Reserve Characteristics and Mining Costs  
*An Empirical Study of the Phosphate Industry*

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**Abstract.** This paper deals with an estimation of phosphate mining cost function. Here, it is argued that other characteristics of reserves, besides their size, could be quite important in the cost function. The result of a cross-sectional analysis of phosphate mining in the world shows that reserve size and average total cost have a positive and modest statistically significant relationship in one of the two models. Among many qualitative characteristics and location factors tested in this paper, overburden, grade, ore/product ratio, water availability, and the price of capital are significant with expected signs. Finally, the results confirm the existence of economies of scale in phosphate mining which seem to be more related to mining technology than to reserve size.

**Key words:** phosphate mining, extract cost function, ore/product ratio

1. **Introduction**

This paper offers an empirical test of determinants of extraction cost functions as viewed by phosphate mining firms in the world. Theoretical models of resource exploitation usually assume that reserve size is the main, and often the only, factor that determines extraction cost. Most estimates of extraction cost functions have concentrated on a few minerals, namely coal, uranium, and oil. The need to identify and to include a wide range of physical characteristics of mineral deposits in empirical studies of mining was initially overlooked. In the 1970s, a few voices began to question the accuracy of the National Coal Model which estimated coal supplies in the U.S. Gordon reviewed several studies of the economics of coal mining, including the National Coal Model, for the Electric Power Research Institute (EPRI). In these reviews, Gordon called for a systematic evaluation of the present and prospective supply of coal which would consider all relevant physical characteristics of the deposits (Gordon, 1975, 1976, 1977, 1979). Of course, Gordon acknowledged that while many of the differences of the physical characteristics of deposits may have negligible effects on mining costs to be statistically significant, a manageable number of influences are likely to explain most of the relationship between mining conditions, in general, and variations in mining cost. According to Gordon (1976), Zimmerman, in his thesis, was also critical of the U.S. Department of Interior Coal Supply Model for using seam thickness as the only determinant of cost.
Joining Gordon and Zimmerman in their argument, Newcomb stated that coal deposits are heterogeneous and a wide variety of differences in geological conditions can affect mining cost (Gordon, 1977). Newcomb maintained that seam thickness is not the only factor affecting productivity in coal mining. He also pointed out a lack of systematic data collection for these geologic conditions. Based on the above findings, he included only seam thickness and sulfur dioxide contents of raw coal in his simulation programming model of the U.S. coal supply, demand, and trade. As a part of his simulation model, Newcomb developed an index of coal availability which he applied to the Appalachian coal deposits to estimate their mining cost (Newcomb, 1980).

In the 1970s, there were some descriptive and graphical analyses of coal mining which included other physical characteristics of coal deposits besides seam thickness, such as Malhotra (Gordon, 1976) and Evans and Bitter (Gordon, 1977). However, insufficient data on physical characteristics of coal deposits had made robust statistical analysis difficult. Zimmerman (1977) produced the first rigorous statistical analysis of cost and productivity functions for underground coal mining in the U.S. In his theoretical analysis, Zimmerman acknowledged the significance of a multiplicity of geologic factors such as thickness of seam, water conditions, roof conditions, and gas conditions in mining. However, due to the difficulty in obtaining the relevant data, he only included seam thickness in his estimates and found the coefficient for this factor to be statistically significant. He also concluded that the minimum efficient mine size was a function of seam thickness and other geological factors which were unobservable directly in his model and were analyzed through the error term in his equations.

In another study of the U.S. coal industry, Zimmerman (1981) developed a simulation model for policy analysis of the impact of environmental regulations on coal mining. Zimmerman again identified a group of geologic, engineering, and locational factors that affected mining cost. However, seam thickness remained the major concern in his cost model. In his analysis of individual deposits, Zimmerman demonstrated that distribution of coal remaining in the ground based on the mining cost was a truncated lognormal due to the tendency to mine the best deposits first and also due to the impact of depletion on mining cost. Later, again, in a study conducted for the EPRI, the issue of including geologic factors in establishing the cost function was raised (Toth and Annett, 1984). In this project, a computer program was developed to estimate production cost which included variables that identified the geologic characteristics of coal deposits. But no actual cost function was estimated in this project.

Other studies of mining cost and productivity in extractive industries have focused on the possible correlation between deposit size and ore grade. For example, Brinck (1972) and Harris (1977) found a positive correlation between grade and deposit size among uranium mines. The results of Agterberg and Divi's analysis of 180 base metal deposits in Canada also claimed a positive