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Internal resource waste and centralization degree in two-stage systems: An efficiency analysis ☆

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ABSTRACT

Internal resource waste refers to the waste in the intermediate resources between the upstream stage and downstream stage in a production or service system. This study examines a system with a two-stage structure, in which the outputs from the first stage are taken as the inputs for the second stage. Two-stage systems can exist in centralized, decentralized, or mixed organizational modes. In this paper, we propose two-stage DEA models considering a degree of centralization that makes it possible to measure internal resource waste in different system modes. Some managerial insights are tested and verified from the perspective of efficiency analysis. We find that: 1) when there is only one intermediate measure in a centralized two-stage system, internal resource waste can be eliminated completely, and 2) a higher degree of centralization in a two-stage system can lead to less internal resource waste and more expected outputs. Finally, we present a numerical example and two practical real-world examples that illustrate our approach and findings.

1. Introduction

Internal resource waste (IRW) in a production or service system refers to the waste of intermediate resources that is caused by imbalances between the initial and final stages in internal processes. IRW can be an outcome of a number of factors, including asymmetric information, inconsistent production pace, imperfect quality management, and uncertain inbound logistics processes. It occurs when the intermediate products produced by a stage in a process exceed the needs of the next stage. Most of these over-supplied products become waste and are typically stored in the warehouses of either the buyer or the vender, sold to others at a relatively low price, or even disposed of. Thus, it is necessary to investigate the IRW for realizing waste reduction which is one of the primary long-term goals of organizations [1].

A good example of internal resource waste reduction can be seen in the case of the famous Japanese company, Toyota Motor Corporation. After World War II, Toyota experienced a severe shortage of materials, and could not afford the high level of waste that was characteristic of most American companies at that time, in areas such as labor, inventory, space, and processing. Therefore, Toyota created a production mode that it named the Toyota Production System (TPS), which is driven by orders and demand, allowing it to produce only the necessary products within the required time. The physical flow of Toyota's production system is shown as follows. Parts are produced by suppliers and transported to factories based on inbound logistics. Factories use the parts to produce vehicles. Finally, the vehicles are sent to dealers based on outbound logistics. We define the processes moving from suppliers to factories as part of the production stage and the processes moving from factories to dealers as part of the sale stage.

Toyota made a great effort to reduce internal resource waste between two nearby stages. For example, the company tried its best to realize a goal of “zero inventory” in factories by ensuring that they produced only the necessary vehicles to meet customer orders in the sales stage. Because of its ability to reduce internal resource waste, Toyota underwent rapid development and became one of the most competitive motor makers in the world. And in 2012, it was ranked first in the world in automobile sales [2].

Another more traditional example can be found in the banking industry. Yang and Liu [3] analyzed the banking industry in Taiwan, and divided the operations of banks into two sub-stages, the productivity stage and the profitability stage. In the productivity stage, a bank consumes personnel costs, operation costs, and interest costs to produce deposits, which are then used in the profitability stage to bring in interest income, fee income, and fund transfer income. This is a common mechanism among banks. Different kinds of banks' structures may vary slightly, but most take “deposits” as an intermediate measure [4,5]. Based on this, we can analyze the following real example from the banking industry, which reflects the importance of deposits as an intermediate measure. During the 2008

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financial crisis, Iceland was one of the countries in Europe that suffered most heavily. The economic crisis in Iceland involved all three of the country's major banks.[1] The debts of Iceland's banks increased to roughly twelve times the amount of the country's gross domestic product (GDP). These high levels of foreign debt meant excessive deposits for the banks because the banks could not find enough companies, governments, or other organizations in which to properly invest their deposits because of the bad investment environment. Finally, the excessive debts of Iceland's banks led to a collapse of the banking industry, which was the largest experienced by any country in economic history (see 〈http://www.economist.com/node/12762027〉 for a detailed description [6]). These excessive deposits could not only be seen as increasing the financial risks faced by banks, but also as increasing internal resource waste, because the deposits were not used to produce profits in the latter stages of the banks' processes, and were only held in the bank. Morrison and White [7] suggested that in order to reduce the damage caused by these excessive deposits (waste), banks and governments should consider supporting deposit insurance schemes, as the soundness of the financial sector was uncertain.

As internal resource waste results from bad coordination between stages of production, two possible approaches can be used to reduce it. One is to reduce the products produced in the former stage while still meeting the demands of the latter stage, and the other is to boost the expected input consumption in the latter stage without exceeding the supply of the former stage [1]. These approaches both suggest that products should be produced only as needed for the next stage in an entire production process. This is also the main goal of the *just in time* (JIT) system [1,8,9]. Therefore, in order to measure and decrease or even eliminate the amount of internal resource waste produced in a production system, it is essential to first evaluate the system's actual internal performance and benchmarking.

Evaluating the efficiency of a production system can contribute to the understanding of the system's performance and the factors leading to efficiency. There are several methods for measuring efficiency, such as the stochastic frontier function and data envelopment analysis. Data envelopment analysis (DEA) is a popular non-parameter approach for evaluating the relative efficiency of homogenous decision making units (DMUs), especially with multiple inputs and multiple outputs [10–12]. Through the DEA approach, the inefficiency of resource utilization in a production system can be detected. Since the relative efficiency indicates a gap between the evaluated production system and an efficient one, it can set a benchmark for the production system to improve its performance [13–15]. Because of these advantages, we choose the DEA approach to investigate the performance of production systems.

The single-stage DEA model, which is the conventional DEA model, perceives the internal structure of a production system as a "black box." In other words, it does not take into account the internal structure of the production system, and provides no information about internal resource utilization performance. Because of this, the efficiency of a DMU's performance is often overrated. In this study, a two-stage DEA approach is proposed for examining the relationship between two stages, for example between a supplier in the first stage and a manufacturer in the second stage. So far, a number of studies have been conducted using the two-stage DEA approach to measure the efficiency of two-stage network structure systems where the outputs from the first stage are referred to as intermediate measures and are taken as inputs for the second stage. Cook et al. [16] reviewed the studies on two-stage DEA models and classified them into four categories: standard DEA approach, efficiency decomposition approach, network-DEA approach, and game-theoretic approach. Some latest studies of two-stage DEA can also be classified into these four categories. For example, Du et al. [17] developed a Nash bargaining game model to evaluate the performance of DMUs in a two-stage system, which can be classified as a game-theoretic approach, while Kao and Hwang [18] proposed decomposing overall efficiency into technical efficiency and scale elasticity in two-stage systems, which can be classified as an efficiency decomposition approach. Sahoo et al. [19,20] estimated the technical efficiency by two approaches, one of which uses a single network technology for two interdependent sub-technologies which can be classified as network-DEA approach and the other uses two independent sub-technology frontiers which can be classified as efficiency decomposition approach. Premachandra et al. [21] devised a two-stage DEA model for efficiency decomposition and applied it to US mutual fund families from 1993 to 2008. However, all of these two-stage DEA models only focus on efficiency measurement and efficiency decomposition [17–25].

In the abovementioned two-stage DEA studies, only very limited attention has been paid to the problem of internal resource waste in a two-stage production system. Sahoo et al. [19] proposed the DEA model based on the assumption of allocative inefficiency that exists between the two stages when the sub-technology managers have the conflicting objectives. The conflicting objectives may result in the internal resource waste when difference exists in how much of intermediate products to produce and consume, which further results in the inefficiency. Chen and Yan [25] have employed network DEA models to measure the efficiency of a parallel two-stage production system. They analyzed the relationship between a production system and two divisions. Their study also attempts to explore the concept of internal resource waste but is limited. In their work, centralized, decentralized and mixed scenarios are analyzed individually, but the relationship between each scenarios are less studied. In this paper, we will integrate these three scenario in a general DEA model, and investigate the quantitative relationship between degree of centralization and internal resource allocation.

Imbalance between different stages in a production system causes IRW. Different kinds of controls on a production system will bring different degrees of imbalance or coordination performance, and will further affect the amount of IRW. Many scholars and managers believe that centralization in an organization can assist managers in integrating and using decentralized and limited resources to improve utilization efficiency and achieve returns to scale [26]. For example, Tomasz [26] indicates that a centralized distribution storage system allows a company to operate at a lower cost while providing customers with better service. This implies that a higher degree of centralization in a production system is more likely to decrease waste. However, thus far, this has never been theoretically proven from an efficiency perspective, which is the focus of this study. Based on degree of centralization, we classify production systems into three categories: centralized, decentralized, and mixed. A centralized system is supervised by a single super decision maker who can arrange the operations of the two stages, while a decentralized production system is one without such a super decision maker. In a mixed production system, a decision maker has decision-making power that is not absolute. Compared to the previous two-stage DEA works, this study firstly measures the quantitative relationship between degree of centralization and internal resource waste in a production system. It examines a generic two-stage system, in which all outputs of the first stage are intermediate measures that can be used as inputs in the second stage. A centralization degree index is then introduced into the two-stage DEA model. The change in the value of the centralization degree index enables us to identify the amount of IRW produced in scenarios with different degrees of centralization, ranging from those that are centralized to those

[1] NBI (referred to as Landsbanki), Arion Bank (formerly Kaupthing Bank) and Islandsbanki (formerly Glitnir).