



# Research on a dynamics with bounded rationality for high-carbon and low-carbon energy economic system



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## ABSTRACT

For the energy economic system, a dynamics with bounded rationality is built to describe a decision-making problem that decision-makers select high-carbon energy input and low-carbon energy investment to maximize the weighted utility of consumption and environmental quality in two adjacent periods. The technical level of low-carbon energy development, the weight coefficient, the rate of high-carbon energy pollution on the environment and the environmental quality self-repair coefficient are the major parameters in the model. Stability analysis and numerical simulation are mathematically done for this dynamics. The mathematical analysis shows that decision-makers' focusing on the long-term profits, improving the technology level of low-carbon energy development and reducing pollution rate of high-carbon energy are helpful for the sustainable development of the energy economic system.

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## 1. Introduction

Energy is an important factor for economic development and is playing an important role in economic activity. Energy consumption and economic growth have been the focus of our attention over the past decades. Lots of work have been done on the relationship between energy consumption and economic growth (Apergis and Payne, 2009; Chiou-Wei et al., 2008; Ozturk et al., 2010; Sharma, 2010; Wang et al., 2011), where the main focus is on unidirectional causality in the short-run and bidirectional causality between energy consumption and economic growth in the long-run. Apergis and Payne (2009) think that energy consumption and economic development are interrelated. Wang et al. (2011) also hold that there is a causal relationship among energy consumption, capital and employability in the short- and long-run of the economic growth. Under the trend of global economic integration, energy as an important source of economic growth will play an increasingly important role in the future.

Energy and environment are two major factors that restrict economic development. Energy occupies an important position in economic development. However, with the energy consumption increasing, excessive carbon emissions have caused much more damage to the environment. Therefore, humans began to concern not only about their own economic interests but also the relations between the environmental quality and the economic growth. There has been research work on how to conserve energy and reduce carbon emissions with little effect on economic growth (Arrow et al., 1995; Bartz

and Kelly, 2008; Nakata, 2004; Orubu and Omotor, 2011; Soytaş and Sari, 2009). Arrow et al. (1995) think that economic growth is not a panacea for improving the environmental quality and the most important is the content of economic growth: the composition of inputs (including environmental resources) and outputs (including waste products).

In recent years, researchers have carried out a lot of research work on other economic models with the bounded rationality assumption (Agiza et al., 2001; Ding et al., 2009; Du et al., 2010; Elabbasy et al., 2009; Zhang et al., 2007). These models assume that the decision-makers do not have full information about the market and make optimal decisions according to the information in a limited number of periods.

In this work, it is by the bounded rationality method that we are to study the dynamic process of energy consumption, environmental quality and economic growth. We assume that various periods of decision-makers, possessing bounded rationality, concern mainly with the economic benefits and the environmental quality in the current period (or contemporary) and the next period (or next generation) and make a trade-off between the two periods.

In our model, some basic assumptions are followed: an energy economic system is assumed; the energy factor plays a key role in the energy economic system and the economic output is determined by the energy input; with different levels of environmental pollution, the energy resource is divided into high-carbon energy (fossil fuels, like coal, oil, etc.) and low-carbon energy (new energy, as solar, wind, geothermal, etc.); owing to the scarcity of high-carbon energy, social policy-makers must consider high-carbon energy reserve in the economic dynamics; high-carbon energy input has high carbon emissions and will lead to environmental degradation; low-carbon energy

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input has low carbon emissions (or zero-emissions) and will not affect the environmental quality; the development of low-carbon energy (new energy) needs investment and the accumulation of investment determines the output potential of low-carbon energy; the social policy-makers concern not only about the consumption resulting in the economic output but also the quality of the environment.

It is assumed that decision-makers in various periods possess the same rationality (making trade-off between the current period and next period) and make decisions on high-carbon energy extraction and low-carbon energy investment. A strategy dynamics is built to describe such decision-making behaviors period after period (or generation after generation).

## 2. The model

We think of high-carbon energy and low-carbon energy, denoted by  $Q$  and  $R$ , as factors of the economic output. The extraction of high-carbon energy and output of low-carbon energy occurs in discrete periods  $t = 1, 2, \dots$ . Let  $Q_t$  represent the reserve in period  $t$  of high-carbon energy and  $q_t$  represent the extraction of high-carbon energy in period  $t$ . As a matter of course, the reserve of high-carbon energy  $Q_t$  is a function of the extraction  $q_t$ , satisfying the equation

$$Q_t = Q_{t-1} - q_t, \quad (1)$$

where  $Q_{t-1}$  is the reserve of high-carbon energy in period  $t - 1$ .

Let  $I_t$  represent the cumulative investment in period  $t$  of low-carbon energy and  $R_t$  the output of low-carbon energy in period  $t$ . We assume that the output function of low-carbon energy is linear:

$$R_t = BI_{t-1}, \quad (2)$$

where  $B$  is a positive parameter, which can be viewed as the technical level of low-carbon energy development.

The total production of energy in period  $t$  is the sum of the extraction of high-carbon energy and the output of low-carbon energy:  $q_t + R_t$ . We assume the economic output  $Y_t$  is determined by the energy input  $q_t + R_t$ , and the output function takes a linear form:

$$Y_t = K \cdot (q_t + R_t).$$

By changing the unit of its measure, we can simplify the economic output function as:

$$Y_t = q_t + R_t. \quad (3)$$

And we assume the economic output  $Y_t$  in period  $t$  is divided into two parts. One is the social consumption  $c_t$ , and the other is the investment  $e_t$  in low-carbon energy. That is,  $Y_t = c_t + e_t$ . Noting that the cumulative investment  $I_t$  and  $I_{t-1}$  satisfies the equation  $I_t = I_{t-1} + e_t$ , we get a relationship among  $Y_t$ ,  $c_t$ ,  $I_t$  and  $I_{t-1}$  as follows:

$$I_t = I_{t-1} + Y_t - c_t. \quad (4)$$

In our model, we assume that the nature environment quality  $V$  meets a dynamics

$$V_t = V_{t-1} + \lambda(w - V_{t-1}),$$

which has an equilibrium state  $w$  ( $w > 0$ ). We also assume the input of low-carbon energy to economic production has no negative effect on the environment because of its low-emissions or zero-emissions, but the consumption of high-carbon energy has high-emissions and has damage the natural environmental quality according to the following equation

$$V_t = V_{t-1} + \lambda(w - V_{t-1}) - \mu q_t, \quad (5)$$

where  $V_t$  is the environmental quality in period  $t$ ,  $q_t$  is the high-carbon energy input to the economic production in period  $t$ ,  $\lambda$  is viewed as the environmental quality self-repair coefficient and  $\mu$  the rate of high-carbon energy pollution on the environment.

Social decision-makers consider not only the consumption  $c_t$  from the economic output, but the environmental quality  $V_t$  as well.  $U_t$  is assumed to stand for the utility of the decision-makers and takes a Cobb–Douglas function:

$$U_t = c_t V_t. \quad (6)$$

It is assumed that, with bounded rationality, the social decision-makers focus on two periods: the present period and the next one.<sup>1</sup> During period  $t$ , a social decision-maker considers not only the economic interests in the current period (or contemporary) but also that in the next period (or next generation).

In period  $t + 1$ , the high-carbon energy available will be  $Q_t$  (the reserve of high-carbon energy in period  $t$ ) and the potential output (from Eq. (2)) of low-carbon energy will be

$$R_{t+1} = BI_t. \quad (7)$$

<sup>1</sup> The present period and the next one can be explained as two generations. Then the bounded rationality assumed means that a decision-maker cares about both and only his generation and his coming generation. If this kind of rationality is assumed to generation after generation, the economic welfare will be balanced among all generations in a sense.

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