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Resource extraction under heterogeneous growth in demand☆

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ABSTRACT

We study the effect of heterogeneous growth in demand on resource extraction. Using the Great Fish War framework of Levhari and Mirman (1980), we show that heterogeneity in demand growth has a profound effect on both non-cooperative (Cournot-Nash and Stackelberg) and cooperative solutions.

1. Introduction

Since the beginning of the 20th century, the use of global materials has increased 8-fold (Krausmann et al., 2009). This increase in world demand ranges from natural resources such as fish to energy-related resources. See Figs. 1 and 2 in Appendix A. Moreover, the growth of demand for natural resources

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varies considerably among countries. For instance, the annual fish consumption growth rate for the years 1999–2013 is only 1.06% for the US, but 3.43% for China. Similarly, for total primary energy consumption, the annual growth rate for the years 2006–2013 is negative for the US (−0.44%), but positive for both India (5.14%) and China (7.16%). Figs. 3 and 4 in Appendix A further illustrate this heterogeneity of demand growth among countries for both fish and primary energy consumption. In view of such heterogeneity with the particular case of China's exploding demand for resources, it is important to understand how the anticipation of growing demand affects extraction and thus welfare.

In this paper, we study the effect of heterogeneous growth in demand on extraction. To that end, we extend the Great Fish War framework (Levhari and Mirman, 1980) to a situation in which demand for the resource grows exogenously and heterogeneously.[1] Specifically, we consider the case of two countries with heterogeneous growth in demand. The growth in demand is assumed exogenous in order to identify clearly the effect of growing demand on behavior, thereby abstracting from the effect of natural resource utilization on demand growth.

In order to provide a general view of the effect of demand growth on extraction, we solve for non-cooperative and cooperative solutions. Under non-cooperation, both Cournot-Nash and Stackelberg frameworks are considered. Under Cournot-Nash non-cooperation, a higher demand for one country leads both countries to extract more. In contrast, in a Stackelberg environment, a higher demand for the leader induces him to increase extraction while the follower reduces his. On the other hand, an increase in the demand of the follower yields an increase in the follower's extraction without any effect on the leader's. Next, under cooperation, each country increases extraction along with an increase in his own demand, but decreases extraction when demand of the other country decreases.

The rest of the paper is organized as follows. In Section 2, we present the model. Section 3 provides Cournot-Nash non-cooperative and cooperative solutions, which are then analyzed in Section 4. We then extend the analysis to the Stackelberg environment in Section 5. Finally, Section 6 provides concluding remarks.

2. The model

Consider the Great Fish War (Levhari and Mirman, 1980) dynamic game in which two countries derive utility from the utilization of a common-pool resource. Let y_t be the stock of the resource at time t. In the absence of extraction, the stock evolves according to the following rule,

$$y_{t+1} = y_t^{\alpha} \tag{1}$$

where $\alpha \in (0, 1]$. From (1), the evolution of the stock applies to both renewable resources (i.e., $\alpha \in (0, 1)$) and depletable resources (i.e., $\alpha = 1$).

At time t, for $i = 1, 2$, country i utilizes $q_{i,t}$ units of the stock. Using (1), the evolution of the stock under exploitation is given by

$$y_{t+1} = (y_t - q_{1,t} - q_{2,t})^{\alpha} \tag{2}$$

where a total of $q_{1,t} + q_{2,t}$ is utilized at time t. For country i at time t, utilizing $q_{i,t}$ yields utility $u_i(q_{i,t}) = g_{i,t} \ln q_{i,t}$ where $g_{i,t} > 0$ reflects country i's present level of demand.[2]

In order to study the effect of exogenous and heterogeneous growth in demand on behavior, we assume that the demand parameter evolves over time. For $i = 1, 2$ and $t = 1, 2, \ldots,$

$$g_{i,t+1} = \lambda_i g_{i,t} + \theta_i \tag{3}$$

[1] See Long (2011) for an exhaustive survey of models of dynamic games in the exploitation of renewable and exhaustible resources. None considers exogenous growth in demand with the possibility of heterogeneity in the growth rates, as in our paper.

[2] In Levhari and Mirman (1980), $g_{i,t} = 1$ for all i and t.