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Efficiency performance of the world's leading corporations in phosphate rock mining

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ABSTRACT

The prominence of phosphorus (P) is represented by three major aspects: first and most important, P is essential for all life on Earth; second, no other element or substance can act as a substitute for P; and third, P is considered a non-renewable resource and thus finite. In regard to global food security and P as one of the three major macronutrients, the world faces an extensive challenge to utilize this finite and unsubstitutable commodity in the most effective as well as the most efficient way. Efficiency in general has increasingly become of major importance over the last several decades, especially within competitive commodities. Practically all PR used for chemical fertilizers originates from exploitable deposits that are concentrated in a rather small number of countries and mined vastly by only a limited number of global enterprises. Whereas these enterprises differ in factors such as size, vertical and horizontal integration, legal form, or type of ownership, their overall goal as corporations remains the same-the optimization of their operations. Consequently, firms can strive to (a) minimize their inputs at constant output levels; (b) maximize their outputs at constant input levels; or (c) increase their efficiency ratio by adjusting inputs and outputs at the same time. In contrast to the oil industry, the PR market is demand driven, which means that not everything that could be produced is immediately consumed. This study attempts to measure, compare, and analyze the technical efficiency performance of the major global corporations involved in PR mining by using the BCC (Banker, Charnes, and Cooper) and CCR (Charnes, Cooper, and Rhodes) models of data envelopment analysis. The analysis includes total technical efficiency as well as the disaggregated pure technical and scale efficiency and a breakdown of the factors accounting for inefficiency. The 24 firms included in the analysis account for 67.3% of the global phosphate rock ore capacity and 61.4% of phosphate rock concentrate capacity. Based on the BCC and CCR modeling a higher percentage (36% vs. 20% – Model 1; 36% vs. 10% – Model 2) of publicly quoted companies (such as PotashCorp) are classified as efficient compared to state-owned companies (such as OCP). However, the frequencies of efficiency performance do not differ in such a way that a Fisher Exact Test would suggest statistical significance for these data. This indicates that general assumptions regarding the different strategies of state-owned and publicly quoted firms are not necessarily valid.

Abbreviations: BCC, Banker, Charnes, and Cooper, DEA model with the assumption of variable returns to scale; CCR, Charnes, Cooper, and Rhodes, DEA model with the assumption of constant returns to scale; CRS, constant returns to scale, operation level of a company implying that a change of inputs leads to a proportional change of outputs; DAP, diammonium phosphate, group of phosphorus fertilizers; DEA, data envelopment analysis, method for efficiency benchmarking of multiple inputs and outputs; DMU, decision making unit, comparison unit used in our case for PR mining firms; DRS, decreasing returns to scale, operation level of a company implying that a change of inputs leads to an under-proportional change of outputs; EBIT, earnings before interest and tax, common performance indicator in accounting and finance; HHI, Herfindahl–Hirschman-Index, concentration indicator for markets; IRS, increasing returns to scale, operation level of a company implying that a change of inputs leads to an over-proportional change of outputs; P, phosphorus, chemical element; PR, phosphate rock, not further specified (PR-M or PR-Ore); PA, phosphoric acid, downstream product in the P supply chain; PR-M, phosphate rock concentrate, marketable concentrate; PR-Ore, phosphate rock ore; RTS, returns to scale, operation level of a company (CRS, DRS, IRS or VRS); SBM, slack-based model, further step in DEA analysis in order to recognize non-zero slacks; SE, scale efficiency; SFA, stochastic frontier analysis, alternative to DEA; VRS, variable returns to scale, operation level of a company implying that a change of inputs leads to an non-proportional change of outputs.

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1. Introduction

The human-induced global demand for minerals and metals is rising, and this, in turn, is causing increasing concerns about long-term supply security (Wellmer and Scholz, 2015) and, consequently, concerns about efficiency. In particular, the case of phosphorus, which is neither substitutable nor infinite, is of major importance for the global food supply because of its function in chemical fertilizers. While crop production in the pre-industrial era relied mainly on natural levels of soil phosphorus and locally available organic matter (Cordell et al., 2009), nowadays major portions of the world's total crop yield are attributed directly to the application of chemical fertilizers. The use of fertilizers increased vastly over the twentieth century and is estimated to continue to grow in the future (Enger, 2010). P represents one of three macronutrients for which no substitute exists, while nitrogen (N) and potassium (K) are practically unlimited and exploitable resources through processing air and seawater, respectively. This is not the case for P (Wellmer and Scholz, 2015). Practically all of today's inorganic P used for agricultural purposes (approximately 85% of total P) is produced from phosphate rock, a naturally occurring geological material that contains a relatively high concentration of P (approximately 85% from sedimentary deposits and the rest from igneous and guano deposits). The majority of PR mining market shares are controlled by a limited number of corporations. Although these firms differ vastly in categories such as size (e.g., Vale SA vs. Jordan Phosphate Mines Company – JPMC); vertical and horizontal integration (e.g., mining activities related to other commodities vs. solely PR raw material supplier); and legal form or type of ownership (e.g., publicly traded vs. privately held and state-owned), their overall goals remain the same, namely, successful business operations.

The paper proceeds as follows: Sections 1.1 and 1.2 introduce the reader to basic economic efficiency considerations, followed by a brief overview of PR mining and the global phosphate industry. Section 2 provides insights on the DEA method and its applications in mining. It continues with the outlined sample data and the resulting DEA models. Section 3 proceeds with a discussion of the detailed results in regard to the research question. The paper concludes with Section 4, including an outlook on challenges for future research. In order to assist the reader with the used abbreviations we point to the included abbreviations above.

1.1. Basic economic efficiency considerations

Efficiency is crucial for successful long-term business operations on all levels and in all operations. Although productivity is similar to efficiency and many authors do not differentiate between the two (Daraio and Simar, 2007), a distinction is necessary. Productivity can be defined as the ratio between an output and the factor that made it possible (Vincent, 1968). The ratio itself is simple to calculate if only a single input and a single output are present; in the case of several inputs and outputs, they must be aggregated in order for productivity to remain a ratio of two scalars. In contrast to productivity, efficiency can be described as "*. . . a valuation function that assesses how much we have to invest in order to receive a certain quantity and/or quality of a desired outcome or product*" (Scholz and Wellmer, 2015c, Abstract). Technical efficiency was first defined by Koopmans (1951, p. 60) in the following way: "*. . . an input–output vector is technically efficient if, and only if, increasing any output or decreasing any input is possible only by decreasing some other output or increasing some other input.*". In the same year, Debreu (1951) provided the first measure of productive efficiency by a coefficient of resource utilization, which represents a radial measure (interpretable as the ratio of two distance measures according to Cooper et al., 2006) of technical efficiency. Farrell (1957) extended the previous work of Koopmans and Debreu by raising the question of the selection of the "right" technically efficient input–output vector under the consideration of given input and output prices, which is considered allocative efficiency. Therefore, Farrell (1957) defined overall productive efficiency as the product of technical efficiency and allocative efficiency. In addition to the concept above, he introduced the concept of structural efficiency, which basically measures to what extent an overall industry (i.e., the "technical efficiency" of an industry) keeps up with the performances of its closest competitors (e.g., best firms within a sector). The original developments by Farrell (1957) assumed constant returns to scale, which was the foundation of the linear programming framework of Charnes, Cooper, and Rhodes in 1978, known as the CCR model, and led to the introduction of the BCC model assuming variable returns to scale (Daraio and Simar, 2007). Here, we want to emphasize that efficiency must not be confused with effectiveness or with efficacy. A detailed discussion of the distinction, especially for P-mining, can be found at Scholz and Wellmer (2015b).

Considering the concepts above, a company trying to increase its production efficiency can either adjust the input side, the output side, or both sides simultaneously. This leads to the conclusion that the input side (x_i) as well as the output side (y_i) separately allow for three different possibilities in terms of parameter change. Inputs (outputs) can either be decreased ($x_1 < x_0$, $y_1 < y_0$), kept constant ($x_1 = x_0$, $y_1 = y_0$), or increased ($x_1 > x_0$, $y_1 > y_0$), which implies a total of nine possibilities (illustrated in Fig. 1).

If the input (output) is kept constant while the output (input) is increased (decreased), then efficiency will increase, while for the opposite it will decrease. Additionally, if both parameters are adjusted in opposite directions, with increasing (decreasing) inputs and decreasing (increasing) outputs, efficiency will decrease (increase). The upper-left and lower-right corner fields are most crucial, since both parameters are adjusted at the same time in the same direction; in these cases, the efficiency development depends on the proportional increase (decrease) of the numerator (output) and the denominator (input), and can either increase or decrease.

1.2. Phosphate rock mining, industry, and phosphate reserve estimation

The increasing human demand for minerals and metals raises questions about their long-term supply security, which holds especially true for the case of phosphorus mainly in the form of phosphate rock. A growing world population is combined with the fact that half of all food production relies on this mineral. The accuracy of current projections depends on the quality of the data we have today (Scholz and Wellmer, 2013, 2015a; Wellmer and Scholz, 2015). Phosphorus scarcity has been discussed repeatedly in history (Emsley, 2000). The present circle started with a workshop launched by Swiss environmental agencies and research groups of ETH in 2007, which included the world's leading resource specialists (Wolfensberger et al., 2007). Global public attention was first raised, unfortunately, through a scientifically incorrect application of the Hubbert Curve by a report of the Global Phosphorus Research Initiative, in which the members estimated peak phosphorus (the point in time at which world production will peak and slowly decrease regardless of the growing demand) for the year 2033, followed by a full depletion 50–100 years later (Cordell et al., 2009; GPRI, 2010). These figures were later adjusted based on new data, with a revised peak production around 2070 (De Ridder et al., 2012). In contrast to this static approach, Global TraPs emerged as a global transdisciplinary project involving experts from science and practice with the scope of sustainable phosphorus management (see www.globaltraps.ch for further details). Scholz and Wellmer (2013, 2015a), in addition to others, claim the inappropriate use of peak theory in the case of PR, which started the scarcity discussion,