economy, which may result from the unobservability of output gap and hence problems with estimating it precisely.

The estimated reaction's functions of reference rate to changes in the output gap and inflation level, differ from the original Taylor rule because they include the internal structure of processes (compare Table 1 and Table 3).

Parameter estimates of lagged output gap (gap 2 and 4) are statistically significant with expected positive signs. In the case of the remaining models the influence of estimating the potential GDP on the relevance of the Taylor rule is not so clear. It can be noticed that regardless of the way of seasonal adjustment of real GDP the accumulated impact of inflation and the output gap is similar in models where potential GDP was estimated using linear trend.

4. Conclusions

Based on the obtained results one cannot tell categorically which of the analyzed methods of estimating the potential GDP gives better results in the contest of estimation of the Taylor rule. The inclusion of the internal structure of processes eliminates the autocorrelations of residual process, however it changes the coefficient estimates in comparison with the original Taylor rule. In that case, the Taylor-type rules were considered. The Taylor condition (the impact of inflation on the reference rate is bigger than one) was satisfied only in model 5 (gap5 (0-1;hp;r)). However it should be noticed, that the recommended original time series for estimating the output gap is real GDP. In the presented analysis, the assumption of nonstationarity in mean was taken into consideration, however processes can also be nonstationary in variance. In such a case, the recommended method of estimating the output gap is the HP filter.

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Znaczenie szacowania potencjalnego PKB w kontekście reguły Taylora

Z a r y s t r e ś c i. Taylor wypowiedział się żartobliwie o swojej regule, że jest tak prosta, iż można ją zapisać na odwrocie wizytówki. Rzeczywistość pokazuje, że praktyczne wykorzystanie tego typu reguły implikuje przyjęcie wielu założeń, co do ostatecznego jej kształtu. Artykuł porusza jedynie kwestię wpływu zastosowanych metod szacowania potencjalnego PKB, luki PKB na estymację parametrów reguły Taylora. Przedstawiono dwa sposoby szacowania PKB potencjalnego: filtr HP oraz trend liniowy, przy czym bazowano na wyrównanych sezonowo (model addytywny ze zm. 0-1; procedura TRAMO/SEATS) szeregach: PKB bieżący oraz PKB realny.

S ł o w a k l u c z o w e: reguła Taylora, luka popytowa.