DYNAMIC ANALYSIS OF THE COOPERATION AND COMPETITION RELATIONSHIP IN THE OIL AND GAS INDUSTRY IN ROMANIA

Doriana Andreea Rămescu[*], Nicoleta Sîrghi, Mihaela Neamțu
Economy, Faculty of Economics and Business Administration, West University of Timisoara, Timișoara, Romania
doriana.ramescu@e-uvt.ro
nicoleta.sirghi@e-uvt.ro
mihaela.neamtu@e-uvt.ro

Abstract: *The aim of the paper is to analyse the cooperation and competition relationship in the oil and gas industry in Romania using the game theory. The players are the companies, the payoffs are the profits obtained by the entities and there are two strategies as cooperation and competition. Two cases are considered: duopolistic and triopolistic market. The mathematical models have as variables the probabilities of choosing cooperation and competition by each player. They are described by two and three nonlinear differential equations. The time delay is introduced in order to highlight the time between choosing a strategy and its effect. The case studies use real data for two and three companies, respectively, with two scenarios related to the obtained payoffs if they cooperate or not. The time evolutions of the variables are carried out using Wolfram Mathematica 9. Finally, some conclusions and future research are drawn.*

Keywords: competition, cooperation, oligopolistic market, evolutionary games, replicator dynamics.

JEL classification: D21, C02, C73, D50, H32

1. Introduction

The evolutionary game theory is a framework to model and study continuous interaction in a large population of agents (Weibull, 1997); Khalifa and al., 2014; Khalifa and al., 2015). In particular, in the oligopolistic market it is based on the survival of the fittest entity. The replicator dynamics is a standard approach that uses differential equations to model the choice of the agents between two strategies. Each strategy leads to a payoff (Zhao and Yuxin, 2015). It is assumed that the strategy of choice has a payoff more than the average payoffs (Zhao and al. 2015).
Lately, the replicator dynamics was studied by (Yi and Wang, 1997; Alboszta and Jacek 2004; Iijima, 2012; Sirghi and al., 2012; Khalifa and al., 2015; Zhao and al. 2015; Khalifa and al., 2017; Aliaga, 2017). In Wesson and Richard (2016), the time delay is considered in the fitness of each strategy and the existence of the oscillations are investigated for the replicator dynamic model.
Taking into account the previous considerations, we consider the mathematical models for the replicator dynamic corresponding to duopoly and triopoly market, respectively, where the players are bounded rational. They can choose two strategies, one being cooperation and the other one competition.
The structure of the paper is as follows. The methodology of the paper is presented in Section 2. Section 3 stands for the analysis of the duopolistic market, where OMV Petrom and Rompetrol are taken into account. Section 4 deals with the analysis of the triopolistic

[*] Corresponding author: Doriana Andreea Rămescu

market, where OMV Petrom, Rompetrol and Lukoil are considered. The conclusions and future research are given in Section 5.

2. Methodology

Firstly, we consider two bounded players as two companies which have to choose between two strategies: cooperation and competition. We denote by p_{11} and p_{21} the net incomes of the players, when they both choose cooperation. In case of competition the net incomes are p_{14} and p_{24}, respectively. When there are different strategies and the first player goes for cooperation and the second one for competition, the payoff for the first company is p_{12} and for the second one is p_{22}. If the first company chooses competition and the second one cooperation, the payoff for the first one is p_{13} and for the second one is p_{23}. Therefore, the payoffs of the firms are displayed in the following table:

Table 1: Payoffs in a duopoly game

No.	Strategies		Company 1	Company 2
1	x_1	x_2	p_{11}	p_{21}
2	x_1	$1-x_2$	p_{12}	p_{22}
3	$1-x_1$	x_2	p_{13}	p_{23}
4	$1-x_1$	$1-x_2$	p_{14}	p_{24}

Source: Neamțu M., Sîrghi N., Rămescu D. (2017)

The change rates of the probabilities for both players to choose cooperation is given by (Neamtu M., Sîrghi N., Rămescu D., 2017):

$$\begin{aligned} x_1'(t) &= x_1(t)(1-x_1(t))(\alpha_0+\alpha_2 x_2(t)) \\ x_2'(t) &= x_2(t)(1-x_2(t))(\beta_0+\beta_1 x_2(t)) \end{aligned} \tag{1}$$

where

$$\alpha_0 = p_{12}-p_{14}, \alpha_2 = p_{11}-p_{12}- p_{13}+p_{14}, \beta_0 = p_{23}-p_{24}, \beta_1 = p_{21}-p_{22}- p_2$$

We consider that there is time delay between choosing a strategy and its effect, therefore the dynamic replicator becomes (Neamțu M., Sîrghi N., Rămescu D., 2017):

$$\begin{aligned} x_1'(t) &= x_1(t)(1-x_1(t-\tau_1))(\alpha_0+\alpha_2 x_2(t)) \\ x_2'(t) &= y_2(t)(1-x_2(t-\tau_2))(\beta_0+\beta_1 x_1(t)) \end{aligned} \tag{2}$$

with $\tau_1 \geq 0$, $\tau_2 \geq 0$.

Proposition 1. (Neamțu M., Sîrghi N., Rămescu D., 2017) *If* $p_{12}-p_{14}<0, p_{23}-b_{24}<0$, *the equilibrium point* O(0, 0) *is locally asymptotically stable, for all* $\tau_1 \geq 0$, $\tau_2 \geq 0$.

Proposition 2. (Neamțu M., Sîrghi N., Rămescu D., 2017) *If there are no delays and* $p_{11}-p_{13}>0, p_{21}-p_{22}>0$, *the equilibrium point* C(1, 1) *is locally asymptotically stable. If* $p_{11}-p_{13}>0, p_{21}-p_{22}>0$,, C(1, 1) *is locally asymptotically stable, for any* $0<\tau_1, \tau_2<$ min $\{\tau_{10}, \tau_{20}\} = \tau_{12}$, *where* $\tau_{10} = \frac{\pi}{2(p_{11}-p_{13})}$, $\tau_{20} = \frac{\pi}{2(p_{21}-p_{22})}$ *a Hopf bifurcation occurs when* $\tau_1 = \tau_2 = \tau_{12}$.

Secondly, we consider three companies denoted by F_i, i = 1,2,3. Company F_1 chooses *competition* with the probability $x_1(0 \le x_1 \le 1)$ and *cooperation* with „$1-x_1$”. In a similar way the probabilities for the other companies are denoted by x_2 and x_3, respectively. The payoffs corresponding to the strategies are given in Table 2.

Table 2: Payoffs in a triopoly game

Nr.	Strategies			Company 1	Company 2	Company 3
1	x_1	x_2	x_3	p_{11}	p_{21}	p_{31}
2	x_1	x_2	$1-x_3$	p_{12}	p_{22}	p_{32}
3	x_1	$1-x_2$	x_3	p_{13}	p_{23}	p_{33}
4	x_1	$1-x_2$	$1-x_3$	p_{14}	p_{24}	p_{34}
5	$1-x_1$	x_2	x_3	p_{15}	p_{25}	p_{35}
6	$1-x_1$	x_2	$1-x_3$	p_{16}	p_{26}	p_{36}
7	$1-x_1$	$1-x_2$	x_3	p_{17}	p_{27}	p_{37}
8	$1-x_1$	$1-x_2$	$1-x_3$	p_{18}	p_{28}	p_{38}

Source: Neamțu M., Sîrghi N., Rămescu D. (2017)

The dynamic replicator with time delay is given by (Neamțu M., Sîrghi N., Rămescu D., pag. 338, 2017):

$$\begin{aligned} \dot{x}_1(t) &= x_1(t)\left(1-x_1(t-\tau_1)\right)\left(\alpha_0+\alpha_2 x_2(t)\right)+\alpha_3 x_3(t)+\alpha_{23} x_2(t) x_3(y)) \\ \dot{x}_2(t) &= x_2(t)\left(1-x_2(t-\tau_2)\right)\left(\beta_0+\beta_1 x_1(t)\right)+\beta_3 x_3(t)+\beta_{13} x_1(t) x_3(t)) \\ \dot{x}_3(t) &= x_3(t)\left(1-x_3(t-\tau_3)\right)\left(\gamma_0+\gamma_1 x_1(t)\right)+\gamma_2 x_2(t)+\gamma_{12} x_1(t) x_2(t)) \end{aligned} \quad (3)$$

with $\tau_1 \ge 0, \tau_2 \ge 0, \tau_3 \ge 0$ and

$$\begin{aligned} &\alpha_0 = p_{14}-p_{18}, \alpha_2 = p_{12}-p_{14}-p_{16}+p_{18}, \\ &\alpha_3 = p_{13}-p_{14}-p_{17}+p_{18}, \\ &\alpha_{23} = p_{11}-p_{12}-p_{13}+p_{14}-p_{15}+p_{16}+p_{17}-p_{18}, \\ &\beta_0 = p_{26}-p_{28}, \beta_1 = p_{22}-p_{24}-p_{26}+p_{28}, \\ &\beta_3 = p_{25}-p_{26}-p_{27}+p_{28} \\ &\beta_{13} = p_{21}-p_{22}-p_{23}+p_{24}-p_{25}+p_{26}+p_{27}-p_{28} \\ &\gamma_0 = p_{37}-p_{38}, \gamma_1 = p_{33}-p_{34}-p_{37}+p_{38}, \\ &\gamma_2 = p_{35}-p_{36}-p_{37}+p_{38}, \\ &\gamma_{12} = p_{31}-p_{32}-p_{33}+p_{34}-p_{35}+p_{36}+p_{37}-p_{38} \end{aligned} \quad (4)$$

Proposition 3. (Neamțu M., Sîrghi N., Rămescu D., 2017). If $p_{14}-p_{18}<0, p_{26}-p_{28}<0, p_{37}-p_{38}<0$, the equilibrium point $A_0(0,0,0)$ is locally asymptotically stable for all $\tau_1 \ge 0, \tau_2 \ge 0, \tau_3 \ge 0$.

Proposition 4. (Neamțu M., Sîrghi N., Rămescu D., 2017). If $p_{11}-p_{15}>0, p_{21}-p_{23}>0, p_{31}-p_{32}>0, \tau_1=\tau_2=\tau_3=0$, the equilibrium point $A_{123}(1,1,1)$ is locally asymptotically stable. If $p_{11}-p_{15}>0, p_{21}-p_{23}>0, p_{31}-p_{32}>0$, and

$\tau_1 = \tau_2 = \tau_3 \in [0, \tau_{123})$, where $\tau_{23} =$ min $\{\tau_{10}, \tau_{20}, \tau_{30}\}, \tau_{10} = \frac{\pi}{2(p_{11}-p_{15})}$, $\tau_{20} = \frac{\pi}{2(p_{21}-p_{23})}$, $\tau_{30} = \frac{\pi}{2(p_{31}-p_{32})}$, then $A_{123}(1,1,1)$ is locally asymptotically stable. A Hopf bifurcation occurs when $\tau_1 = \tau_2 = \tau_3 = \tau_{123}$.

3. Duopoly in the gas and oil Industry

For the particular case of OMV Petrom (Company 1) and Rompetrol (Company 2), the payoff matrix is given by:

Tabel 3: The payoffs of the companies

No.	Strategies		Company 1	Company 2
1	x_1	x_2	373	190.74
2	x_1	$1-x_2$	834	0
3	$1-x_1$	x_2	0	853.74
4	$1-x_1$	$1-x_2$	$V_{\text{OMV Petrom}} - 503$	$V_{Rompetrol} - 503$

Source: own processing

We consider two scenarios:
Scenario 1. $OMV\ Petrom$ and $Rompetrol$ get greater payoffs in the competition case ($V_{OMV\ Petrom} = 1330, V_{Rompetrol} = 1350$);
Scenario 2. $OMV\ Petrom$ and $Rompetrol$ get greater payoffs in the cooperation case ($V_{OMV\ Petrom} = 2000, V_{Rompetrol} = 2100$).

If there are no delays $\tau_1 = \tau_2 = 0$, the equilibrium point (1, 1) is locally asymptotically stable (see Figure 1):

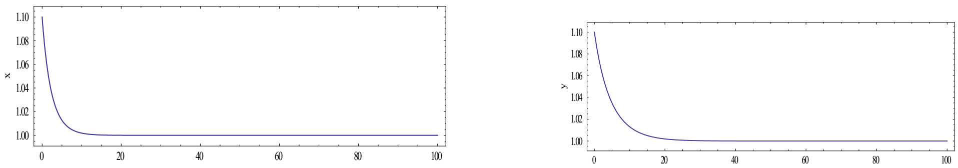

Figure 1: The equilibrium point (1, 1) is locally asymptotically stable for $\tau_1 = \tau_2 = 0$ and $V_{OMV\ Petrom} = 1330, V_{Rompetrol} = 1350;$
Source: own processing

The decisions of competition lead to a favourable situation. If there are no delays $\tau_1 = \tau_2 = 0$, the equilibrium point (0,0) is unstable (see Figure 2). The decisions of cooperation lead to an unstable situation.

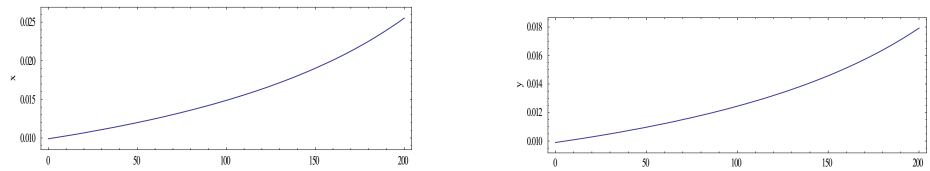

Figure 2: The equilibrium point (0,0) is unstable for $\tau_1 = \tau_2 = 0$ and $V_{OMV\ Petrom} = 1330, V_{Rompetrol} = 1350;$
Source: own processing

If there is delay only for $OMV\ Petrom$ ($\tau_2 = 0$), the equilibrium point (1,1) is locally asymptotically stable for (τ_1 ∈[0, 4.21)) (see Figure 3).
The decisions of competition lead to a favourable situation for τ_1 ∈[0, 4.21), $\tau_2 = 0$

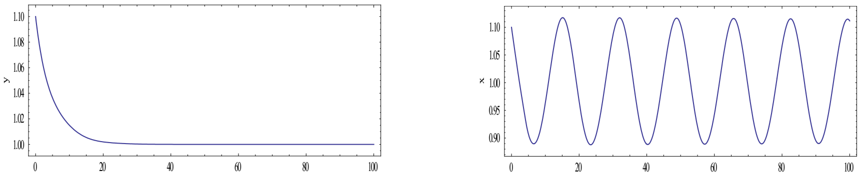

Figure 3: If there is delay only for $OMV\ Petrom$ ($\tau_2 = 0$), there are oscillations for τ_1 ∈[0, 4.21), $\tau_2 = 0$ and $V_{OMV\ Petrom} = 1330\ and\ V_{Rompetrol} = 1350$;
Source: own processing

If there is delay only for $Rompetrol\ \tau_1 = 0$, the equilibrium point (1,1) is locally asymptotically stable for τ_2∈ [0, 8.23) (see Figure 4):
The decisions of competition lead to a favourable situation for τ_2 ∈[0, 8.23), $\tau_1 = 0$

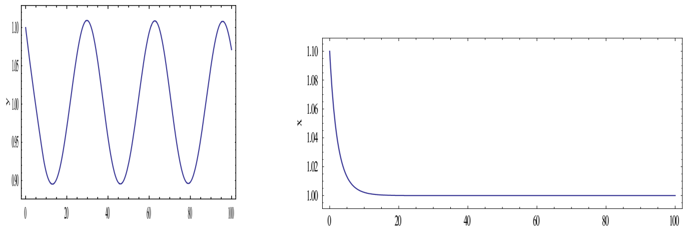

Figure 4: If there is delay only for $Rompetrol\ \tau_1 = 0$, there are oscillations for τ_2 ∈[0, 8.23), $\tau_1 = 0$ and $V_{OMV\ Petrom} = 1330\ și\ V_{Rompetrol} = 1350$;
Source: own processing

4. Triopoly in the gas and oil Industry

In the triopoly case we consider three players as: OMV Petrom (Company 1), Rompetrol (Company 2) and Lukoil (Company 3) with the probabilities to choose cooperation x_1, x_2 and x_3, respectively and $1 - x_1$, $1 - x_2$ and $1 - x_3$ the probabilities to choose competition.
The payoffs are given in Table 4:

Table 4: The payoffs in the triopoly game

Nr.	Strategies			OMV Petrom Company 1	Rompetrol Company 2	Lukoil Company 3
1	x_1	x_2	x_3	$T_{\text{OMV Petrom}} - C_{OMV\ Petrom}$	$T_{Rompetrol} - C_{Rompetrol}$	$T_{Lukoil} - C_{Lukoil}$
2	x_1	x_2	$1 - x_3$	$T - T_{Rompetrol} - C_{OMV\ Petrom}$	$T - T_{OMV\ Petrom} - C_{Rompetrol}$	0
3	x_1	$1 - x_2$	x_3	$T - T_{Lukoil} - C_{OMV\ Petrom}$	0	$T - T_{OMV\ Petrom} - C_{Lukoi}$
4	x_1	$1 - x_2$	$1 - x_3$	$T_{\text{OMV Petrom}} - C_{OMV\ Petrom}$	$V_{Rompetrol} - A$	$V_{Lukoil} - A$
5.	$1 - x_1$	x_2	x_3	0	$T - T_{Lukoil} - C_{Rompetrol}$	$T - T_{Rompetrol} - C_{Lukoil}$

Nr.	Strategies			OMV Petrom Company 1	Rompetrol Company 2	Lukoil Company 3
6	$1-x_1$	x_2	$1-x_3$	$V_{OMV\ Petrom}-A$	$T_{Rompetrol}-C_{Rompetrol}$	$V_{Lukoil}-A$
7	$1-x_1$	$1-x_2$	x_3	$V_{OMV\ Petrom}-A$	$V_{Rompetrol}-A$	$V_{Lukoil}-C_{Lukoil}$
8	$1-x_1$	$1-x_2$	$1-x_3$	$V_{OMV\ Petrom}-A$	$V_{Rompetrol}-A$	$V_{Lukoil}-A$

Source: own processing

Where
$T_{omv\ Petrom}$ = overall potential market for OMV Petrom
$T_{Rompetrol}$ = overall potential market for Rompetrol
T_{Lukoil} = overall potential market for Lukoil
$C_{OMV\ Petrom}$ = cost of engaging in competition for OMV Petrom
$C_{Rompetrol}$ = cost of engaging in competition for Rompetrol
C_{Lukoil} = cost of engaging in competiton for Lukoil
T = overall potential market = 855 mil Ron
A = penalties if the companies (OMV Petrom, Rompetrol, Lukoil) are found to practice illegal type of cooperation = 503 mil Ron

$T_{OMV\ Petrom}-C_{OMV\ Petrom}=394-21=373$ mil Ron
$T_{Rompetrol}-C_{Rompetrol}=192-1.26=190.74$ mil Ron
$T_{Lukoil}-C_{Lukoil}=98-0.6=97.4$ mil Ron
$T-T_{Rompetrol}-C_{OMV\ Petrom}=855-192-21=642$ mil Ron
$T-T_{OMV\ Petrom}-C_{Rompetrol}=855-394-1.26=459.74$ mil Ron
$T-T_{Lukoil}-C_{OMV\ Petrom}=855-98-21=736$ mil Ron
$T-T_{OMV\ Petrom}-C_{Lukoil}=855-394-0.6=460.4$ mil Ron
$T-T_{Lukoil}-C_{Rompetrol}=855-98-1.26=755.74$ mil Ron
$T-T_{Rompetrol}-C_{Lukoil}=855-192-0.6=662.4$ mil Ron
$T_{Lukoil}-C_{Lukoil}=98-0.6=97.4$ mil Ron

The companies (OMV Petrom, Rompetrol și Lukoil) obtain greater payoffs if they cooperate in the following conditions:

$$V_{OMV\ Petrom}-A>\max(T-T_{Lukoil}-C_{OMV\ Petrom},T-T_{Rompetrol}-C_{OMV\ Petrom},T_{OMV\ Petrom}-C_{OMV\ Petrom})$$

that leads to

$$V_{OMV\ Petrom}-A>736$$

$$V_{Rompetrol}-A>\max(T-T_{Lukoil}-C_{Rompetrol},T-T_{OMV\ Petrom}-C_{Rompetrol},T_{Rompetrol}-C_{Rompetrol})$$

with $V_{Rompetrol}-A>755.74$

$$V_{Lukoil}-A>\max(T-T_{Rompetrol}-C_{Lukoil},T-T_{OMV\ Petrom}-C_{Lukoil},\quad T_{Lukoil}-C_{Lukoil})$$

with $V_{Lukoil}-A>662.4$.
This is equivalent to:

$$V_{OMV\ Petrom}>1239, V_{Rompetrol}>1258.74, V_{Lukoil}>1165.4$$

To visualize the variables $x_1(t)$, $x_2(t)$ and $x_3(t)$ we consider two scenarios:

Scenario 1. All companies get smaller payoffs when they cooperate as opposed to the situation when they do not: $V_{OMV\ Petrom} = 870,\ V_{Rompetrol} = 860,\ V_{Lukoil} = 700$
Scenario 2. All companies get greater payoffs when they cooperate as opposed to the situation when they do not: $V_{OMV\ Petrom} = 2300,\ V_{Rompetrol} = 2500,\ V_{Lukoil} = 2000$
In *Scenario 1***,** the payoffs obtained in the competition are greater than in cooperation, the equilibrium point (1,1,1) is locally asymptotically stable, that means the competition is a preferred situation. The equilibrium point (0,0,0) is unstable and making a cooperative decision is unfavourable.
In *Scenario 2***,** for $V_{OMV\ Petrom} = 2300,\ V_{Rompetrol} = 2500,\ V_{Lukoil} = 2000,$ the equilibrium point (0,0,0) is locally asymptotically stable for all values of the delay parameter. In Figure 5, we can notice if there is delay for *OMV Petrom (Company 1)* than the equilibrium point (1,1,1) is locally asymptotically stable for τ_1 ∈ (0, 4.21) and there are oscillations for $\tau_1 = 4.21\ days, \tau_2 = 0\ , \tau_3 = 0$:

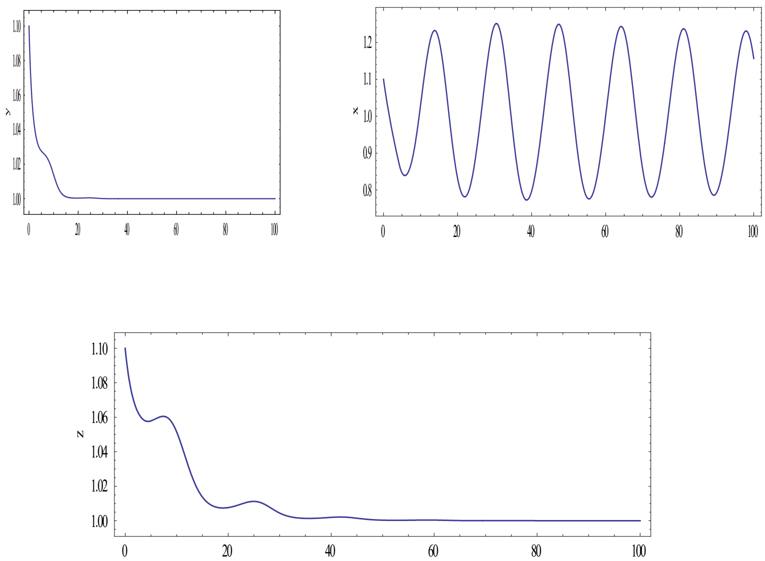

Figure 5: There are oscillations for $\tau_1 = 4.21\ days, \tau_2 = 0, \tau_2 = 0$ and $V_{OMV\ Petrom} = 2300,\ V_{Rompetrol} = 2500,\ V_{Lukoil} = 2000$
Source: own processing

If there is delay for *Rompetrol (Company 2***),** then the equilibrium point (1,1,1) is locally asymptotically stable for τ_2 ∈ (0, 8,23) and there are oscillations for $\tau_2 = 8.23\ days, \tau_1 = 0\ , \tau_3 = 0.$
If there is delay for *Lukoil (Company 3),* then the equilibrium point (1,1,1) is locally asymptotically stable for τ_3 ∈ (0, 16,12) and there are oscillations for $\tau_3 = 16{,}12\ days, \tau_1 = 0\ , \tau_2 = 0$.
If for Rompetrol (Company 2) and Lukoil (Company 3) there is no delay in making the competition decision, then OMV Petrom (Company 1) has to make the competition decision in [0,4.21) for an economic profitability for all. If there is no delay in making the competion decision for OMV Petrom and Lukoil, then Rompetrol has to make the competition decision in [0,8.23) for an economic profitability on behalf of all all. In a similar way, Lukoil has to make the competition decision in [0,16.12).

In Figure 6, we can notice that if there is no delay, the equilibrium point (1, 1, 1) is locally asymptotically stable, that means the competition decision for all is convenient.

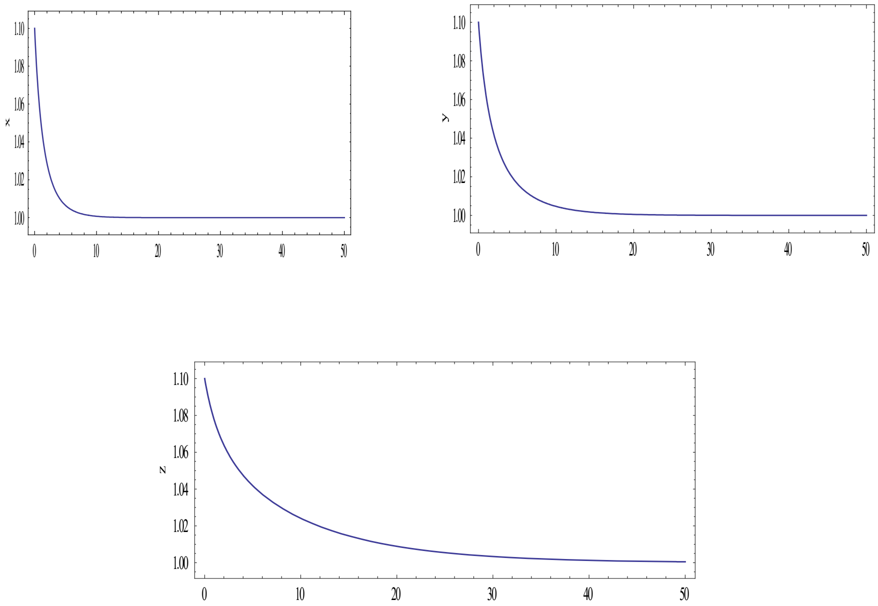

Figure 6: The equilibrium point (1,1,1) is locally asymptotically stable for $\tau_1 = 0, \tau_2 = 0, \tau_3 = 0$ and $V_{OMV\ Petrom} = 2300,\ V_{Rompetrol} = 2500,\ V_{Lukoil} = 2000$
Source: own processing

4. Conclusion

In the framework of game theory, the paper has analysed the cooperation and competition relationship among two and three companies, respectively. The mathematical models are described by nonlinear differential equations with time delay. The introduction of the time delay is mandatory, because the effect of choosing a strategy becomes visible after a period of time. The existence of the oscillations in the economic processes has been investigated, in two scenarios: the competition leads to a greater payoff than the cooperation and vice versa. For duopolistic case two companies (OMV Petrom and Rompetrol) are considered with two strategies: cooperation and competition. Their payoffs are represented in a matrix and the replicator dynamics with time delay is formulated. In order to visualize the evolution of the probabilities for making the cooperation decision Mathematics software is used.
Two scenarios are taken into consideration for OMV Petrom are Rompetrol. In Scenario 1 the companies obtain smaller payoffs if they cooperate and greater payoff if they compete, in Scenario 2. Similarly, we conduct an analysis for the triopolistic case, where three players are introduced: OMV Petrom (Company 1), Rompetrol (Company 2) and Lukoil (Company 3). Each company has to choose between two strategies: cooperation and competition.
Moreover, as a future work we can investigate the stochastic mathematical model that considers the economical environmental perturbations, as in (Neamțu, 2010; Sirghi, Neamțu, 2013).

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Bio-note

Doriana Andreea Rămescu is a third year *PhD Student at the Department of Economics at the Faculty of Economics and Business Administration, West University of Timişoara, Romania*. The thesis title is: „Relation competition - Game theory in market structures”.

Nicoleta Sîrghi, is *Professor PhD habil. of Economics at the Faculty of Economics and Business Administration, West University of Timisoara, Romania*. The current research field is related to study the oligopolistic market and the game theory with applications in economics. She reviewed articles submitted to ISI and IDB journals and published 9 books and over 85 articles in ISI and IDB journals.

Mihaela Neamțu, is *Professor PhD habil. of Mathematics at the Faculty of Economics and Business Administration, West University of Timisoara, Romania*. The main direction of the research field is related to the study of dynamical systems from economy, computer science, biology and medicine described by nonlinear differential equations with time delay. She is the Director of two national research projects and the Management Committee Membership in a COST Action 2016-2020. She published 6 books, over 110 articles in ISI and IDB journals, reviewed articles submitted to IDB and ISI journals, and has over 100 citations in ISI and IDB journals.