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Physical versus economic depletion of a nonrenewable natural resource

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ABSTRACT

The present paper explores the relationship between physical and economic depletion of a nonrenewable natural resource using a decomposition of mining costs akin to the one used in the literature on productivity and technical change. We argue that this decomposition can provide key insights on future availability of nonrenewable natural resources. Using data on slate mining in Galicia (Northern Spain), we provide quantitative evidence of the role played by physical depletion in economic exhaustion but also of the offsetting effects of technical change. Additionally, we provide a measure of the effects on economic depletion of input prices, output, fixed inputs and production scale. Input prices and fixed input misallocation contributes far more to economic depletion than physical depletion while technical change has a remarkable negative contribution to economic depletion. Policy implications are discussed, particularly, the importance of promoting technical change.

1. Introduction

The canonical model of physical depletion of a nonrenewable natural resource is quite simple. There is a roughly fixed stock of the resource of which a constant quantity gets extracted each year so the remaining reserves will only last for a number of years. The main assumptions of the model are a somehow known stock of the natural resource and a constant yearly consumption rate. As a matter of fact, this seems to be the model behind the calculation of the number of years that the remaining reserves of oil, coal and other minerals will last – which is known as the reserves to production ratio (BP Statistical Review of World Energy, 2014).

However, there is another point of view on the issue of depletion of nonrenewable natural resources: economic depletion (Tilton, 2009). In this case, the focus is not as much in the stock of the resource but in the opportunity cost of extracting it. In other words, the amount of other resources (e.g. capital and labor) required to extract a unit of the nonrenewable resource. In this setting, economic depletion would mean the increasing difficulty and eventual unfeasibility of extracting the natural resource due to mining costs. Economic depletion increases with physical depletion since a reduction of stocks increases the amount of other resources required to mine one unit of the natural resource (Rodríguez and Arias, 2008). However, technical change can alleviate the effects of physical depletion in the cost of extracting the natural resources and, as a result, slow down economic depletion. Economic depletion is a broader concept than physical depletion since mining costs can halt the extraction of the natural resource well before physical scarcity is a pressing concern.

The objective of the present paper is to analyze economic depletion (i.e. the cost of extracting and processing the natural resource) using the cost decomposition behind the analysis of productivity and technical change (Bauer, 1990). The evolution of mining costs can provide a more accurate measure of resource exhaustion than commonly used indexes such as the reserves to production ratio (Feygin and Satkin, 2004) or the real price of the

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natural resource (Tilton and Lagos, 2007; Tilton, 2009). On the one hand, physical availability as measured by the reserves to production ratio cannot guarantee extraction of the resource if the mining cost increases over a certain level. On the other hand, real prices of the natural resource can be affected by market shocks unrelated to the physical availability of the natural resource. However, a continuous increase in extraction costs is a sure sign of problems to use the non-renewable natural resource in the short or medium run. Furthermore, the cost decomposition provides a measure of the sources of the increase in extraction costs (e.g. input prices or physical depletion). Of particular interest are the role of stock reduction (physical depletion) and the potential offsetting effect of technical change. Additionally, the decomposition shows the effects on economic depletion of factors outside the control of the industry such as input prices and output changes but also the effects of variables that can be changed by management such as fixed inputs and production scale.

The structure of the paper is as follows. In Section 2, we review the relationship between economic and physical depletion using a cost function that has reserves of the natural resource as an explanatory variable. In Section 3, we propose a decomposition of changes in total cost of extracting the natural resource as a way to analyze the sources of economic depletion. In Section 4, we estimate a cost function of mining using data on slate mining and we decompose total cost changes in six components related to economic depletion. The paper ends with some conclusions and policy recommendations in Section 5.

2. Physical and economic depletion of a nonrenewable natural resource

Physical depletion of a nonrenewable natural resource refers simply to the continuous decrease in stock as a result of extracting it. It is commonplace to measure physical depletion by the number of years remaining of the stock at current rates of extraction. The simplicity of the proposal no doubt contributes to its popularity. However, besides the difficulties of estimating the stock and the oversimplification of projecting current extraction rates into the future, Tilton (2009) lists a number of shortcomings of this approach. Namely, the physical approach to depletion cannot account for the role played by technical change in mining, recycling or development of substitutes for the natural resource.

Tilton and Lagos (2007) and Tilton (2009) propose an economic perspective for the analysis of depletion of nonrenewable natural resources. More precisely, they propose to measure economic depletion by the opportunity costs of mining the natural resource. In this setting, physical depletion contributes to economic depletion by increasing the cost of extracting the natural resource. The relationship between the level of reserves and extraction costs has been analyzed by Zimmerman (1981), Harris (1990), Epple and Londregan (1993) and Cuddington and Moss (2001). The rationale is that easy to extract veins of the resource are mined first while more costly to extract veins are mined later on. On the other hand, technical change could offset the effects of physical depletion by reducing the cost of extracting the natural resource. In other words, technical change can alleviate economic depletion (Rodríguez and Arias, 2008). In the same manner, recycling and substitutes for the natural resources operate by putting a cap on the cost of extracting the natural resource and, as a result, limiting economic depletion.

In the present paper we take on the proposal of measuring depletion by the opportunity cost of mining a nonrenewable natural resource. Further, we extend this idea by linking changes in mining costs over time to decreases in stock of the natural resource (physical depletion), technical change, changes in inputs prices, fixed inputs and scale of operation. For that purpose, we use the cost decomposition from the literature on productivity and technical change following the proposal to analyze the relationship between resource depletion and technical change of Rodríguez and Arias (2008).

The starting point is the cost of extracting a non-renewable natural resource that can be written as:

$$C = C(W, Q, t, R)$$

Where C is the cost of extracting the natural resource, W is a vector of input prices, Q is the quantity of the resource extracted, t is a time trend that accounts for technical change over time and R is the stock of the natural resource.

It is common to assume that technical change reduces the cost over time $\frac{\partial C}{\partial t} < 0$ and that a larger stock of resources decreases mining costs $\frac{\partial C}{\partial R} < 0$. The stock R decreases over time due to extraction following the rule: $\frac{\partial R}{\partial t} = -Q$. Therefore, mining costs are going to increase over time due to the reduction of the stock. In other words, there is economic depletion linked to the reduction of the stock. However, technical change can reduce the cost of extracting the natural resource offsetting the effects of the reduction of the stock (physical depletion) on mining cost (economic depletion). Moreover, inputs prices and output can play a role too in economic depletion.

In the next section, we present a decomposition of mining cost that provides a measure of the effect of different factors on economic depletion.

3. A decomposition of economic depletion

In this section we propose a decomposition of the total cost of mining a non-renewable natural resource in order to assess the contribution to economic depletion of input prices, quasi-fixed inputs, output, production scale, technical change and the level of reserves of the natural resource. The starting point is the production function:

$$Q = f\left(X_L, X_E, X_M, X_K, t, R\right) \tag{1}$$

where Q is the quantity of the natural resource mined using three variable inputs: Employment (X_L), Energy (X_E) and Materials (X_M). We assume that Capital (X_K) is a quasi-fixed input. In other words, we assume that the industry is in a short-run competitive equilibrium where some inputs cannot be changed instantaneously. In addition, the technology represented by a time trend (t) and the level of reserves of the natural resource denoted by R affect the mining of the natural resource. Finally, assuming cost-minimizing behavior and certain regularity conditions of the production function (Lau, 1976) we obtain a dual variable cost function containing all relevant information of the technology such as:

$$VC = h\left(W_L, W_E, W_M, X_K, Q, t, R\right) \tag{2}$$

Where VC denotes variable cost and W_L, W_E and W_M are the input prices of labor, energy and materials. The total cost function can be written as:

$$C = h\left(W_L, W_E, W_M, X_K, Q, t, R\right) + W_K X_K \tag{3}$$

where W_K is the user cost of capital.

Differentiating the total cost function with respect to time we have that:

$$\frac{\partial C}{\partial t} = \sum_i \frac{\partial h}{\partial W_i}\frac{\partial W_i}{\partial t} + \frac{\partial h}{\partial X_K}\frac{\partial X_K}{\partial t} + \frac{\partial h}{\partial Q}\frac{\partial Q}{\partial t} + \frac{\partial h}{\partial t} + \frac{\partial h}{\partial R}\frac{\partial R}{\partial t} + X_K\frac{\partial W_K}{\partial t} + W_K\frac{\partial X_K}{\partial t}$$
$$i = L, E, M \tag{4}$$