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# Evaluation of ecological systems and the recycling of undesirable outputs: An efficiency study of regions in China

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ABSTRACT

A balance between environmental regulation and economic prosperity has become a major issue of concern to attain a sustainable society in China. This study proposes the application of Data Envelopment Analysis (DEA) for measuring the efficiencies of the ecological systems in various regions of that country. The proposed approach differs from most of the previous ecological systems models in that we view it in a two stage setting; the first stage models the ecological system itself, and from an economic perspective, while the second stage (decontamination system) models water recycling as a feedback process, and the treatment of other undesirable outputs coming from the first stage. There, we separate polluting gases and water into two parts; one part is treated, while the other is discharged. The model considers two major desirable outputs from the first stage, namely Population and Gross Region Product by expenditure (GRP), as well as undesirable variables in the form of consumed water, and certain pollutants, namely nitrogen oxide, sulfur dioxide and soot. At the same time, these undesirable outputs from the first stage are inputs to the second decontamination stage. As well, recycled water is fed back into stage 1. Thus, intermediate variables such as consumed water and waste gas emission simultaneously play dual roles of both outputs and inputs in the ecological system.



## 1. Introduction

With rapid industrial growth in China, environment problems are growing worse each year. The Chinese, especially the governors, researchers, and corporate leaders believe that it is critical to do more to prevent water and air pollution in the form of nitrogen oxide, sulfur dioxide, carbon dioxide and soot (dust), etc. Strategists have a variety of ideas between environmental protection and economic prosperity issues. Environment protection proponents are concerned about air and water pollution, while other, more business activists believe that regulation on water and gas pollution may damage economic prosperity. The two conflicting ideas lead to different business and policy implications. There would appear to be a growing desire for a National anti-pollution policy.

There is a significant literature relating to the impact of economic development on the environment. One particular industry that has a major influence on energy consumption and the environment is the iron and steel industry as discussed in Guo and Fu [15]. Those authors survey many of the key issues associated with the development in that industry, and some economic policy implications are suggested. One of the key features of economic development in China is the recycling of scarce resources such as iron, steel, copper, asphalt on roads, etc. See, for example, Mo et al. [29]. Those authors conduct a detailed survey in Suzhou city relating to the collection and recovery processes of recyclable resources, and the issues that impact recycling systems, and the main actors involved in each recycling system.

A recent paper by Ma et al. [27] discusses China's growing *circular economy*, a concept based on the principles of reduce, reuse and recycle. In a resource-starved country like China, this closed-loop concept has become critical to its growth. Many studies have shown that the development of a circular economy is important to mitigating undesirable environmental impacts at source.

In this paper we apply Data Envelopment Analysis (DEA) models to measure the regional ecological efficiency of the full set of 31 administrative regions in China. Then, based on empirical results, concerning the environment, and human and economic sustainable development, we study the factors associated with improvement in

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environmental performance in the different regions of China. There is a substantial amount of research on global environmental protection, as mentioned above. Charnes et al. [2,3] were the first to apply analytical approaches to study several global environmental protection issues. Cooper et al. [12] summarizes more than 100 papers that discuss most kinds of air pollution issues. Zhou et al. [35] provides a summary of more than 100 DEA studies on environment and energy policy.

An important consideration when modeling environmental issues in a DEA setting is the presence of undesirable factors (e.g. air pollutants.) Färe et al. [14] were the first to develop the concept of undesirable and desirable outputs. Other studies have been conducted by Dodos and Vorosmarly [13]; Lim and Zhu [25]; Liu et al. [26]; Maghbouli et al. [28] and Zhou et al. [33,34,35].

Previous ecology-based research has tended to pay little attention to settings involving two-stage network structures with intermediate measures. In that regard, the current study proposes a model that views the regional ecological system as a two-stage network structure with feedback. The study concerns the treatment of both desirable and undesirable outputs that flow from the first stage, some of which represent inputs to the second stage of assessment. Recycled water, as one of the outputs from the second stage, is fed back to the first stage as one of that stage's inputs. Thus, these *intermediate variables* simultaneously play an important role of both output and input. Both intermediate variables and the feedback variables constitute what Cook et al. [8], Cook and Zhu [9] call *dual-role variables*. We use the DEA methodology in a two stage process to account for such treatment.

Since pollution is such an important consideration in the sustainability of the Chinese economy, it is critical to explore the internal ecological process, human sustainable development, water recycling, and air cleaning. If water and air are polluted, that situation will not lead to sustainable development. Water is a core resource for human survival in any region. In recent years in China, continued news reports point to serious water shortages that continue to get worse every year. With water shortage, it becomes very difficult to support the population. Similarly, soot and other forms of air pollution seriously impact people's health. There is a growing concern about this situation, not only from an economic development perspective, but also from the viewpoint of human survival.

One first impression of the approach in this paper might be that it is similar to other circular economy literature, such as that of Ma et al. [27]; it definitely subscribes to the principles “reduce, reuse, recycle”. Arguably, however, there are certain features that distinguish our problem setting and chosen methodology from that of earlier literature. First, our study is at a rather macro level, namely the entire economy in China, as opposed to those studies that examine a specific industry such as iron and steel. Second, given this macro thrust, our choice of decision making units, namely regions, cities or provinces in China would seem to be justified, as opposed to using say industry sectors or particular companies. Third, the predominant input variables used to support the analysis are water, land and investment. Fourth, a region's natural resources can help to feed people; hence population would appear to be an important consideration in the ecological system. In economic terms, it is a measure of the total *consumption* of goods and services created by the economic system. In short, it is a measure of the “structure” supported by the macro inputs to that system. At the same time, it is necessary to have a concrete measure of the total value of all generated goods and services; hence we have chosen Gross Region Product by expenditure (GRP) as a key regional desirable output. At the same time, consumed water and three polluting gases (nitrogen oxide, sulfur dioxide and soot) are undesirable outputs from the first stage. Treated waste water and treated polluting gases are desirable outputs, while discharged waste water and discharged waste gases are undesirable outputs at the second stage.

It is important to point out here what “efficiency” means in the two stage process discussed above. Stage 1 describes the process of converting macro inputs into desirable (and undesirable) outputs. The extent to which a region is more or less successful in doing this, as compared to other regions, is best captured by an efficiency measurement tool such as DEA. A region that supports a larger population, generates a higher GRP and creates less pollutants would be deemed more *efficient* than a region with less desirable outputs and/or more undesirable outputs. If no process were in place to address decontamination of consumed water and air pollutants, and if recycled water was not fed back into the input side of the first stage, a single stage model would suffice to describe the economic system. In the current setting, however, a concerted effort is in place to address the severe pollution issue, hence the need for a second stage decontamination process. Stage 2's efficiency refers to the conversion of contaminants (consumed water and waste gasses), and the use of a portion of the GRP to treat some of those contaminants. The greater the portion of the contaminants treated, the greater is the efficiency of that second stage process.

In summary, this paper sets out to measure the regional economic and ecological efficiency of the 31 administrative regions in China. Specifically, we study the factors associated with economic development and improvement in environmental performance in those different regions.

The remainder of this paper is organized as follows: Section 2 summarizes previous contributions on two-stage DEA approaches. In Section 3 we extend the models for environmental assessment, while taking account of the inherent two-stage structure. Section 4 discusses the DEA model used to measure the environmental efficiency of the set of 31 administrative regions in China. Concluding remarks appear in Section 5.

## 2. Modeling efficiency in two-stage processes: the literature

The modeling of efficiency in two-stage processes has been the subject of numerous papers including Maghbouli et al. [28]; Liu et al. [26]; Chen et al. [6,7]; Kao and Hwang [20]; Kao [18,19]; Liang et al. [22,23,24]. A recent paper by Cook et al. [11] provides a comprehensive survey of developments in this area. A number of important recent articles on internal DEA structures and networks appear in Cook and Zhu [10]. As background for the development herein, we briefly review the methodology for one of the most common two-stage structures, namely the serial process.

For discussion purposes, let $\{x_{ij}\}$ and $\{z_{dj}\}$ denote the inputs and outputs respectively for stage 1, and $\{z_{dj}\}$, and $\{y_{rj}\}$ the inputs to and outputs from stage 2. Their corresponding multipliers are denoted by $v_i, \eta_d, u_r$, respectively. In a *closed serial system*, the variables $\{z_{dj}\}$ are referred to as *intermediate* variables. Fig. 1 is a pictorial representation of a conventional two stage closed serial process.

To evaluate the overall efficiency of the set of decision make units (DMUs) considered herein, we choose to adopt an output-oriented (rather than input-oriented) model, since it is outcomes or outputs from the ecological system that we wish to enhance, as opposed to reducing resources (inputs) to that process. Furthermore, we propose to use the variable returns to scale (VRS) model of Banker et al. [1]; as opposed to the CRS model. There are at least two reasons for this choice. First, the choice is partially driven by the fact that the relative “sizes” of the DMUs (provinces or regions) range from what might be deemed very small (e.g. Tibet), to very large (such as Jiangsu.) This being the case, the CRS can often produce scores that exaggerate inefficiencies. The second reason for the VRS choice is that in a two stage setting the stages act as

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