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Sustainable water resource and endogenous economic growth

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ABSTRACT

Poyang Lake suffers from a severe shortage of water, due to the construction of the Three Gorges Dam and other hydropower stations along the upper Yangtze River. In this paper, we propose a two-sector endogenous growth model to investigate the effects of extractive water use and impoundment activities on the optimal sustainable growth path. To offset the negative impact of the extractive use on the regenerative capacities of water resources, the impoundment activities should grow at a constant rate. We also provide a numerical example to illustrate the mechanisms of the endowment and the regenerative capacities of water resources on the long-run economic growth path. We find out some theoretical evidence to support the construction of a water conservancy project to restore regeneration capacities of Poyang Lake.

1. Introduction

The Three Gorges Dam is the largest operating hydroelectric facility in the world, generating 83.7 TWh in 2013 and 98.8 TWh in 2014.[1] The impoundment project of the Three Gorges Dam was separated into four phases. Beginning in November of 1997, the water level of the Yangtze River was increased to 10–75 m. In June 2003, the second phase of the project, the water level was increased to 135 m. In 2006, the water level was increased to 156 m. After completion of the Three Gorges project in 2009, the water level was increased to 175 m.

Although the extractive use of water in the Three Gorges Dam contributes to the economic growth of China by generating electricity, it causes a severe shortage of water in areas of the lower Yangtze River such as Poyang Lake. Located in Jiangxi Province, Poyang Lake is the largest freshwater lake in China. It connects to the lower Yangtze River through a channel. Fig. 1 shows the average, the highest and lowest monthly water levels of Poyang Lake for the last 30 years (1983–2012).[2] We can see that all three indicators decreased dramatically following completion of the four impoundment phases of the Three Gorges Dam project.

The shortage of water has a negative influence on local agriculture and manufacturing industries and impedes economic growth. To deal with this problem, the local government of Jiangxi Province proposed the construction of a new water conservancy project on Poyang Lake to impound water during drought periods and restore the regeneration capacities of Poyang Lake. The plan attracted international attention, with much of the controversy focusing on the effects of the project on the ecological system of the Poyang Lake Wetland and animal protection. However, few opinions about the relationship between the long-run economic growth and the construction and maintenance costs of impoundment projects were offered.

Many scholars have contributed to study of the relationship between economic growth and environment quality and the effects of technological change on this relationship. (See the reviews of Brock and Taylor (2005); Foray and Grübler (1996); Löschel (2002); Van Den Bergh and Hofkes (1998)) An important theoretical branch of this literature is the economic modeling of sustainable development using the endogenous growth model. Based on the work of Lucas (1988) and Rebelo (1991); Bovenberg and Smulders (1995) present a two-sector endogenous model in which the production of new technical knowledge in the knowledge sector will improve the effective use of the renewable resources and reduce pollution. Hofkes (1996) introduces the concept of abatement into the two-sector endogenous model, which assumes that a proportion of final output can be used as

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[1] "Three Gorges breaks world record for hydropower generation". Xinhua. January 1, 2014. Accessed on November 30, 2015.

[2] The raw data is drawn from the daily observations of water levels from 10 stations around Poyang Lake. We calculate the monthly water levels of all 10 stations.

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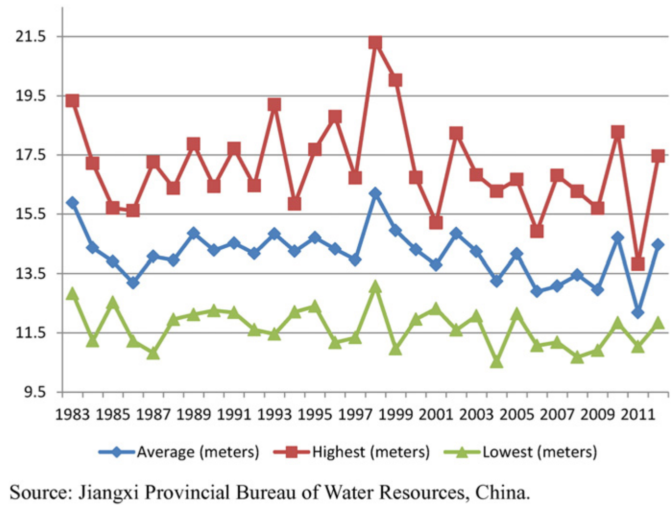

Fig. 1. Water levels of Poyang Lake. Source: Jiangxi Provincial Bureau of Water Resources, China.

abatement to reduce the level of pollution and recover the regenerative capacities of nature resources. The literature focuses on either optimal pollution/abatement choices (Byrne, 1997; Grimaud, 1999; Michel and Rotillon, 1995; Schou, 2000; Withagen, 1995), or the endogenous technical change and the optimal environmental regulation (Acemoglu et al., 2009; Barbier, 1999; Groth and Schou, 2007; Hart, 2004; Rosendahl, 2004; Smulders and De Nooij, 2003). Though theoretical analysis of the optimal management of groundwater resources has been provided (Esteban and Dinar., 2013; Hannouche et al., 2016; Roseta-Palma, 2002, 2003), it has not been in the framework of the endogenous growth model.

Many empirical studies have investigated the relationship between economic growth and environment quality (Brock and Taylor, 2010; De Bruyn, 2012; Du et al., 2016; Färe et al., 2005), including several on China (Choi et al., 2015; Sun et al., 2008; Wang and Song, 2014; Yu, 2015; Zhang and Cheng, 2009; Zhang et al., 2014a, 2015; Zhang and Xie, 2015). Deng et al. (2011) studied economic growth and pollution in and around Poyang Lake. However, theoretical and empirical studies that incorporate water resources and impoundment activities into a sustainable economic growth model remain scarce. This study addresses this gap by applying an endogenous growth model to the optimal levels of extractive water use and impoundment activities, which has policy implications for the problem of Poyang Lake.

Based on the work of Bovenberg and Smulders (1995) and Hofkes (1996), we construct a two-sector endogenous growth model to study the problem of the long-run economic growth with restrictions on water resources. This paper contributes to the literature in the following ways. First, we construct a theoretical framework for analyzing the long-run sustainable economic growth path with extractive water use and impoundment activities, based on a two-sector endogenous growth model. Second, our study gives a numerical analysis of the sustainable growth path and detailed policy implications for Poyang Lake, which has been neglected in previous studies.

The results show that the impoundment activities should grow at a constant rate to offset the negative impact of the extractive use on the regenerative capacities of water resources in a sustainable growth path. We then provide a numerical example that illustrates when the endowment or the regenerative capacities of water resources are low, the long-run sustainable growth cannot be achieved without sufficient impoundment activities.

The paper is organized as follows. Section 2 presents the setting of model. The feasibility and optimality conditions of the long-run sustainable growth are derived in Section 3. Section 4 provides a numerical example. Finally, Section 5 concludes.

2. Model setting

2.1. Regenerative capacities of water resources

First, we introduce the assumptions about the regenerative capacities of water resources. The aggregate stock of water resources (N) is modeled as a renewable resource and can be regenerated by itself. The regenerative capacities of water resources will decrease as the gross extractive use of water (denoted Q, e.g., the water used in the generation of hydropower stations) increases. Meanwhile, the regenerative capacities will be restored with increasing intensity of impoundment activities (denoted I, e.g., constructing impounding reservoirs to increase the stock of water resources). Because the construction and maintenance costs of reservoirs, which offset the negative influence of the gross extractive use of water, are funded in terms of physical capital, we introduce a variable of the net extractive use of water, $X \equiv X(Q, I)$. It is clear that $X_Q > 0$ and $X_I < 0$.

The regenerative capacities of water resources are described by the following function E:

$$\dot{N} \equiv \frac{dN}{dt} = E(N, X(Q, I)). \tag{1}$$

We assume that the function E is twice continuously differentiable and concave, and $E_X < 0$, $E_{NX} > 0$ and $E_{XX} < 0$. The regenerative capacities of water resources will decrease as the net extractive use of water increases ($E_X < 0$). Furthermore, we assume that the higher the stock of water resources, the smaller the negative influence of the net extractive use on regenerative capacity ($E_{NX} > 0$). If the stock of water resources is high, nature can easily recover from the extractive use of water and a change in the net extractive use of water has only negligible effects on the regeneration capacities. Finally, higher levels of net extractive use affect nature at an increasing rate, or the marginal reduction of the net extractive use on water resources increases ($E_{XX} < 0$).

According to the literature on environment quality and pollution, we assume that E is an inverted U-shape function with respect to N. When the stock of water resources decreases below a certain threshold level (or the net extractive use of water resources grows beyond a certain threshold level), the degeneration process becomes irreversible. Conversely, for some high values of N the regenerative capacities of the water resources will also decrease because it becomes more and more difficult to regenerate the entire stock of water resources. For each level of net extractive use, the stock of water will stabilize at a long-run equilibrium level. At this stable level the regenerative capacities are such that the stock of water resources remains constant. This is ensured by assuming $E_N(N, X(Q, I)) < 0$ in a neighborhood of this stable level (as shown in Bovenberg and Smulders (1995)).

Proposition 1. *If the stock of water resources grows at a constant (maybe zero) rate, the net extractive use should be reduced at an increasing (maybe zero) rate.*

Proof: Following the Appendix of Hofkes (1996).[3]

Proposition 1 implies that the stock of water resources (N) can only increase at a constant rate if the net extractive use (X) decreases at an increasing rate, which means either impoundment activities (I) grow at an increasing rate or the gross extractive use of water resources (Q) decreases at an increasing rate. Note that, both growth rates of N and X could equal zero in the extreme case, which implies that I and Q grow at some constant rate. Given the fact that an increasing number of hydropower stations, in addition to the Three Gorges Dam, are being constructed in the upper Yangtze River, we predict that the gross extractive use of water resources will not fall in the near future. Hence, to maintain sustainable growth, the intensity of impoundment activities should grow, minimally, at a constant rate.

[3] Although we change the form of some functions in the two-sector endogenous growth model, and apply it to a different issue, the basic logic and conclusions of this proof are similar to those of Hofkes (1996).