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Article

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FINANCIAL ECONOMICS | RESEARCH ARTICLE

The Nash equilibrium in the policy mix model for Czechia, Hungary, and Romania

Joanna Stawska^{1*}, Maciej Malaczewski², Paulina Malaczewska² and Ewa Stawasz-Grabowska³

Abstract: The aim of the paper is to compare the sensitivity of a government's fiscal policy and a central bank's monetary policy, which are in Nash equilibrium in the case of a non-cooperative game between the government and the central bank in Czechia, Hungary, and Romania. The analysis for each country is conducted from the date of its accession to the European Union. The research period for Czechia and Hungary includes the quarters 2004Q2-2019Q2, and for Romania, 2007Q1-2019Q2. The study has demonstrated that in Romania the government's response to interest rate changes is the strongest and the central bank's response to changes in the budget deficit turned out to be the weakest. On the other hand, the strongest response of the central bank to changes in the budget deficit turned out to be in Hungary, which means that the central bank in Hungary makes a significant correction of interest rates as a result of changes in the budget deficit.

Subjects: Economics; Political Economy; Finance

Keywords: monetary policy; fiscal policy; game theory; Nash equilibrium; non-cooperative game; policy mix

JEL Codes: C70; C72; E52; E62

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PUBLIC INTEREST STATEMENT

The aim of the article is to compare the reactions of government decisions to the actions of central banks in three selected European Union countries, i.e. the Czech Republic, Romania, and Hungary. This study is based on quarterly data and covers year 2004Q2-2019Q2 for the Czech Republic and Hungary, while for Romania it covers year 2007Q1-2019Q2, according to the dates of their accession to the European Union. The results of the research indicate that the government in Romania reacts most strongly to the central bank's decisions on interest rates in selected countries. On the other hand, central bank in Romania reacts weakest to changes in the budget deficit, compared to the three analyzed countries, and the strongest reaction of the central bank to changes in the budget deficit was in Hungary. The results of these studies are important for economic decision-makers as they provide insightful information on the relationship between independent players—banks and governments—of European Union countries outside the euro area.

1. Introduction

Game theory is a mathematical formulation of situations where for two or more players, the result of one of them depends not only on the specific action taken by that player but on the action taken by the co-player (or others) (Carmichael, 2005). Game theory has gained great attention in recent years, as evidenced by a growing number of theoretical and empirical studies using this approach (Gibbons (1992), Borm and Peters (2002), Vega-Redondo (2003), and Binmore (2007)). After the book by Von Neuman and Morgenstern (1944), which was the first important text in game theory, John Nash (1950, 1953) made an important contribution to this theory.

Interactions between monetary and fiscal policy can be analyzed using game theory. Interactions between the government's fiscal policy and the monetary policy of the central bank affect the country's economy. The combination of these policies is known in the economic literature as a "policy mix." Coordinating these two policies is important for the economy because decisions made by one authority may have a negative impact on the other authority's results, causing a deterioration in the welfare of society. Coordinating fiscal and monetary policy should contribute to resolving conflicts of interest, as each decision-maker primarily deals with its goals (Saulo et al., 2013). Frankel and Rockett (1986) indicated that, overall, it would be better for countries to run a cooperative game than a non-cooperative one, in which each government sets its own policy regardless of the policy taken by the other side. There are many voices in the literature that state that the gains from coordination are small, but they are generally positive.

In economic reality, however, the game between the government and the central bank more often takes the form of a non-cooperative game. Non-cooperative models of the monetary and fiscal (policy mix) game are frequently employed to study the interactions between both authorities. The models assume that the authorities make their decisions taking account of each other's choices. It is also important to remember when seeking equilibrium in non-cooperative models that in the Nash equilibrium, the parties try to come up with the best response to the opponent's decision.

We suggest using a non-cooperative game to explore the issue of coordinating fiscal and monetary policies in the EU Member States. The study is conducted for a set of countries from Central and Eastern Europe (henceforth CEE) which have rarely been included in studies of a similar nature. More specifically, we include Czechia, Hungary, and Romania. All of them joined the ranks of the European Union (EU) at the beginning of the 21st century, pursue an independent monetary policy within the framework of inflation targeting, and are obliged to adopt the euro in the future. The Nash Equilibrium in the non-cooperative game model with institutional restrictions has not yet been thoroughly analyzed. In addition, the analysis of sensitivity conducted in this article is a study based on the original equilibrium model for the non-cooperative game of monetary and fiscal authorities in selected countries. The aim of the paper is to compare the mutual sensitivity of the government's fiscal policy and the central bank's monetary policy which are in Nash equilibrium in the case of a non-cooperative game between the government and the central bank in Czechia, Hungary, and Romania.

The structure of the paper is as follows: Section 1 is the introduction. Section 2 presents the findings of a review of studies on the coordination of fiscal and monetary policies using game theory, especially in the non-cooperative game. In Section 3, our Nash equilibrium of a non-cooperative game between the central bank and the government is introduced. The section also explains the model's assumptions and different variants of the Nash equilibrium. Section 4 presents the estimation of the parameters in the Nash equilibrium equations and then the calculations of the parameters from the central bank and government reaction functions. The last section presents the conclusions.

2. Literature review

Studies on the interactions between monetary and fiscal policy have been conducted by Clarida et al. (2000), Buti (2003), Canzoneri et al. (2006), Flanagan et al. (2011), Badarau and Leveuge

(2011), Saulo et al. (2013), and Cui (2016), among others, all of whom considered the coordination of monetary and fiscal policy to be beneficial. At the same time, Libich and Nguyen (2015) show that such coordination might be problematic. In particular, it pertains to countries whose central bank pursues an inflation targeting strategy. Coordination of monetary and fiscal policy actions may be perceived by market participants as a breach of central bank independence, which is inextricably related to the inflation targeting framework.

To analyze the interaction of the monetary and fiscal policies, Dixit (2001) built several models of the Economic and Monetary Union (EMU) and the European Central Bank (ECB) for a group of 12 EMU countries. Dixit (2001) noted, however, the dangerous role that independent fiscal policies could have played, which could often have undermined the ECB's commitment to the inflation target. Most studies on the interaction between monetary and fiscal policy are carried out for the euro area countries. This is a specific scope of research, and according to Afonso et al. (2019), the introduction of a single currency by 19 out of the 28 EU Member States had a structural impact on the responses and interactions between monetary policy and fiscal policy. In this context, it is worth undertaking a policy mix interaction study in EU countries outside the euro area. An autonomous monetary policy is pursued in these countries, which may contribute to different fiscal policy responses to central bank decisions and vice versa.

Lambertini and Rovelli (2003) also studied the coordination of monetary and fiscal policy using game theory. Each player's preference can be represented by an objective function optimized for the selected restrictions. To determine the optimal behavior of each player, a so-called reaction function is constructed that shows the likely response of one player to a specific decision made by a co-player. The reaction functions make it possible to identify the level of equilibrium where each player's decision is the best answer to the co-player's choice; this is called the Nash equilibrium (Bennett & Loayza, 2000; Cechetti, 2000; Gibbons, 1997; Nash, 1950; Kishan & Opiela, 2000).

Some authors indicated that the monetary and fiscal game is very much a part of the policy process. Thus, the theory of policy, as developed by Tinbergen (1952), visualized a unitary policy-maker optimizing policy in the face of economic constraints and uncertainties. The possibility of conflicts between decision-makers was formally analyzed in early studies by Pindyck (1976), which were devoted to the general problem of conflicting goals among decision-makers. The most thorough analysis was that of Ribe (1980), which concentrated on the impact of coordination or lack of coordination on the efficiency of macroeconomic policy. Blinder (1982) analyzed coordination issues when decision-makers have two or three discrete options and suggested that the game takes the form of a prisoner dilemma. The studies of these authors are pioneering studies on fiscal-monetary policy interactions with the use of game theory approach.

Favero (2004) shows that strategic complementarity or substitutability between fiscal and monetary policy depends on the type of shock hitting the economy. In addition, countercyclical fiscal policy can reduce prosperity if the fiscal and monetary policies are inert and uncoordinated. Afonso et al. (2019) found a substitutable relationship between fiscal and monetary policy, in which the central bank takes an active role, mainly in terms of higher levels of debt. This is how the traditional Taylor equation model was extended by Kirsanova et al. (2005) to include fiscal policy and policy coordination analysis. The idea was to describe the role of fiscal policy, which could give feedback on debt and help the monetary authority stabilize inflation. Interactions between monetary policy and fiscal policy are most often considered in three variants: (i) a policy of non-cooperation, (ii) a policy partly based on cooperation, and (iii) benevolent policies. The results suggest that if the authorities are benevolent and cooperate, then the monetary authority bears the full burden of stabilization.

In addition, the Nash equilibrium will cause great social losses when the monetary authority is benevolent and the fiscal authority discounts too much of the future or strives for excessive production. It is worth emphasizing that when making policy decisions, economic authorities do not have full

knowledge of past, current, and future economic data, so it is important to take into account uncertainty in the area of fiscal and monetary policy. Uncertainty about monetary and fiscal instruments such as inflation, exchange rate, real interest rate, spending, etc., plays a significant role in stabilization policy (see Lane, 2003). In addition, monetary authorities usually have a longer time horizon, but they also tend to be cautious and sometimes even sluggish. Therefore, when the economy is locked into high-deficit equilibrium, the strategy of deficit reduction in the face of slow monetary reactions may risk a short-term, but a politically lethal economic slowdown. Interested politicians may, therefore, consider the status quo with a high deficit as the lesser evil. This syndrome is called *a monetary and fiscal game* to reflect the fact that the monetary and fiscal policies in many large countries are essentially independent and have conflicting goals. Steps to reduce the fiscal deficit must have an impact on how they will unfold in the light of the monetary and fiscal game. Where the game is basically non-cooperative, the fiscal authorities must guess to what extent the short-term contraction impulse to reduce the deficit will be balanced by financial markets, exchange rates, domestic and foreign monetary policy, or a growing wave of private spending (Nordhaus et al., 1994).

In the EU countries outside the euro area, monetary and fiscal policy are conducted by independent, separate institutions. The monetary authority is independent and aimed at achieving specific goals, in particular, price stability. The game between the central bank and the government can be seen as a two-player game with a non-zero sum. Each player decides its policy, taking into account the policy of the other party.

Nordhaus et al. (1994) presented the results of the Nash equilibrium—a non-cooperative game of the central bank and government. Non-cooperative game is a technical term for a game in which the players generally do not agree on their own policies and do not agree on a common strategy. The results are as follows: each response function has a negative slope; the slope of the monetary response function is steeper than the fiscal response function; optimal policies (or bliss points) are those where the monetary authority has a higher optimal fiscal surplus (but not necessarily a higher level of real interest rates) than the fiscal authority. The reaction functions illustrate how the monetary authority reacts to the fiscal authority's decisions and vice versa. The results indicate that decision-makers actually respond to the state of the economy (inflation, unemployment, increase in potential output) and adapt to the policy of the second decision-maker. Thus, Nordhaus et al. (1994) note that the central bank does not raise interest rates in response to changes in fiscal policy, but rather it reacts to changes in the state of the economy. The Nash equilibrium was at a point where the deficit is higher than the desired deficits on both sides, due to a conflict of goals between the players. The government tries to reduce unemployment by increasing the deficit, while the monetary authority raises interest rates to combat inflation and so on. In the Nash equilibrium, in a non-cooperative game, the interest rate is also higher than either side would want. Foresti (2018) produced similar results, which indicates that the incompatibility of monetary and fiscal policy objectives does not allow symbiosis. There is a non-cooperative race between economic authorities; fiscal authorities are trying to achieve output that exceeds the ideal of the central bank, and the central bank seeks to achieve an inflation rate below the ideal of the government. This causes an equilibrium with too-low inflation and too-high output. The result of this equilibrium is excessive debt and too-high interest rates.

Changes in the decisions of monetary and fiscal authorities in response to specific reactions of the central bank and the government are also described by Woroniecka – Leciejewicz (2015). Thus, the central bank reacts to the increase in fiscal expansion by tightening monetary policy to avoid exceeding a certain rate of inflation. In turn, in the case of expansive fiscal policy, there is usually a dominant or almost dominant monetary policy. In turn, in the case of extremely expansive monetary policy—the optimal fiscal response ceases to change, and a tendency to dominate the fiscal strategy can be observed. To sum up, under the influence of changes in the priorities of the central bank and the government, optimal fiscal and monetary responses change, and as a consequence, the Nash equilibrium changes. As the growth rate planned by the fiscal authorities increases, the optimal response of fiscal policy becomes more expansive. Similarly, when monetary authorities change their priorities, e.g., they accept higher inflation, the optimal monetary policy response becomes more expansive.

3. The simple model of a non-cooperative game

3.1. The Nash equilibrium—The assumptions of the policy mix model for non-cooperative games

The following model is presented and thoroughly analyzed in terms of the theoretical properties in the paper by Stawska et al. (2019). It describes a simple economic game between the government (responsible for the fiscal policy in a given economy) and the central bank (which shapes the monetary policy). Each of these institutions pursues its own economic goals. In this case, a non-cooperative game is proposed. Although both the government and the central bank are fully autonomous and independent institutions, in making their decisions, they take into account the decisions of the other, which also affects the macroeconomic conditions.

The government determines the size of the budget deficit d to maximize its goal function¹:

$$F_F(d) = g_y^2 - \alpha_0(d - d_M)^2 \xrightarrow{d} \max \quad (1)$$

subject to the given budget constraint²:

$$g_y = \alpha_1 \cdot d + \alpha_2 \cdot r + \alpha_3 \cdot \pi \quad (2)$$

where g_y is the growth rate of GDP per capita, r is the interest rate, d_M is the Maastricht deficit limit, π is the level of inflation, and $\alpha_0, \alpha_1, \alpha_3 > 0$ and $\alpha_2 < 0$ are constant parameters.³

Thus, the government aims to achieve the highest possible growth rate while maintaining some budgetary discipline in line with the Maastricht deficit limit. At the same time, the central bank determines the interest rate r to minimize the square of the difference between current inflation and the inflation target⁴:

$$F_M(\pi) = (\pi - \pi^t)^2 \xrightarrow{r} \min \quad (3)$$

subject to:

$$\pi = \pi_0 + \beta_1 \cdot r + \beta_2 \cdot g_y + \beta_3 \cdot d \quad (4)$$

where $\pi_0 > 0$ is the base inflation, π^t is the inflation target, and $\beta_2, \beta_3 > 0$ and $\beta_1 < 0$ are constant parameters.

It is worth noting that the objective function of the government (1) also depends on the interest rate r ; similarly, the objective function of the central bank (3) depends on the size of the current budget deficit d . Thus, there is an interaction between the fiscal and monetary policies in the economy. Thus, when determining the size of the budget deficit, the government has to take into account any potential decisions that the central bank might take and vice versa.

After substituting Equations (2) and (4) for, respectively, (1) and (3), the final problem of optimization of the proposed game was obtained:

$$F_F(d) = \left(\frac{\alpha_1 + \alpha_3 \beta_3}{1 - \alpha_3 \beta_2} \cdot d + \frac{\alpha_2 + \alpha_3 \beta_1}{1 - \alpha_3 \beta_2} \cdot r + \frac{\alpha_3}{1 - \alpha_3 \beta_2} \cdot \pi_0 \right)^2 - \alpha_0(d - d_M)^2 \xrightarrow{d} \max$$

$$F_M(r) = \left(\frac{1}{1 - \alpha_3 \beta_2} \cdot \pi_0 + \frac{\beta_1 + \beta_2 \alpha_2}{1 - \alpha_3 \beta_2} \cdot r + \frac{\beta_3 + \beta_2 \alpha_1}{1 - \alpha_3 \beta_2} \cdot d - \pi^t \right)^2 \xrightarrow{r} \min \quad (5)$$

In order to determine the Nash equilibrium of model (5), the reaction functions of the government (denoted as \tilde{d}) and the central bank (denoted as \tilde{r}) are obtained:⁵

$$\tilde{d} = \tilde{a}_1 \cdot r + \tilde{a}_2 \cdot \pi_0 + \tilde{a}_3 \cdot d_M \quad (6)$$

$$\tilde{r} = \tilde{b}_1 \cdot \pi^t + \tilde{b}_2 \cdot \pi_0 + \tilde{b}_3 \cdot d \quad (7)$$

where $\tilde{a}_2, \tilde{a}_3, \tilde{b}_2, \tilde{b}_3 > 0, \tilde{a}_1, \tilde{b}_1 < 0$ are non-linear combinations of parameters $\alpha_0, \alpha_1, \alpha_2, \alpha_3, \beta_1, \beta_2, \beta_3$.⁶

Function (6) indicates what should be the optimal fiscal policy response to the adopted monetary strategy of the central bank. Similarly, (7) shows the level of interest rates set by the central bank at the government's budget deficit level.

The Nash equilibrium of the proposed model (denoted as (d^*, r^*)) corresponds to a situation where the actions of both the government and the central bank represent the best response to the best response of the other player. It is, therefore, a level of d and r which is the solution of Equation (6) and also (7). The Nash equilibrium can, therefore, be written as:

$$d^* = a_1^* \cdot \pi^t + a_2^* \cdot \pi_0 + a_3^* \cdot d_M \quad (8)$$

$$r^* = b_1^* \cdot \pi^t + b_2^* \cdot \pi_0 + b_3^* \cdot d_M \quad (9)$$

where $a_1^*, a_3^*, b_2^*, b_3^* > 0, b_1^* < 0, a_2^* \in \mathbb{R}$ are also non-linear combinations of parameters $\alpha_0, \alpha_1, \alpha_2, \alpha_3, \beta_1, \beta_2, \beta_3$.⁷

Equations (8) and (9) in the next part will be used as the theoretical basis for our empirical research.

4. Empirical evidence

4.1. Dataset

The study focuses on the so-called new EU member states from the CEE region. Estimating Equations (6) and (7) requires several conditions to be met. First, it should be remembered that these equations are derived from a model in which there were two independent entities—the government and the central bank—whose decisions interacted with each other.⁸ This means that the parameters of these equations can only be estimated for countries that are not in the euro area. Out of these economies, countries that do not conduct independent monetary policy, such as Bulgaria, should also be excluded. Secondly, it should be noted that the condition concerning the deficit level required by the Maastricht Treaty was the same for the entire period. This means that the variable d_M is constant over time, and the associated parameter can be estimated from the constant term in the equation. It also means, however, that all other variables are required not to be constant over the period for which we estimate the parameters. Therefore, Poland, where the inflation target was at the same level throughout the examined period, should also be removed from the sample.

Czechia, Hungary, and Romania were, therefore, ultimately included in the study. The sample range in each case is equal to their membership in the EU. In each case, the base/reference rates of the national central banks were adopted as interest rates in the model. As the base inflation rate in each country, a different core inflation indicator is taken. Table 1 provides details of these variables.⁹

Table 1. Interest rates and base inflation dataset details

Country	Sample range	Number of observations	Interest rate	Base inflation	Source
Czechia	2004Q2-2019Q2	61	Repo rate	Core inflation excluding prices of energy, food, alcohol, and tobacco	Czech National Bank (CNB), IMF, FRED
Hungary	2004Q2-2019Q2	61	Base rate	MNB core inflation	Magyar Nemzeti Bank (MNB), IMF
Romania	2007Q1-2019Q2	50	NBR reference interest rate, Policy Rate (since 2011)	Core inflation	National Bank of Romania (NBR), IMF, Thomson Reuters Eikon

Inflation targets were obtained from the national banks' websites. The annual deficit level (cyclically adjusted balance,¹⁰ % of potential GDP) was derived from the IMF's Fiscal Monitor (October 2019).

4.2. Estimation details

The aim of the empirical study is to obtain estimates of the parameters of reaction functions (6) and (7). These equations are a set of mutually interdependent equations. However, this system has a reduced form (8) and (9), in which the random terms in both equations are already independent. Therefore, we make the assumption that the deficit and interest rate levels in individual economies follow models (1)–(4), and therefore are at the level of the Nash equilibrium, taking into account the random deviation associated with the imperfection of the data set. Having estimates of the parameters for the equations of the Nash equilibrium levels, we will obtain the values of the parameters of the reaction functions, as model (6)–(7) is unequivocally identifiable. Estimating the parameters of model (6)–(7) will, therefore, be carried out by the Indirect Least Square Method.

Equations (8) and (9) were, therefore, subject to parameter estimation using the Least Squares Method. The data collected and described in section 4.1 required minor conversions. For variable d (deficit), the annual data are converted into quarterly data by inserting a fourth part of the year-round deficit for each quarter of the year. As a result, the set of data used has increased from several to several dozen observations. The resulting time series are then multiplied by (-1) to reflect the deficit according to a theoretical model (1)–(4). Let us also note that during the analyzed period, the variable d_M took a constant value of 3%, so the parameter is obtained from the estimated constant term.

The parameters $a_1^*, a_2^*, a_3^*, b_1^*, b_2^*, b_3^*$ of six functions expressing the Nash equilibrium are therefore estimated, two for each of the three countries. In each case, it was necessary to remove the third-degree trend from the dependent variable or from one of the explanatory variables before estimating. Some dummy variables were also added in each estimation. The final forms of the estimated functions were free from autocorrelation; the determination coefficient ranged from 0.40 to 0.92 in various equations. The obtained estimates of the parameters of Equations (8) and (9) are contained in Table 2.

4.3. Results of the reaction functions and discussion

After estimating parameters $a_1^*, a_2^*, a_3^*, b_1^*, b_2^*, b_3^*$ in the Nash equilibrium Equations (8)–(9), it was then possible to calculate the values of parameters $\tilde{a}_1, \tilde{a}_2, \tilde{a}_3, \tilde{b}_1, \tilde{b}_2, \tilde{b}_3$ from reaction functions (6)–(7). For this purpose, the following formulas were used:

Table 2. Calculated values of the parameters of the Nash equilibrium functions (8) and (9)

												Country
a1*	a2*	a3*	R ²	F	DW	b1*	b2*	b3*	R ²	F	DW	
Czechia	0,1162	-0,3825	0,1230	0,77	126,47	1,28	-0,1912	0,6334	0,7665	0,92	722,53	1,31
	(0,54)	(0,00)	(0,34)				(0,38)	(0,00)	(0,00)			
Hungary	1,5169	-0,1622	0,2069	0,92	403,47	-0,61**	-1,7228	0,2726	1,4818	0,66	68,16	1,29
	(0,28)	(0,17)	(0,04)				(0,00)	(0,01)	(0,00)			
Romania	5,2014	0,0975	0,1317	0,86	932,65	1,44	-4,7454	0,0861	0,0206	0,40	15,77	1,21
	(0,00)	(0,00)	(0,00)				(0,00)	(0,18)	(0,84)			

* P-value are given in parenthesis. Table presents adjusted R².

** Durbin—h due to use of lagged dependent variable as explanatory one.

$$a_1^* = \frac{\tilde{a}_1 \tilde{b}_1}{1 - \tilde{a}_1 \tilde{b}_3}, a_2^* = \frac{\tilde{a}_1 \tilde{b}_2 + \tilde{a}_2}{1 - \tilde{a}_1 \tilde{b}_3}, a_3^* = \frac{\tilde{a}_3}{1 - \tilde{a}_1 \tilde{b}_3}, b_1^* = \frac{\tilde{b}_1}{1 - \tilde{a}_1 \tilde{b}_3}, b_2^* = \frac{\tilde{b}_2 + \tilde{b}_3 \tilde{a}_2}{1 - \tilde{a}_1 \tilde{b}_3}, b_3^* = \frac{\tilde{b}_3 \tilde{a}_3}{1 - \tilde{a}_1 \tilde{b}_3} \quad (10)$$

resulting in a system of six equations with six unknowns. The values of the parameters of the reaction functions for each country are shown in [Table 3](#).

Parameters $\tilde{a}_1, \tilde{a}_2, \tilde{a}_3$ provide the appropriate information on what kind of government response is to be expected as a result of a change in the interest rate level r , base inflation π_0 or Maastricht deficit limit d_M . Similarly, the values of parameters $\tilde{b}_1, \tilde{b}_2, \tilde{b}_3$ inform about the expected reaction of the central bank to the change in, respectively, the level of the inflation target π^t , base inflation π_0 , and budget deficit d .

Particularly interesting from the perspective of this study are the values of the parameters \tilde{a}_1 and \tilde{b}_3 . This is because they indicate the mutual reactions of the fiscal and monetary policy, i.e., they inform us about the mutual interactions within the policy-mix. The higher the absolute value of parameter \tilde{a}_1 , the stronger the reaction of the government to a change in the interest rate introduced by the country's central bank. A lower budget deficit is, therefore, to be expected. Similarly, the higher the value of parameter \tilde{b}_3 , the stronger the central bank's reaction to the change in the budget deficit and the higher the expected interest rate. Comparing the values of these parameters in the analyzed countries will provide us with information about the degree of the interrelation of fiscal and monetary policies in a given economy and allow us to compare their sensitivity to each other. To increase the transparency of the analysis, the results are presented in [Figures 1 and 2](#). The reaction functions are determined on a case-by-case basis for the average values of the other variables π^t, π_0, d_M .

For each of the countries concerned, the value of parameter \tilde{a}_1 is negative. This means that in each of these economies, the best government response to the central bank's interest rate increase is to reduce the size of the budget deficit. These results are consistent with the conclusions of our theoretical model. This is because raising the interest rate causes an increase in debt servicing costs, which, in turn, could negatively impact the country's promises to deliver on a balanced budget or debt-reduction strategies. Thus, the government could, among other things, limit government spending and thus reduce the budget deficit. This result is also in line with previous research (Beck & Wieland., 2017; Bi et al., 2019; Faria-e Castro & Bharadwaj, 2018; Scheinert, 2017).

Table 3. Calculated values of the reaction functions parameters

Country	\tilde{a}_1	\tilde{a}_2	\tilde{a}_3	\tilde{b}_1	\tilde{b}_2	\tilde{b}_3
Czechia	-0.6080	0.0026	0.5890	-0.9155	3.0169	6.2318
Hungary	-0.8805	0.0778	1.5116	-12.5861	1.4338	7.1615
Romania	-1.0961	0.1919	0.1543	-5.5598	0.0708	0.1566

The highest value (in absolute terms) of parameter \tilde{a}_1 is for Romania. It means that for this economy, the government's response to the interest rate change will be the strongest. We can, therefore, conclude that Romania's fiscal policy is most sensitive to changes introduced by the central bank. The lowest level of sensitivity is in Czechia, although it is worth noting that the values of parameter \tilde{a}_1 are at a similar level in all countries.

The cross-country differences regarding the strength of the reaction of fiscal policy to monetary policy can be interpreted in the context of these countries' experiences over the course of the 2008 crisis and its legacy. More specifically, compared with Czechia, Romania, and Hungary recorded large fiscal deficits in the analyzed period, particularly in the pre-crisis and crisis years. It was these fiscal imbalances, combined with the external ones, that caused these countries problems in accessing the bond market for public borrowing at the beginning of the crisis, and which made them seek financial aid from official creditors.

Thus, between 2009 and 2015, Romania was under three assistance programmes. The first one, with the dominant contributions from the EU and the IMF, amounted to EUR 20 billion, while the other two were of a precautionary nature, with no disbursements of funds (European Commission). When it comes to Hungary, it benefited from EU/IMF/World Bank-organized official aid between 2008 and 2010, receiving EUR 14.2 billion overall. The disbursement within those programmes was contingent on the countries' progress in introducing pre-defined reforms, including fiscal consolidation. Hence, given that the higher policy rate has fiscal consequences in the form of increased yields and debt service on government bonds, and taking into consideration the recent negative experiences of Romania and Hungary with government and external debt refinancing, one can see that these countries' fiscal policies are more sensitive to the actions undertaken by the respective national central banks.

In the case of the second reaction curve $\tilde{r}(d)$, the estimates indicate positive values for parameter \tilde{b}_3 for all the analyzed countries. It means that the central bank will respond to an increase in the budget deficit by raising interest rates, and is due to the fact that higher deficits are likely to increase inflationary pressure, which requires monetary policy tightening on the central bank's

Figure 1. Deficit reaction functions to interest rate changes.

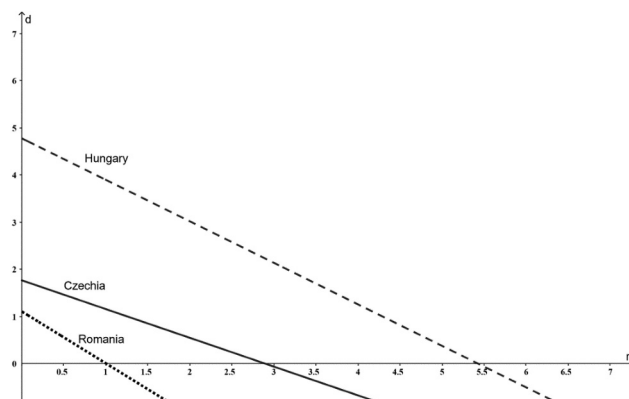
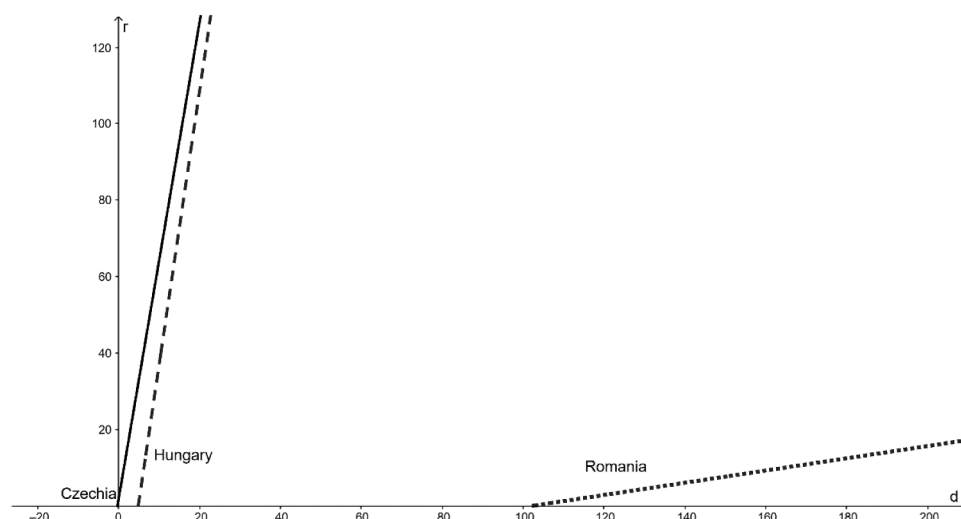


Figure 2. Interest rate reaction functions to deficit change.



side. The result (the positive value of parameter \tilde{b}_3) is also in line with our non-cooperative theoretical game (Stawska et al., 2019) and many previous research studies (cf. Bennett & Loayza, 2000; Blinder, 1982; Dixit & Lambertini, 2001; Nordhaus, 1994, etc.).

The highest value of parameter \tilde{b}_3 was for Hungary. The Hungarian central bank's reaction to changes in the budget deficit level will, therefore, be the strongest, so the degree of sensitivity of the monetary policy to the government's actions is the highest. It comes as no surprise, given that persistent fiscal deficits can be a source of an increase in the price level. Hungary had a long history of unsustainable fiscal policy combined with elevated inflation. In particular, from the beginning of the 21st century, it was only 2012 when the ratio of General Government (GG) deficit to GDP fell below the threshold of 3%; in the preceding years, it averaged at 6.1%. Hence, it is the Hungarian central bank that reacted particularly strongly to fiscal imbalances.

It is also worth noting that the \tilde{b}_3 value for Romania is several dozen times lower than the respective values obtained for the other two countries. This may indicate that in this economy, the central bank makes only a slight adjustment to the monetary policy as a result of changes in the budget deficit. Rugea (2018) partly confirms this low sensitivity of monetary policy to decisions of fiscal authorities. This author examined the level of coordination of monetary and fiscal policy in Romania between 2004 and 2016 using the STA (Set-Theoretic Approach) method. Her research confirms the weak level of coordination of monetary and fiscal policy in Romania estimated at 30%. However, the reason for this weak coordination may be the lack of institutions that ensure good communication and cooperation between the monetary and fiscal authorities.

5. Conclusions

This article considers the Nash equilibrium in the case of a non-cooperative fiscal-monetary game between governments and central banks in three EU member states outside the euro area (Czechia, Romania, and Hungary). It is assumed that both players (the central bank and the government) are independent in making decisions and react (mutually) optimally to each other's best decisions. These assumptions were used to construct our original (own) policy-mix model for a non-cooperative game whose solution is the Nash equilibrium. Our original policy model was built on the basis of previous research conducted by: Bennett and Loayza (2000), Blinder (1982), Dixit & Lambertini (2000), Kuttner (2002) and Nordhaus (1994). They constructed a model of strategic cooperation between both

authorities using various loss functions, which differ in design from our proposal in this paper. The mathematical model (presented in the study by Stawska et al., 2019) shows that in the Nash equilibrium, the level of the budget deficit and the interest rate—as the policy tools of the government and the central bank, respectively—depend on exogenous factors such as the inflation target, base inflation, and the Maastricht deficit limit. Therefore, the inflation target rate and the Maastricht deficit limit, which are set institutionally, are important determinants of the fiscal-monetary balance in the EU countries. To the authors' best knowledge, using these variables to construct objective functions (and their limitations) for the monetary and fiscal authorities is an innovative approach in that it takes into consideration both economic mechanisms and the mandatory EU legislation (mainly laws capping budget deficits). An important innovative element of this article which is a contribution to literature is the empirical development of the constructed mathematical model.

In this study, in the beginning, the parameters in the Nash equilibrium equations were estimated, and then the parameters from the reaction function of the central bank and government were calculated. The study has demonstrated that in the Nash equilibrium in the non-cooperative game for Czechia, Hungary, and Romania, the higher the value of parameter \tilde{a}_1 (from the government's response function), the stronger the reaction of the fiscal authorities to a change in the central bank's interest rate. As a result, a lower budget deficit can be expected. Similarly, the higher the value of parameter \tilde{b}_3 (from the central bank's response function), the stronger the monetary authorities' response to the change in the budget deficit. As a result, a higher interest rate can be expected.

In Romania, the government's response to interest rate changes proved to be the strongest, which means that the government's best response to an interest rate increase is to reduce the budget deficit. In turn, the central bank's response to changes in the budget deficit turned out to be the weakest in Romania. This suggests that the central bank of Romania makes a slight correction of interest rates as a result of changes in the budget deficit. On the other hand, the strongest response of the central bank to changes in the budget deficit turned out to be in Hungary, which indicates that its central bank makes a significant correction of interest rates as a result of changes in the budget deficit.

The obtained estimates can be used in further research to simulate the behavior of the central bank and the government in the situation of various exogenous shocks. The proposed model is only a simplification of the policy mix. Possible extensions of the model and empirical analyses based on it might include another set of countries for comparison, or modifying the variable constraints, among others. Further analysis should consider the situation when a given country belongs to a monetary union, and therefore when the monetary policy takes into account the actions of a larger number of players (more fiscal authorities).

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Notes

1. Similar to Kuttner (2002) and Bennett and Loayza (2000).
2. As in Davig and Leeper (2011).
3. $\alpha_3 > 0$; for simplicity we assume that an inflation rate lower than the inflation target (which is under the control of the central bank) positively influences the GDP growth. The literature review informs that high inflation negatively affects the economy (e.g., Barro, 2013). On the other hand, low inflation can positively influence the behaviour of agents through the impact on their decision. Thus, the low inflation can positively influence economic growth. This phenomenon is also investigated by e.g., Mallik and Chowdhury (2001) who found a positive relationship between inflation and economic growth. Thus, the non-linear relationship was found by e.g., Ghosh and Phillips (1998)—in their study based on 145 countries they found a positive relationship between inflation and economic growth when inflation is low and negative for high inflation. Due to the fact that inflation in the euro area is under the control of the ECB (the inflation target is set at the level below, but close to 2%), we adopted a strong assumption of a linear and positive relationship between economic growth and inflation.
4. See Blinder (1982) and Bennett and Loayza (2000).
5. The linear form of reaction functions is a direct consequence of the model assumptions.
6. Exact analytical formulas for the reaction functions of the model can be found in the paper Stawska et al. (2019).
7. Detailed analytical formulas for the Nash equilibrium of the model can be found in the paper Stawska et al. (2019). However, the exact formulas indicating the relationship between parameters $\alpha_1^*, \alpha_2^*, \alpha_3^*, b_1^*, b_2^*, b_3^*$ and $\alpha_1, \alpha_2, \alpha_3, b_1, b_2, b_3$ can be found in part 4.3. of this article in Equation (10).
8. The authors are aware of the fact that politics play a significant role in fiscal policy which is often difficult to identify, let alone quantify. The presented mathematical framework is applied to illustrate a simplified description of reality, i.e. the situation when the government and the central bank are highly-autonomous decision-makers whose primary goals are to maximize economic growth and maintain price stability respectively.
9. The dataset is available upon request.
10. As it is defined by IMF (2016), whose data series we use, cyclically adjusted balance is "Difference between the overall balance and the automatic stabilizers; equivalently, an estimate of the fiscal balance that would apply under current policies if output were equal to potential". Cyclical adjustment allows for making a correction for the impact of the economic cycle on the public finances, hence obtaining a measure which better mirrors the underlying or structural budgetary stance (cf. "ECB," 2012).

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