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An Analysis of Chinese 4G Telecom Market

Xing Tang[1] & Xin Xia[2]

Abstract

Two years after China's 4G mobile networks first began operations, the country now has 562 million 4G subscribers across its three main telcos. This paper considers a triopoly model based on nonlinear demand functions which is different from previous relative studies. We apply the model into Chinese 4G telecommunication market and study game process of the triopoly. By using the theory of bifurcations of dynamical systems, local stable region of Nash equilibrium point is obtained. Then we use simulations to show complex dynamical behaviors of the system. The results illustrate that altering the relevant parameters of the system can affect the stability of Nash equilibrium point and finally cause chaos to occur. The results have an important theoretical and practical significance to Chinese 4G telecom market..

Key words: Triopoly Model, Nonlinear Demand Functions, Nash Equilibrium Point

I. Introduction

Pre-1994, the Chinese telecommunications industry was under the monopoly of the Ministry of Posts and Telecommunications (MPT) (Chen, Maa, Chen, 2009), whose primary aim was to provide the telecommunications service in China, especially the fixed-line telephone services. In July 1994, the government broke the monopoly of the MPT by establishing new state-owned enterprises. The operations arm of MPT was renamed the China Telecommunications Corporation (China Telecom) and the China United Telecommunications (China Unicom) was set up to foster domestic competition. Nonetheless, this was no real competition because China Telecom still controlled the only public Fixed Telephone Network (FTN) in China and all funding and personnel of China Telecom came directly from the MPT. China Unicom was at a serious competitive disadvantage, and was mainly restricted to the mobile sector. The company was simply too weak to pose any threat to China Telecom.

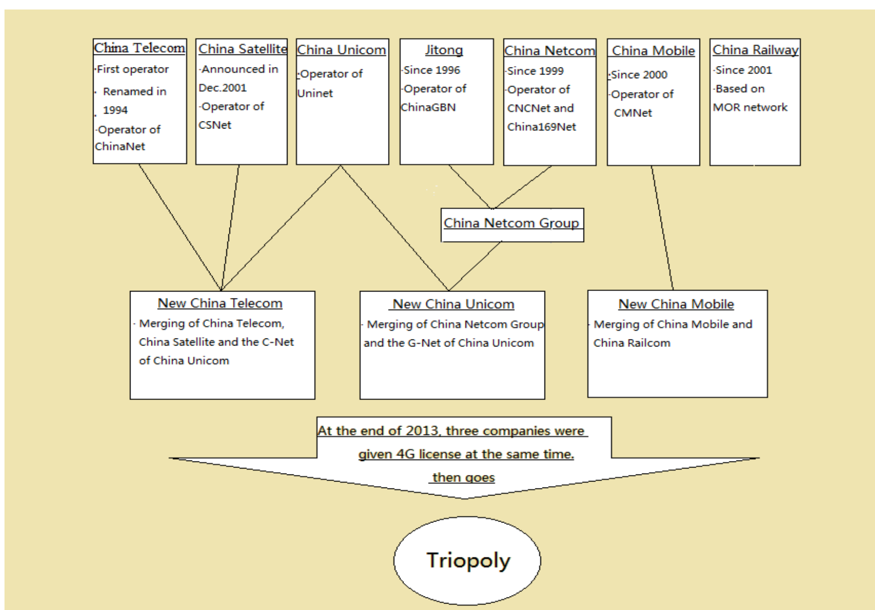
In 2000, the China Mobile Communications Group (China Mobile) and China Satellite Communications Group (China Satellite) broke away from China Telecom in order to encourage domestic competition and enhance efficiency. China Railway Communications Corporation (China Railcom) was also set up and became China's sixth major telecommunications carrier. To further break the monopoly of China Telecom, which still had about 80% of the FTN phone market, on 7th November, 2001, China Satellite became the seventh telecommunications operator in China. Accordingly, China Telecom was reorganized geographically. It retained only 70% of its backbone network in South China. The other 30% of the network was handed over to the new China Netcom Group, formed by the merging of China Netcom and Jitong. On 8 January 2002, to foster domestic competition, China Mobile, China Netcom and China Satellite were allowed to offer restricted non-fixed-line telecommunications services. Yet, these reforms still did not touch on FTN services.

[1] (PhD student & Research Assistant, School of Economics and Resource Management, Beijing Normal University, Beijing, China) Room 211, Emerging Markets Institute, 2nd Floor, Jing Shi Xue Tang, Beijing Normal University, No.19 Xinjiekou Waidajie, Haidian District, Beijing 100875, P. R. China
[2] (MA Student, Department of Economics, University of Missouri-Columbia, MO, USA)

According to the experience of other countries, competition not only drives an improved sector performance, but it also energizes organizational reform of the incumbent and contributes to consolidating and legitimating the regulatory process. For this purpose, Chinese government had done lots to encourage competition before, and would go on in the future. On May 23rd, 2008, In order to make full use of the telecommunication resource, and to encourage healthy competition in telecommunication markets, it was declared that the six operators were merged into three operators. China Mobile and China Railcom were merged into a company named New China Mobile. The G-net of China Unicom and China Netcom were merged into a company named New China Unicom. The C-net of China Unicom, China Satellite and China Telecom were merged into a company named New China Telecom. They would be allowed to offer the full range of fixed telecommunications, mobile phone, data connection and other basic telecommunications services. Though market share was a bit different, now they have been given 4G license at the same time at the end of 2013 and standing at the same starting line again, respectively, which was predicted to increase the degree of competition within China's telecommunications industry substantially. Thus, a triopoly 4G market starts in China. Table 1 shows the progress of the formation of the triopoly.

Analysis of triopoly is not strange anymore as many studies have been undertaken in recent years. The results show the complex dynamic process. T. Puu (1996) first explained chaos solutions for triopoly, then H.N. Agiza (1998) even increased one oligopolist and figured out explicit stability zones and later E.Ahmed and H.N. Agiza (1998) developed the competitors to n, G.I. Bischi, and M. Kopel (1999) improved it with detail computation and simulation. E.M. Elabbasy, H.N. Agiza, A.A. Elsadany, and H. EL-Metwally (2007) considered heterogeneous players in dynamics of triopoly game.

TABLE 1



1.Model

Actually in the market, it is mainly the price competition. We let p_i (t) (i = 1, 2, 3) represent the price of China Telecom①, China Unicom ②and China Mobile③, respectively, and q_i (t) (i = 1, 2, 3) represent their demand during period t = 0, 1, 2, ...Fang Chen , Jun Hai Ma, and Xiao Qiang Chen modeled a similar topic which is Chinese 3G market in 2009, they use a linear model : $Q_i(t) = a_i + b_i p_i(t) + c_i p_i(t) + d_i p_i(t)$. Actually in practice, relationship between demand and price of mobile telecommunication is very complex and it is not a simple linear relationship.

Hence, we choose the nonlinear demand function which is closer to reality: $q = ap^{-2}$ $(a > 0)$ (Chen and Miu, 2002) and this kind of function is used once by Zhihui Sun · Junhai Ma. Since products that the three companies produce are similar, we add alternatives to the function. The following are the demand functions respectively for ①②③:

$$Q_1(t) = a_1 + b_1p_1(t)^{-2} + c_1p_2(t) + d_1p_3(t)$$
$$Q_2(t) = a_2 + b_2p_1(t) + c_2p_2(t)^{-2} + d_1p_3(t)$$
$$Q_3(t) = a_3 + b_3p_1(t) + c_3p_2(t) + d_3p_3(t)^{-2}$$

The cost function: $C_i(t)= m+s_iQ_i(t)$, and $L_i(t) = p_i(t)q_i(t)-C_i(t)$, where L_i represents profit of each tripolist. The game between the firms is continuous; therefore, decision-making is a repeated process. According to the technique of Agiza (2002), it is an adjustment process on the basis of the last period game results. Thus the price for period t + 1 is decided as follows:

$p_1(t+1) = p_1(t)+\alpha_1p_1(t)\partial L_1(t)/\partial p_1(t)$, where α_1 is the price adjustment speed of China Telecom.
The dynamical system in Chinese 4G telecom market can be modeled as follows:

$$p_1(t+1) = p_1(t)+\alpha_1p_1(t)(a_1 - b_1p_1^{-2} + c_1p_2 + d_1p_3 + 2s_1b_1p_1^{-3})$$
$$P_2(t+1) = p_2(t)+\alpha_2p_2(t)(a_2 + b_2p_1 - c_2p_2^{-2} + d_2p_3 + 2s_2b_2p_2^{-3})$$
$$P_3(t+1) = p_3(t)+\alpha_3p_3(t)(a_3 + b_3p_1 + c_3p_2 - d_3p_3^{-2} + 2s_3b_3p_3^{-3})$$

2. Simulation analysis

As we assume they have the similar demand function with same pattern, the difference between them will be the adjustment speed parameter α_i (i=1,2,3), so we gonna study on it to see how these parameters would affect the system. Since α_i (i = 1, 2, 3) is a controllable parameter, and when we use the simulation method, other parameters of the system are as follows: $a_1 = 30$, $a_2 = 4$, $a_3 = 23$, $b_1 = 3$, $b_2 = 4$, $b_3 = 4$, $c_1=2$, $c_2=3$, $c_3=3$, $d_1 = 4$, $d_2 = 3$, $d_3 = 3$, $s_1=0.1$, $s_2=0.2$, $s_3=0.1$.(as intercept of the cost function has been eliminated during taking derivative of the profit function, so we do not need to do simulation with it)

The Jacobian matrix of the system is:

$$J = \begin{pmatrix} 1+\alpha_1\Phi_1 & \alpha_1c_1p_1 & \alpha_1d_1p_1 \\ \alpha_2b_2p_2 & 1+\alpha_2\Phi_2 & \alpha_2d_2p_2 \\ \alpha_3b_3p_3 & \alpha_3c_3p_3 & 1+\alpha_3\Phi_3 \end{pmatrix}$$

Where

$$\Phi_1 = a_1 + b_1p_1^{-2} + c_1p_2 + d_1p_3 - 4s_1b_1p_1^{-3} = 64.3283$$
$$\Phi_2 = a_2 + b_2p_1 + c_2p_2^{-2} + d_2p_3 - 4s_2b_2p_2^{-3} = 11.2167$$
$$\Phi_3 = a_3 + b_3p_1 + c_3p_3 + d_3p_3^{-2} - 4s_3b_3p_3^{-3} = 50.2937$$

Then the characteristic polynomial of the system is:

$$f(\lambda) = \lambda^3 + A\lambda^2 + B\lambda + C$$
$$A = \Phi_1\alpha_1 + \Phi_2\alpha_2 + \Phi_3\alpha_3 - 3 = 64.3283\alpha_1 + 11.2167\alpha_2 + 50.2937\alpha_3 - 3$$
$$B = \Phi_1\Phi_2\alpha_1\alpha_2 + \Phi_2\Phi_3\alpha_2\alpha_3 + \Phi_1\Phi_3\alpha_1\alpha_3 - 2\Phi_1\alpha_1 - 2\Phi_2\alpha_2 - 2\Phi_3\alpha_3 + 3$$
$$= 721.5512\alpha_1\alpha_2 + 564.1293\alpha_2\alpha_3 + 3235.3082\alpha_1\alpha_3 - 128.6566\alpha_1 - 22.4334\alpha_2 - 100.5875\alpha_3 + 3$$

$C = \Phi_1\Phi_2\Phi_3\alpha_1\alpha_2\alpha_3 - \Phi_1\Phi_2\alpha_1\alpha_2 - \Phi_2\Phi_3\alpha_2\alpha_3 - \Phi_1\Phi_3\alpha_1\alpha_3 + \Phi_1\alpha_1 + \Phi_2\alpha_2 + \Phi_3\alpha_3 - 1$
$= 36289.4817\alpha_1\alpha_2\alpha_3 - 721.5512\alpha_1\alpha_2 - 564.1293\alpha_2\alpha_3 - 3235.3082\alpha_1\alpha_3 + 64.3283\alpha_1 + 11.2167\alpha_2 + 50.2937\alpha_3 - 1$

The local stability of Nash equilibrium can be gained according to Routh-Hurwizs condition (Hurwitz, 1985) :

$f(1) = A + B + C + 1 > 0,$
$-f(-1) = -A + B - C + 1 > 0,$
$C^2 - 1 < 0,$
$(1 - C^2)^2 - (B - AC)^2 > 0,$

By computing the equation with assuming $p_i(t) = p_i(t+1)$, which are:

$\alpha_1 p_1(t)(a_1 - b_1 p_1^{-2} + c_1 p_2 + d_1 p_3 + s_1 b_1 p_1^{-3}) = 0,$
$\alpha_2 p_2(t)(a_2 + b_2 p_1 - c_2 p_2^{-2} + d_2 p_3 + s_2 b_2 p_2^{-3}) = 0,$
$\alpha_3 p_3(t)(a_3 + b_3 p_1 + c_3 p_2 - d_3 p_3^{-2} + s_3 b_3 p_3^{-3}) = 0,$

Fixed points (p_1,p_2,p_3) of the system are obtained: for example (3.3012,0.4634,-0.4129), (0.2273,0.4901,0.2070), (-0.6588,1.2470,0.8548), (-0.3103,15.5728,-0.2488), but in fact as we all know the price must be positive, and we ignore negative ones, that is we only consider the Nash equilibrium point: $p_1 = 0.2273$, $p_2 = 0.4901$, $p_3 = 0.2070$. The Nash equilibrium point is stable with bounded $(\alpha_1,\alpha_2,\alpha_3)$. With α_1 held fixed, we can get the stable region of (α_2,α_3). For example, at $\alpha_1=0.1$, the stable region of (α_2,α_3) is showed in Figure.1. Which means for the value of (α_2,α_3) in the stable region, the Nash equilibrium is also stable. In this way, we can also get stable region of (α_1,α_3) with α_2 held fixed which is showed in Figure.2 and the stable region of (α_1,α_2) with α_3 held fixed with is showed in Figure.3.

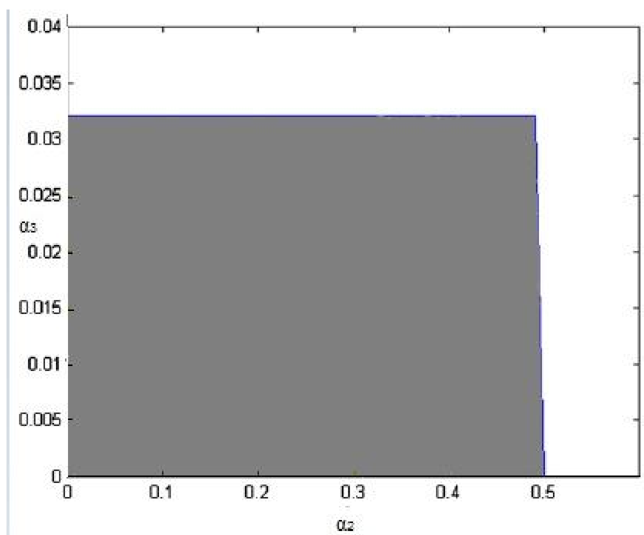


Figure 1: The stable region of Nash point in the phase plane of adjustment speed (α_2,α_3) with α_1 held fixed.

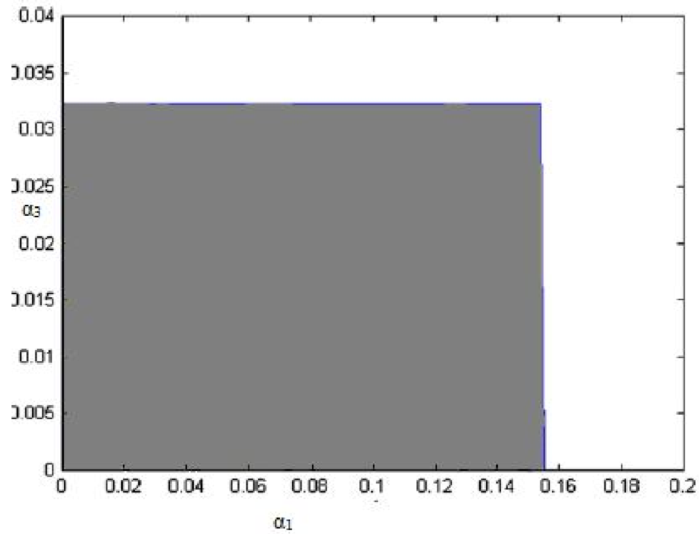


Figure 2: **the stable region of Nash point in the phase plane of adjustment speed(α_1,α_3) with α_1 held fixed.**

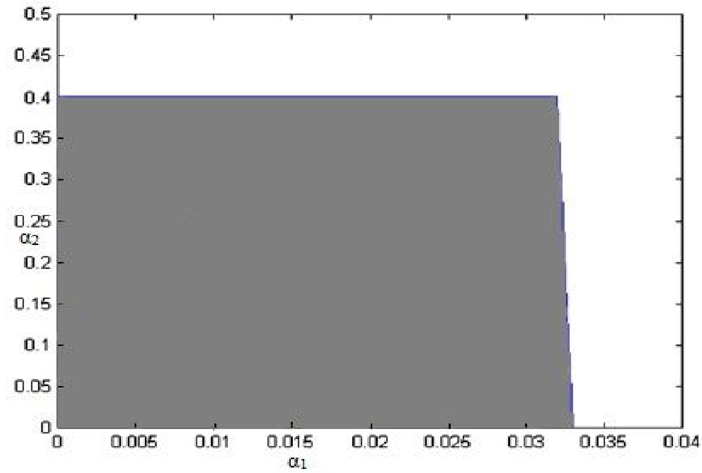


Figure 3: the stable region of Nash point in the phase plane of adjustment speed(α_1,α_2) with α_1 held fixed.

When (α_1,α_2,α_3) is held in the stable region, economic meaning is no matter what (p_1,p_2,p_3) is in the initial situation, the bundle will finally achieve Nash equilibrium which is (0.2273,0.4901,0.2070) after finite games. It is easy to find that when the adjustment speed α_i is increased, the price will be increased, that will also improve their profit. So accelerating the adjustment speed is common knowledge for the three companies. Once one company speeds up too quickly, then it may push (α_1,α_2,α_3) to be out of the stable region, then the system will be unstable and finally be into chaos. So now we need to find the specific region of α to get rid of possibility to be into chaos.

3. The effect of α on the system:

Since we know that once (α_1,α_2,α_3) is out of the stable region, no Nash equilibrium can be achieve then. Take firm 1: China Telecom as an example. That is we will keep α_2 and α_3 fixed with only α_1 changing from the range we have got previously: which is $\alpha_2 = 0.3$, $\alpha_3 = 0.016$, $\alpha_1 \in [0,0.3]$ (the range do not need to be that small since we will get a more precise one). Figure 4 is an bifurcation diagram that shows how the parameter changes will affect the (p_1, p_2, p_3). It is a logistic map; we can see situation of stable, period doubling, and chaos. We find that when α_1 is less or equal to 0.155, the price of the system is stable which an equilibrium state is.

But when α_1 keeps increasing, there will be period doubling bifurcation, since price will change in a range from up and down till 0.2. When it still goes up, another period bifurcation happens which is a 4-cycle area of price range, and then the system will end into chaos with all kind of changed and unatable price bundle (p_1,p_2,p_3). This is good for telling whether the adjustment speed is not appropriate, nor the system is stable for a regular market for oligopolists to make decisions.

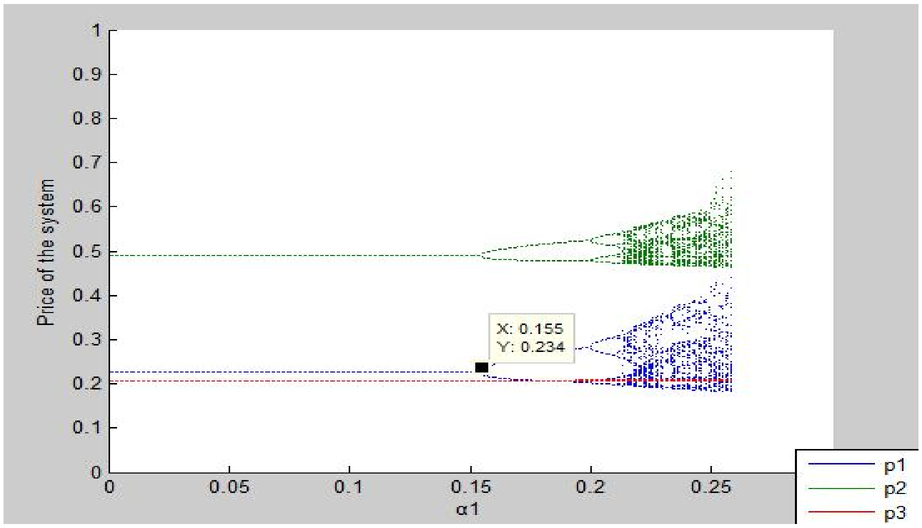


Figure 4.Price bifurcation diagram with $\alpha_2 = 0.3, \alpha_3 = 0.016$ and $\alpha 1 \in [0,0.3]$

And Figure5 shows the chaos attractor of (p_1,p_2,p_3) with $\alpha_2 = 0.3, \alpha_3 = 0.016$ and $\alpha 1 \in [0,0.3]$, we can see the price bundle (p_1,p_2,p_3) are all in a group, which means though they keep changing, the range of the point will always be within some area regardless of what initial prices they are.

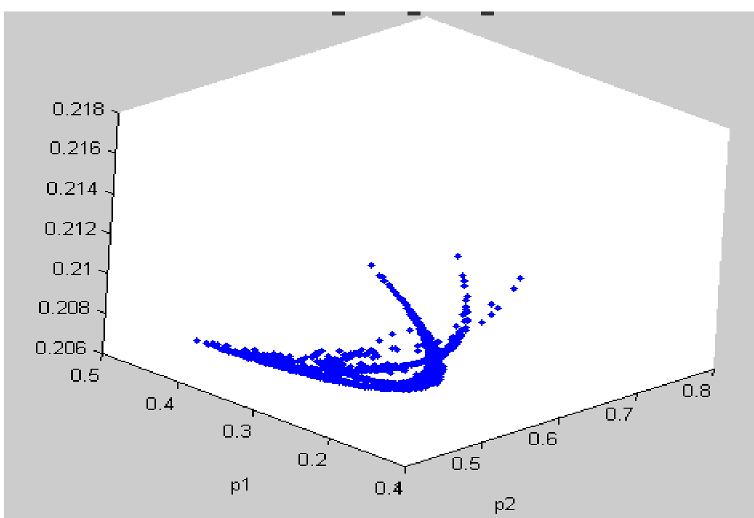


Figure 5: Chaos attractor of the system with price bundle of (p_1,p_2,p_3), while $\alpha_2 = 0.3, \alpha_3 = 0.016$ and $\alpha_1 \in [0,0.3]$

Similarly, Figure 6 is the price bifurcation diagram with $\alpha_1=0.15$, $\alpha_3 = 0.016$ and α_2 keeps changing from 0 to 0.9. Figure 7 shows chaos attractor with the same bundle of (α_1, α_2, α_3) in figure 6. Figure 8 is the price bifurcation diagram with $\alpha_1=0.084$ $\alpha_2 = 0.3$ and α_3 keeps changing from 0 to 0.9. Also figure 9 is chaos attractor of the same (α_1, α_2, α_3) of model in Figure 8.

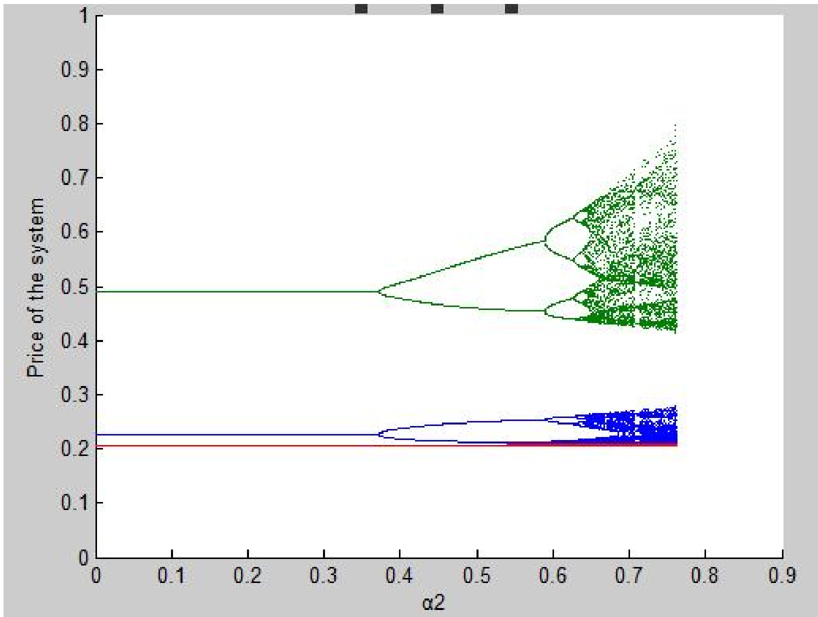


Figure 6: Price bifurcation diagram with α_1= 0.15,α_3 =0.016 and $\alpha 2 \in$ **[0,0.9]**

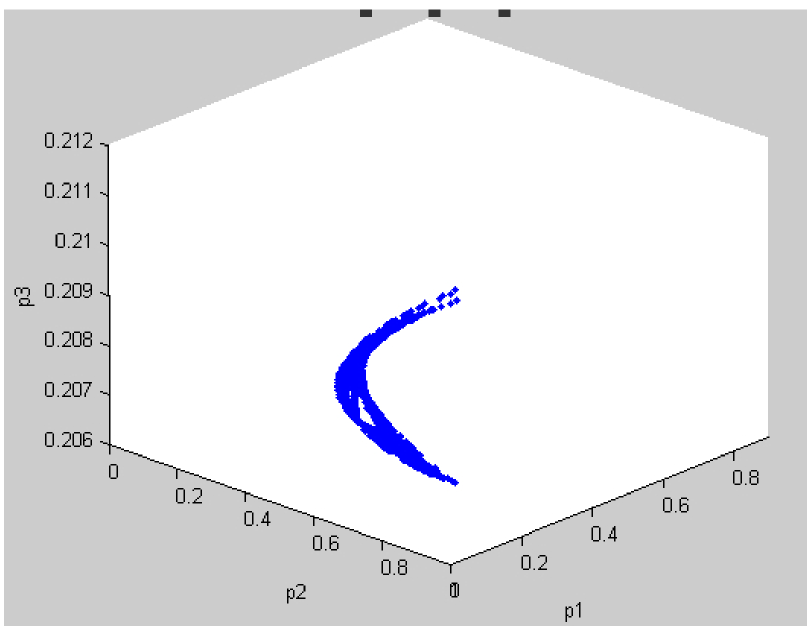


Figure 7: Chaos attractor of the system with price bundle of (p_1,p_2,p_3), while with α_1= 0.15,α_3 **=0.016 and** $\alpha 2 \in$ **[0,0.9].**

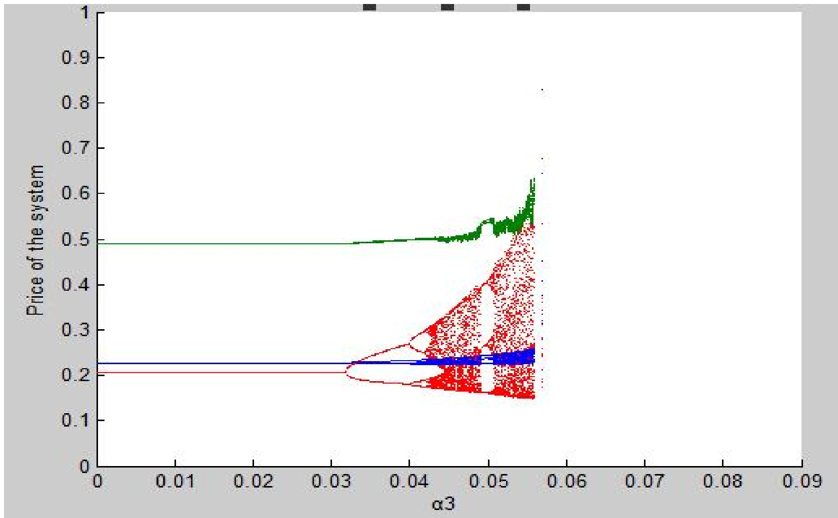


Figure 8: Price bifurcation diagram with α_1= 0.084,α_2=0.3 and $\alpha_3 \in$ [0,0.09]

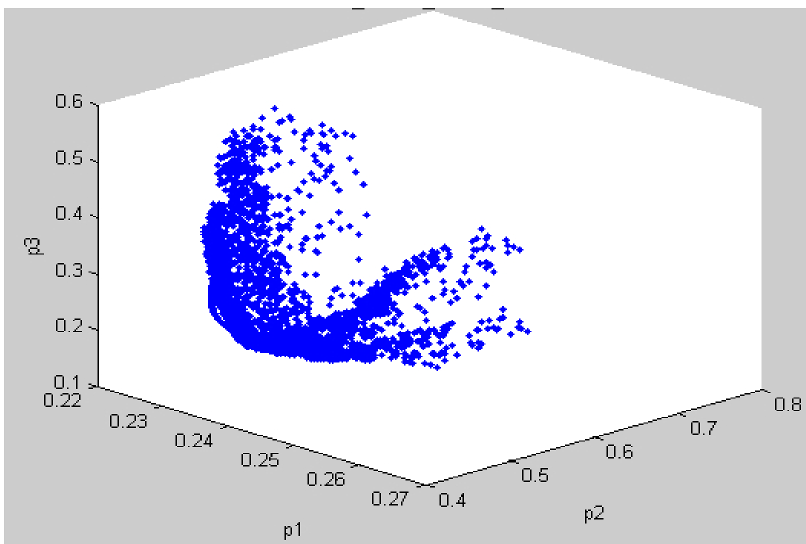


Figure 9: Chaos attractor of the system with price bundle of (p_1,p_2,p_3), while α_1= 0.084,α_2=0.3 and $\alpha_3 \in$ [0,0.09].

So now we can make a short conclusion that with a proper initial value of (p_1,p_2,p_3), the system or we can just say the market can be in a stable Nash equilibrium, but with the changing of adjustment speed, the system will finally go into chaos, that is the price of three oligopolists will be unstable and market will be in a chaos. In a word, any one of the three may not push adjustment speed too fast, which is making bigger value of adjustment speed (parameter α) and more profit, to keep the market in a stable situation.

4. Effect of initial price bundle to the system

The sensitive dependence on initial price bundle of (p_1, p_2, p_3) is one of the important features of chaos. So we need to find whether the system will depend on initial price bundle. Figure 10, Figure 11, and Figure 12 are relationships between respective price and time. We still take firm 1 that is China Telecom, as an example. In figure 10, we get the points comes with different initial price:p1, the smaller dots represent price bundle of (0.2273,0.4901,0.2070) with fixed (α_1,α_2,α_3), while the bigger dots represent price bundle of (0.22731,0.4901,0.2070), which is a little difference on p1, but the diagram shows great differences with each same time period t.

At first we can see the difference between two p1 is small, but as time goes, the difference becomes greater than before rapidly, and that makes the system unstable. This means weak difference between initial price bundles will have a big impact on the system after the game is repeated finitely. And the system will end into chaos. Figure 11 shows the similar result with price bundle is (0.2273, 0.4901, 0.2070) and (0.2273, 0.49011, 0.2070), while (α_1,α_2,α_3) is fixed at(0.1,0.1,0.01). What is interesting in figure 12 is that the price of p3 finally goes in to stable state, the reason for that should be there a so proper adjustment speed. With suitable paremeter, there is possible to make a stable state. There is another possibility: a trick by numbers, we set different (α_1, α_2, α_3) from figure10 anf figure 11, and still set weak difference between p3, but the price of firm 3 finally goes into stable state. We can say occasionally small different is acceptance, but in most situation in our system, weak initial difference will still result in results with large gap.

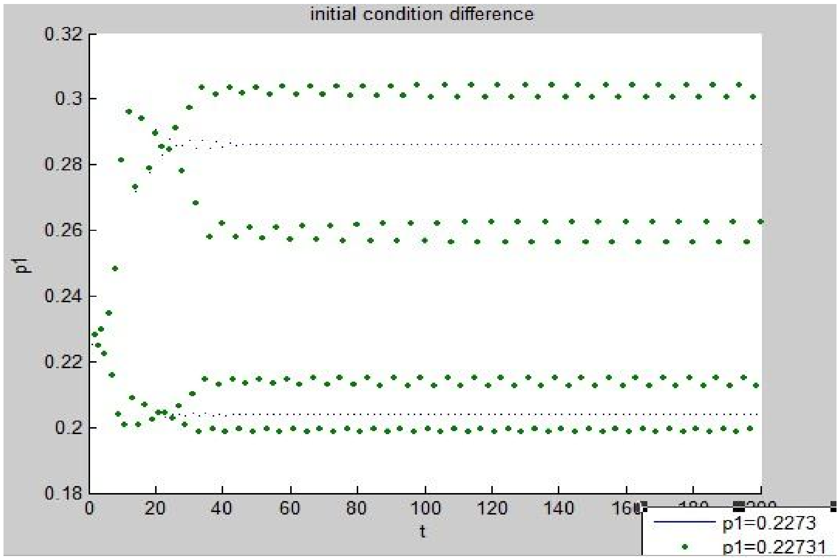


Figure10: sensitive dependence on initial conditions for two bundles (0.2273, 0.4901, 0.2070) and (0.22731, 0.4901, 0.2070) at α_1=0.2, α_2=0.4, α_3=0.005.

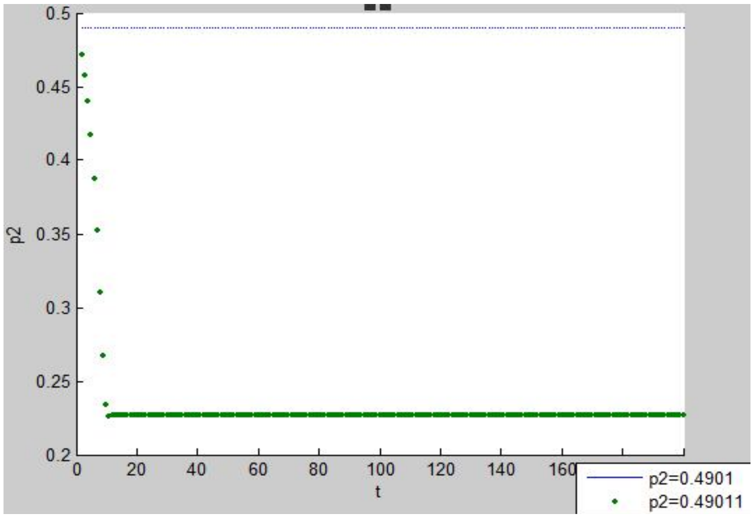


Figure 11: sensitive dependence on initial conditions for two bundles (0.2273, 0.4901, 0.2070) and (0.2273, 0.49011, 0.2070) at α_1=0.1, α_2=0.1, α_3=0.01.

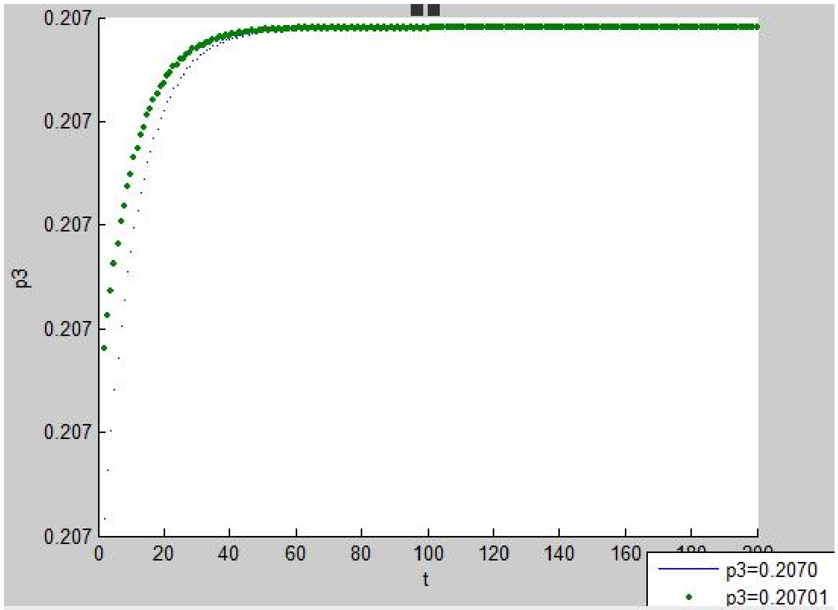


Figure 12: sensitive dependence on initial conditions for two bundles (0.2273, 0.4901, 0.2070) and (0.2273, 0.4901, 0.20701) at α_1=0.15, α_2=0.35,α_3=0.015.

5.Conclusion

This paper which explores a dynamic system by chaos means is likely to be a new approach to analyze a real market. Current research of this field requires further process and expansion. It is a price competition between three oligopolists with Bertrand model. After several analysis, we find that when adjustment speed which is the parameter of the system changes, there will be bifurcation, period doubling, chaos and other complex situation occurring. The price adjustment speed cannot be pushed out of a certain range according to the specific system. If it changes too fast and will ruh out of the stable region, the triopoly market would finally fall into chaos in that repeated competition or the game. When this chaos happens, it will have bad impart on each of the oligopolists and their market will become abnormal, irregular and unpredictable. Thus nobody will be able to make proper decisions or targeted strategies. As rational firms, considering risk aversion, it is totally better for them to keep their price as in a Nash equilibrium.

With simulation, results from this paper show that chaos depends on initial price bundle and also depends on values of parameters in the system. Therefore, if we get the sensitive parameter adjusted appropriately and table initial prices, we can avoid the unstable periodic chaos. Actually Zhui Hui and Junhai Ma (2011) studied some adjustment method to control period doubling bifurcation, which can really makes system stable with Nash equilibrium, but there is no need to do this, since the construction of the system are price decisions from three different oligopolists, it is of small possibility for them to use a same adjustment method to make changes to their price decision strategies, so this paper do not use that kind of adjustment method. But what this paper has done still make strong theoretical significance to the study of the field of this dynamic triopoly competition which is different from previous forms. And also the results of this paper have theoretical and practical significance to Chinese 4G telecom market. As this paper has presents, it is a predicted and possible guidance for three telecom companies to formulate pricing decision strategies and maybe helpful for the relative government to make relevant policies to do macro-control to triopoly market.

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