ISSN 1746-7233, England, UK
World Journal of Modelling and Simulation
Vol. 1, No. 2, 2005, *pp*. 67-74

An investment model for energy resource system *

Ying Fu [1, 2], Lixin Tian [1 +], Mei Sun [1]

[1] Nonlinear Scientific Center, Faculty of Science, Jiangsu University, Zhenjiang, 212013, P.R. China

[2] Department of Agricultural and Recourse Economics, University of Arizona, Tucson, AZ 85721,USA

(*Received July 25 2005, accepted August 26 2005*)

Abstract. An investment model for energy resource system of China is established in this paper. Through analyzing the dynamics behavior of this model, the relationship between the capital investment in energy resource system and the energy resource supply in China has been investigated. The model reveals that there are certain boundaries which restrict the capital investment in energy system, namely, too high investment will lead energy resource supply to increase dramatically, too low investment will cause energy resource supply shrink. In order to keep the energy system of China away from chaos, corresponding countermeasures for energy resource development are also put forward in this paper.

Keywords: induced investment, spontaneous investment, energy supply, energy consumption coefficient.

1. Introduction

China is the world's most populous country and the second largest energy consumer (after the United States). Production and consumption of coal, its dominant fuel, ranks the highest in the world. Although the western of China is rich in energy resources, the eastern of China is poorly endowed. The western energy development needs drives and supports from the eastern economic development, and supports from Chinese governments, such as favorable policies and finances. Meanwhile, the western energy development must expand its opening to the outside world, and greatly attract the domestic non-governmental investment and the investment from foreign countries. It will be favorable to both sides of East and West and will help to realize a new round of economic growth in the whole country if the east investors utilize the advantageous time of the government implementing the Strategy of Developing Western Regions(SDWR) to invest the western energy industry which influences the whole national economic development. The investment model of east-west co-development in energy system of China reflects the relationship between the western energy output and the eastern investment in the western energy system. We suppose that the eastern investment in the western energy system is only used for the part of supplying to the East .

Many researches have been on the predication of the investment model and the energy system. Jostein Tvedt (2002) studied the dynamics of the oil industry and drew a conclusion that in an uncertain oil demand environment cost of structural change creates a value of waiting to invest. This investment behavior influences the oil price process. Hirokatsu Asano (2002) investigated the investment behavior of the US petroleum refining industry and found the minimum amount of investment and disinvestment for these industries. Dominique Finon (2004) discussed policy options available to address the investment price-hike challenge. Waldemar Kamrat (2002) considered the general issues faced when evaluating the risk of investing in a local energy market. Yu and Tian (2002).Fu, Tian (2003) set up chaotic dynamics model of China energy system. Yang and Tian (2003, 2005) analyzed recycling and non-recycling energy and got the optimum methods to be chosen. Ding and Tian (2005) set up a game model of the central government and local government in the West and the East, taking economic growth and energy sustainable development into consideration. Yang and Tian (2005) studied the economic sustainable development under energy restrains. Lu and Tian (1999) studied and analyzed substantially the influence of China's industrial structure

* Research was supported by the National Nature Science Foundation of China (No.90210004), National Social Science Foundation of China (No.02BJY051) and Social Science Foundation of Jiangsu Province of China (No.04SJD790010).

+ Corresponding author. Tel.: +86-511-8791467; fax: +86-8791467.
E-mail address: tianlx@ujs.edu.cn; tianlx@vip.sina.com

adjustment on energy-consuming and demonstrated the energy strategic choice of sustainable development. Gilbert E. Metcalf (1995) considered cumulative investment is generally unaffected by the use of a mean reversion process. Abel Ardrew B. (1994) extended the theory of investment under uncertainty to incorporate fixed costs of investment, a wedge between the purchase price and sale price of capital, and potential irreversibility of investment.

This paper sets up an investment model for China energy resource system and analyzes the relationships among induced investment in energy, spontaneous investment in energy, energy supply and the energy consumption coefficient by nonlinear dynamics theory. The aim of this paper is to give some suggestions about rational energy investment in accordance with the conclusion of this model.

The rest of this paper is made up of 3 sections. Section 2 sets up the investment model. Section 3 improves the model. Section 4 gives the conclusions.

2. Establishment of the model

The investment caused by the growth of the output is called induced investment, particularly, in this paper induced investment means the eastern investment in the western energy system, which is caused by the increase of the western energy output for the eastern area consumption. Suppose $Y_1(t)$ is the western energy output supplying to the eastern energy consumption at time t, and $I_1(t)$ is the eastern induced investment in the western energy system at time t, we get

$$\frac{dI_1}{dt} = \alpha\frac{dY_1}{dt} - kI_1 = -k[I_1 - v_1\frac{dY_1}{dt}] \tag{2.1}$$

$v_1 = const. > 0, v_1$ is defined as investment coefficient of the East to the western energy system. α is a positive constant.

Equation (2.1) shows that the induced investment is caused by the growth of the output, consequently, there is one term $\alpha\frac{dY_1}{dt}$, but the induced investment can not infinitely inflate, usually, the more present investment, the more difficulties in raising money and financing, the underlying reason is that the East (investor) must consider the risk and the profits before they invest in the west, this potential worry causes the exist of $-kI_1$ in the model.

Let $D = \frac{d}{dt}$, then equation(2.1) can be rewritten as below:

$$(D+k)I_1 = kv_1DY_1$$

$$\begin{aligned} I_1 &= \frac{1}{D+k}kv_1DY = kv_1\frac{1}{D+k}DY = kv_1\frac{1}{D+k}(e^{-kt}e^{kt}DY_1) \\ &= kv_1e^{-kt}\frac{1}{D}(e^{kt}DY_1) = kv_1e^{-kt}[\int_0^t e^{kt}DY_1dt + \frac{I_1(0)}{kv_1}] \end{aligned} \tag{2.2}$$

If the rate of the western energy output for the East is invariable, i.e., $Y_1(t) = at + b$, then $DY_1 = a$, It follows,

$$I_1 = kv_1e^{-kt}[\frac{a}{k}(e^{kt}-1) + \frac{I_1(0)}{kv_1}] = av_1 - av_1e^{-kt} + I_1(0)e^{-kt}$$

Obviously, after infinite period of time, the above expression gives $\lim_{t\to+\infty} I_1(t) = av_1$, the eastern induced investment in the western energy system is a constant av_1, which is the product of the Eastern investment coefficient and the rate of western energy production for the East.

If $Y_1(t)$ is accelerated, for example, $Y_1(t) = at^\alpha + b, \alpha > 1$, then $DY_1 = \alpha at^{\alpha-1}$, so

$$I_1(t)=kv_1e^{-kt}\left[\int_0^t \alpha a t^{\alpha-1}e^{kt}dt+\frac{I_1(0)}{kv_1}\right]$$

As $t\to+\infty$, $I(t)\to+\infty$, which means when the acceleration of the western energy production for the East is greater than zero, it will often cause galloping inflation of the eastern induced investment. At this critical time, it is necessary to control the western energy output for the East.

Suppose the east energy shortage is $\beta(Y_1+Y_2)$, where β and Y_2 are constants, Y_2 is the eastern local energy output and imported energy from overseas.

If the eastern induced investment is in direct proportion to the increase of the western energy output for the East, in other words,

$$I_1=v_1\frac{d\beta(Y_1+Y_2)}{dt},\ I_2=v_2\frac{d\beta(Y_1+Y_2)}{dt}$$

Where I_2 is the induced investment which the east invest to itself, and since $\beta(Y_1+Y_2)=C+I_1+I_2+A_1+A_2$, where A_1 and A_2 are constants, which are denoted as the spontaneous investments of east to west and to itself respectively, where C is the eastern consumption function, $C=c\beta(Y_1+Y_2)$, A is the eastern spontaneous investment in the western energy output (such as the investment in the infrastructure construction of energy production, which is not influenced by the quantity of the energy output). So

$$\beta(Y_1+Y_2)=c\beta(Y_1+Y_2)+v_1\frac{d\beta(Y_1+Y_2)}{dt}+v_2\frac{d\beta(Y_1+Y_2)}{dt}+A_1+A_2$$

$$\frac{dY}{dt}=\rho(Y-\frac{B}{s}) \tag{2.3}$$

where $\rho=\dfrac{1-c}{v_1+v_2}, s=1-c>0, B=\dfrac{A_1+A_2}{\beta}-(1-c)Y_2$, formula (2.3) will be

$$(D-\rho)Y=-\frac{B}{v}$$

$$\begin{aligned}Y_{1(t)}&=\frac{-1}{D-\rho}\frac{B}{v}=-e^{\rho t}\frac{1}{D}e^{-\rho t}\frac{B}{v}\\&=-e^{\rho t}[\int_0^t\frac{B}{v}e^{-\rho t}dt-Y(0)]=-e^{\rho t}[\frac{-B}{\rho v}e^{-\rho t}+\frac{B}{\rho v}-Y(0)]\\&=\frac{B}{s}+[Y_1(0)-\frac{B}{s}]e^{\rho t}\end{aligned} \tag{2.4}$$

In addition, equation (2.3) has an ordinary solution $Y_{(1)}(t)=\dfrac{B}{s}$.

From formula(2.4), we get

1° When the initial western energy output for the eastern consumption $Y_1(0)$ is bigger than $\dfrac{B}{S}$ ($Y_1(0)>\dfrac{B}{S}$), the output will increase exponentially. Here

$$I_1(t)=\beta v_1\frac{dY_1}{dt}=\beta v_1\rho[Y_1(0)-\frac{B}{s}]e^{\rho t}$$

The phenomenon of $I_1(t)$ increasing exponentially is called accelerator theory in economics. It must be regulated by the economic means when $I(t)$ has been increased to a certain extent. Otherwise it will cause economy overheating and further cause detrimental consequences, such as galloping inflation of the whole national economy.

2° When $Y_1(0) < \frac{B}{S}$, the initial western energy output for the eastern consumption $Y_1(0)$ can't meet the energy demand of east , furthermore, it can influence the investment enthusiasm of east . This can cause the western energy output for the eastern consumption decreasing in long term.

3° When $Y_1(0) = \frac{B}{S}$,then $Y_1(t) = \frac{B}{S}$,it shows that the western energy output for the eastern consumption will steady at $\frac{B}{S}$. The east investment to the west and the west supply energy for the east will keep on a steady state within a period of time, that is, the produce, the consumption and the investment keep an equilibrium state.

If the eastern spontaneous investment A_1, A_2 in the western energy production is not a constant, we suppose that

$$A = A_1 + A_2 = A_0 e^{rt} \, (r > 0) \tag{2.5}$$

Equation (2.3)becomes

$$\frac{dY_1}{dt} = \rho(Y_1 - \frac{A_0}{\beta s} e^{rt} + Y_2) \tag{2.6}$$

$$Y_1(t) = \left[Y_1(0) + \frac{Y_2}{\rho} - \frac{A_0}{\beta s(\rho - r)} \right] e^{\rho t} + \frac{A_0}{\beta s(\rho - r)} e^{rt} - \frac{Y_2}{\rho} \tag{2.7}$$

We may discuss three different cases as below.

(i) When $\rho > r$, the increase of the eastern induced investment in the western energy output is higher than the increase of the spontaneous investment, if $Y_1(0) \geq \frac{A_0}{\beta s(\rho - r)} - \frac{Y_2}{\rho}$, then the western energy output for the eastern consumption $Y_1(t)$ will increase exponentially.

(ii) When $\rho < r$, if $t \to +\infty$, $Y_1(t) \to -\infty$, this means that due to the fast increase of the eastern spontaneous investment in the western energy production, the eastern productive investment in the western energy will be squeezed out, and the output of the western energy used in eastern consumption falls sharply. Thus it is unsuitable for the eastern spontaneous investment in the western energy production to increase too fast.

(iii) When $\rho = r$, then $Y_1(t) = -\frac{Y_2}{v} + \left[Y_1(0) + \frac{Y_2}{r} - \frac{A_0 t}{\beta s} \right] e^{rt}$, if $t \to +\infty, Y_1(t) \to -\infty$, in other words, when the eastern induced investment in the western energy production equals to the spontaneous investment, the output of the western energy used in the eastern consumption will shrink.

3. Improvement of the model

If the western energy output used in the eastern consumption fluctuates with time too much, then it will lead to the fact that the east-west co-development energy system is unstable. Thus the government must carry out the economic readjustment and make the system develop healthily.

If

$$\frac{dI_1}{dt} = -k(I_1 - v\frac{dY_1}{dt})$$

$$\frac{d\beta(Y_1 + Y_2)}{dt} = -\lambda[\beta(Y_1 + Y_2) - c\beta(Y_1 + Y_2) - I_1 - I_2 - A]$$

$$\beta\frac{dY_1}{dt} = -\lambda[\beta(1-c)Y_1 + \beta(1-c)Y_2 - I_1 - I_2 - A]$$

$$I_1 = \frac{\beta}{\lambda}\frac{dY_1}{dt} + \beta s Y_1 - D \quad (3.1)$$

where $D = -MS + I_2 + A, s = 1-c$ from equation (3.1) we get

$$\frac{dI_1}{dt} = \frac{\beta}{\lambda}\frac{d^2Y_1}{dt^2} + \beta s\frac{dY_1}{dt} \quad (3.2)$$

differentiate equation (3.1)

$$\frac{dI}{dt} = \frac{1}{\lambda}\frac{d^2Y}{dt^2} + s\frac{dY}{dt}$$

Combine equation (2.1) and let $Y_1 = Y$, we get

$$\frac{d^2Y}{dt^2} + (\lambda s + k - \frac{k\lambda\nu}{\beta})\frac{dY}{dt} + ks\lambda Y = \frac{k\lambda D}{\beta} \quad (3.3)$$

Turn equation (3.3) into the equivalent equation group

$$\begin{cases} \frac{dY}{dt} = u \\ \frac{du}{dt} = (\frac{k\lambda\nu}{\beta} - k - \lambda s)u - ks\lambda Y + \frac{k\lambda D}{\beta} \end{cases} \quad (3.4)$$

singular point is $P_0 = (Y_0, u_0) = (\frac{D}{s\beta}, 0)$. Eigen equation is

$$\begin{vmatrix} 0-\mu & 1 \\ -ks\lambda & (\frac{k\lambda\nu}{\beta} - k - \lambda s) - \mu \end{vmatrix} = 0$$

$$\mu^2 - (\frac{k\lambda\nu}{\beta} - k - \lambda s)\mu + ks\lambda = 0$$

$$\mu_{1,2} = \frac{1}{2}[(\frac{k\lambda\nu}{\beta} - k - \lambda s) \pm \sqrt{(\frac{k\lambda\nu}{\beta} - k - \lambda s)^2 - 4ks\lambda}]$$

Let $\Delta = (\frac{k\lambda\nu}{\beta} - k - \lambda s)^2 - 4ks\lambda$. With respect to the value of Δ, three cases will be discussed in detail.

(i) If $\frac{k\lambda\nu}{\beta} - k - \lambda s = 0$, then (Y_0, u_0) is the center point, see fig.1. At this time $Y(t)$ and $\frac{dY}{dt}$ periodically change. $Y(t)$ vibrates around $Y_0 = \frac{D}{s\beta}$; From equation (3.3) we can get

$$\frac{d^2Y}{dt^2} + ks\lambda Y = \frac{k\lambda D}{\beta} \quad (3.5)$$

The general solution of above equation is:

$$Y(t) = c_1\cos(\sqrt{ks\lambda}t + \phi) + \frac{D}{s\beta}$$

c_1 and ϕ are confirmed by initial value, the period of $Y(t)$ is $\frac{2\pi}{\sqrt{ks\lambda}}$.

$ksv - k - \lambda s = 0$ is a kind of critical situation, at this point the western energy output used in the eastern energy consumption fluctuates around $Y_0 = \frac{D}{s\beta}$ by the period of $\frac{2\pi}{\sqrt{ks\lambda}}$

(ii) $\frac{k\lambda v}{\beta} - k - \lambda s > 0$

When $\Delta > 0$, then μ_1 and μ_2 both are positive real number, (Y_0, u_0) is an unstable double tangential point, see fig.2.

When $\Delta = 0$, then $\mu_1 = \mu_2 > 0$, here (Y_0, u_0) is an unstable single tangential point see fig.3.

When $\Delta < 0$, then μ_1 and μ_2 are conjugate complex numbers with positive real part, (Y_0, u_0) is an unstable focus, see fig. 4.

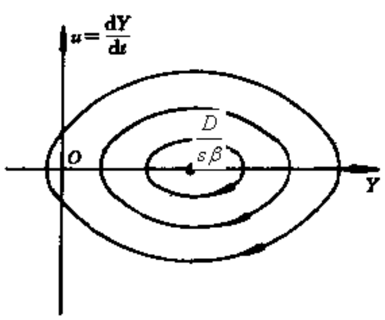

fig.1

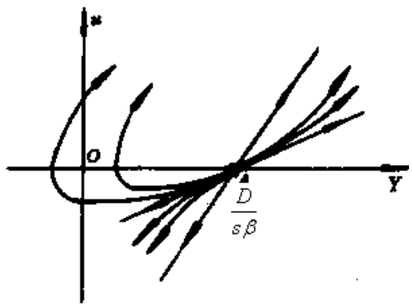

fig.2

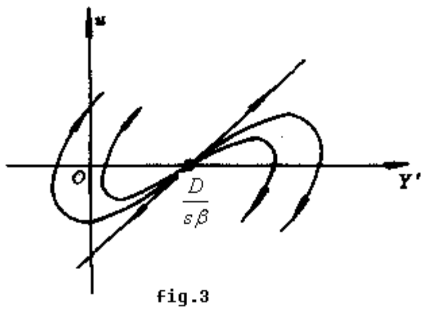

fig.3

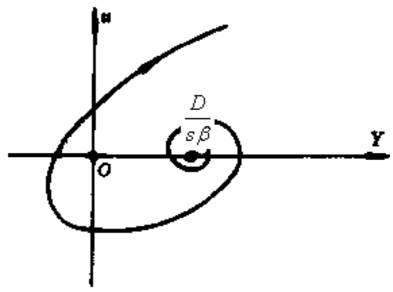

fig.4

(iii) $\frac{k\lambda v}{\beta} - k - \lambda s < 0$

When $\Delta > 0$, then μ_1 and μ_2 both are negative real number, (Y_0, u_0) is a stable double tangential point, see fig. 5.

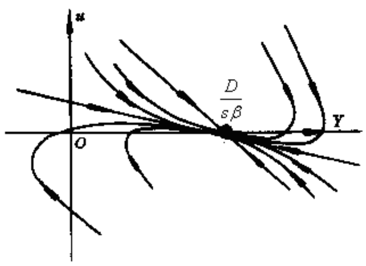

fig.5

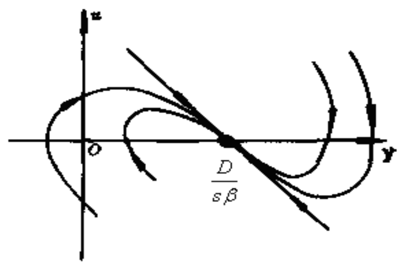

fig.6

When $\Delta = 0$, then $\mu_1 = \mu_2 < 0$, here (Y_0, u_0) is a stable single tangential point, see fig.6.

When $\Delta < 0$, then μ_1 and μ_2 are conjugate complex numbers with negative real part, (Y_0, u_0) is a stable focus, see fig.7.

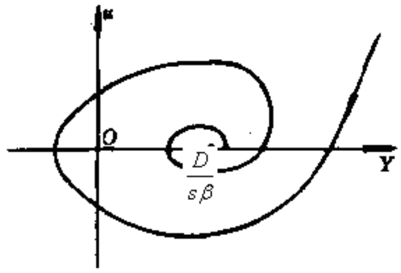

fig.7

In order to make the western energy output used in the East steady, the system must under the condition of $\frac{k\lambda v}{\beta} - k - \lambda s \le 0$, namely $s \ge \frac{kv}{\beta} - \frac{k}{\lambda}$, since $s = 1 - c$, hence, $c \le 1 - \frac{kv}{\beta} + \frac{k}{\lambda}$, c is the eastern consumption coefficient of the western energy. Thus it is necessary to control the eastern consumption of the western energy. From the long-term view of energy supply and environmental protection, the eastern energy consumption still needs optimizing the structure, improving the efficiency and economizing the energy utilization though the energy demand of the developed eastern area is huge and the energy resources are abundant in the West. In the mean time, if $\frac{k\lambda v}{\beta} - k - \lambda s \le 0$, then $v_1 \le \frac{(k+\lambda s)\beta}{k\lambda}$, namely, it is necessary to control the increase rate of the eastern induced investment not too fast in the case of the stimulation of the increase of the western energy output. Meanwhile, in order to alleviate the supply and demand contradiction of eastern energy, some capital can be used for importing the foreign high-quality energy.

4. Conclusions

In the east-west co-development energy system, the relationships between the eastern investment (includes the induced investment and the spontaneous investment) in the western energy production and the western energy output used in the East are as follows:

(1)When the increase of the eastern induced investment in the western energy production is higher than the increase of the eastern spontaneous investment, and when the initial value of the western energy output for the East $Y_1(0)$ is greater than a certain bounded value, $Y_1(t)$ increases at the speed of exponential function.

(2)When the increase of the eastern spontaneous investment is higher than or equal to the eastern productive investment in the western energy production, the western energy output for the East will decrease sharply. Hence that the increase of eastern spontaneous investment in the western energy is too fast is unsuitable.

5. References

[1] Jostein Tvedt, *The effect of uncertainty and aggregate investments on crude oil price dynamics*, Energy Economics, 24 (2002), pp. 615-628.

[2] Hirokatsu Asano, *An empirical analysis of lumpy investment: the case of US petroleum refining industry,* Energy Economics, 24 (2002), pp. 629-645.

[3] Dominique Finon, Tor Arnt Johnsen and Atle Midttun, *Challenges when electricity markets face the investment phase*, Energy Policy, 32 (2004), pp. 1355-1362.

[4] Waldemar Kamrat, *Investment risk forecasting in a local energy market*, Energy Conversion and Management, 43 (2002), pp. 515-522.

[5] Jinghua Yu, and Lixin Tian, *Chaotic time series and application of energy system*, Journal of Jiangsu University, 23 (2002) 4, pp. 84-86.

[6] Ying Fu, and Lixin Tian, *Application of chaotic dynamics model in energy output forecasting of China*, Journal of Jiangsu University, 24 (2003)1, pp. 26-28.

[7] Lixin Tian, and Ying Fu, *Coordinated energy decision making system under nonlinear analysis in western Jiangsu areas*, Journal of Jiangsu University, 24(2003)1, pp. 105-109.

[8] Honglin Yang, and Lixin Tian, *The economic analysis on non-recycling energy*, Journal of Jiangsu University, 24 (2003)1, pp. 78-81.

[9] Honglin Yang, and Lixin Tian, *The sustainable development model of recycling energy*, Mathematics in Practice and Theory, accepted.

[10] Zhanwen Ding, and Lixin Tian, *A game on sustainable development in eastern-western energy economy*, Mathematics in Practice and Theory, accepted.

[11] Honglin Yang, and Lixin Tian, *Economic sustainable growth under restraint of energy*, Systems Engineering, accepted.

[12] Zhengnan Lu, and Lixin Tian, *On energy strategic choice of sustainable development in China*, Quantitative & Technical Economics, 9 (1999), pp. 30-33.

[13] Zhengnan Lu, and Lixin Tian, *A substantial analysis on the influence of industrial structure adjustment on energy-consuming in China*, Quantitative & Technical Economics, 12 (1999), pp. 53-55.

[14] Gilbert E.Metcalf, and Kevin A.Hassett, Investment under alternative return assumptions comparing random walks and mean reversion, Journal of Economic Dynamics and Control, 19 (1995), pp. 1471-1488.

[15] B. Abel Ardrew, C. Eberly Janie, A unified model of investment under uncertainty, American Economic Review, 84 (1994), pp. 1369-1384.