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Stochastic frontier analysis of productive efficiency in China's Forestry Industry

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ABSTRACT

Forest resources are vital to the development of green economics. Given the booming development of China's forestry industry and its ambitious reforestation efforts in the developing world, this paper is the first to use the output distance function to synthetically consider the economic and ecological outputs of China's forestry industry, and discuss its productive efficiency with a stochastic frontier model. Control and environmental variables are incorporated to capture heterogeneity in China's forestry industry, which helps us get an unbiased estimation. The empirical results show that there was no obvious efficiency disparity among China's economic regions except Northeastern China, and the state-owned forestry structure has a significantly negative effect on productive efficiency in China's forestry industry. Moreover, provinces with poor productive performance in the forestry industry such as Inner-Mongolia, Heilongjiang, and Hebei have been identified and their individual characteristics regarding productive efficiency have also been analyzed. The findings in this paper have targeted and practical implications for the development of China's forest green economy.

Introduction

Forest resources are vital to ecological balance and environmental protection, and contribute to the national economic development of many countries. They contribute to soil formation and water regulation and are estimated to provide direct employment to at least 10 million people, apart from being a source of livelihoods to millions more (FAO, 2010). It is estimated that approximately 410 million people are highly dependent on forests for subsistence and income, and 1.6 billion people depend on forest goods and services for some part of their livelihoods (Munang et al., 2011). Wood and manufactured forest products contributed more than $450 billion to the world market economy annually, and the annual value of internationally traded forest products is between $150 billion and $200 billion (Köhl et al., 2015).

The development of the forestry industry, relying on forest resources, serves as an important indicator of the economic utilization of forest resources in China. As a complex industrial group, it comprises the primary industry (e.g. afforestation and regeneration), the secondary industry (e.g. pulp and paper products manufacturing), and tertiary industry (e.g. forest tourism service). Contents for each industry classification in China have been shown in Table 1. With the development of China's economy, the ever-increasing domestic demand for forest products has driven the rapid growth of the forestry industry, and the ratio of forestry to gross domestic product (GDP) rose from 3.16% in 1998 to 8.48% in 2014 according to the *China Forestry Statistical Yearbook.* It has been pointed out that China consumed the most wood-based panels, recovered paper, paper, and paper boards in the world and was the second-greatest consumer of industrial round-wood, sawnwood, and pulp for paper in 2010 (FAO, 2012). Besides, China has been facing serious environmental problems, such as soil erosion, extreme flooding, and dust storms, due to increasing population pressure followed by unsustainable agriculture practices (Liu and Diamond, 2005). One of China's widespread policy responses to these problems is its environmental restoration program of converting croplands to forests, known as the Sloping Land Conversion Program (SLCP), which is one of the largest conservation programs and the most ambitious reforestation efforts in the developing world (Bennett et al., 2008; Wang and Maclaren, 2012). As the production of reforestation efforts is also included in the output value of the forestry industry, China's reforestation efforts also explain

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Table 1
The forestry industry classification.

Forestry industry classification	Content
The primary industry	Breeding of forestry trees, afforestation and regeneration, forest management and protection, wood and bamboo lumbering, cultivation and collection of non-wood forest products, etc.
The secondary industry	Wood processing and manufacturing, pulp and paper products manufacturing, forest chemical products manufacturing, non-wood forest products processing, etc.;
The tertiary industry	Forestry production service, Forestry tourism service, Forestry ecological service, Technical and professional forestry services, Forestry management, etc.

Source: We sorted the content according to *China Forestry Statistical Yearbook (2014)*.

why the ratio of China's forestry to GDP has increased so significantly in recent years.

As for research regarding forest resources in China, most studied ecological services such as carbon sequestration (e.g. Huang et al., 2012; Lun et al., 2012; Wen and He, 2016) and related forestry policy effects such as China's sloping land conversion program and rural forestland tenure reform (e.g. Li et al., 2015; Salant and Yu, 2016; Wang and Maclaren, 2012).

Moreover, considering the growing domestic demand for forest resources and the importance of the forestry industry for green economics in China, more studies began to discuss forest resources economically. Ying et al. (2011) estimated the values of China's forest resources and calculated its forest green GDP for the first time and showed that the annual average growth rate of the environmentally adjusted NDP for forests was less than the annual average growth rate of NDP during 1999–2000. This decrease was caused by the increased depreciation in value of the planted forest and the loss of forest resource assets and degradation of forest environmental assets since the greater economic development of recent years in China. Some research focused on the flowing of forest resources across industrial sectors. For example, Cheng et al. (2010) calculated the quantities and analyzed the characteristics of flows of forest resources (primarily wood and wood byproducts) during the critical early economic development of China (from 1953 to 2000); Chen et al. (2015) examined the forest resource (timber products) utilization in China from a different perspective by combining quantities and values based on input–output tables.

Worldwide, efficiency improvement is often regarded as one of the most important goals behind many social and economic policies and reforms (Kumbhakar et al., 2015), and there is no exception for the development of China's forestry industry. There were studies discussing the efficiency of China's forestry industry. For instance, He and Weng (2012) investigated the technical efficiency of forest product processing mills and the relationship between institutional and managerial practices and efficiency. Tian and Yao (2013) discussed the productive efficiency of the forestry industry in China but only considered the economic output value of the forestry industry.

However, to the best of our knowledge, few studies to date have assessed and analyzed the efficiency of China's forestry industry while considering both economic and ecological output value. Therefore, this study aims to fill this gap in the forestry literature.

Methods of benchmarking for performance

As for methods of benchmarking for performances of decision-making units, two different kinds of approaches have been adopted, Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). DEA is based on linear programming (the non-parametric method) whereas SFA employs econometric techniques (the parametric frontier model). There are volumes of literature measuring the productive efficiency of the forestry industry using these two methods. For example, Kao and Yang (1991) and Kao (2000, 2010) look at efficiency related issues connected to forestry in Taiwan based on DEA. Lundgren et al. (2015) used DEA to compute a total factor productivity indicator for the Swedish pulp and paper industry 1998–2008. Bostian et al. (2016a, 2016b) also focused on Swedish pulp and paper industry by employing a network DEA approach and extending time substitution models based on DEA. As for the method of SFA, Helvoigt and Adams (2009) employed SFA to investigate technical efficiency and productivity growth in the sawmilling industry of the U.S. Pacific Northwest over the period 1968–2002. Tian and Yao (2013) used SFA to research the technical efficiency of forestry production in China during 1999–2011. Chand et al. (2015) used stochastic frontier production analysis to study the production relationship between environmental and community benefits and production efficiency analysis to study the extent to which communities could achieve maximum benefits.

The choice of estimation method has been an issue of debate. Generally speaking, both methods have their strengths and weaknesses. The main disadvantage of non-parametric approaches such as DEA is their deterministic nature, which does not distinguish between technical inefficiency and statistical noise effects (Murillo-Zamorano and Vega-Cervera, 2001). However, the main disadvantage of parametric frontier functions such as SFA is requiring the definition of a specific functional form for the technology and for the inefficiency error term, which causes both specification and estimation problems (Celen, 2013; Murillo-Zamorano and Vega-Cervera, 2001).

For the issue we focus on in this paper, we prefer the SFA method. The specific reasons are as follows. First, we separate the statistical noise effects from technical inefficiency, which is the main advantage of SFA. Second, we employ the translog production function (Ghosh and Kathuria, 2016; Mastromarco and Ghosh, 2009), a more flexible functional form of the production relationship between inputs and outputs, in order to reduce the specification problem. Third, we assume the mean of the inefficiency error term is a linear function of some exogenous variables by the one-step estimation method to reduce the estimation problem (Battese and Coelli, 1995; Huang and Liu, 1994). Fourth, by using the model extended by Battese and Coelli (1995), we attempt to incorporate control variables and environmental variables (or exogenous variables) to capture heterogeneity (Dong et al., 2015, 2016), which is seldom considered when employing the method of DEA.

It is worth mentioning that the two-step DEA method can also use regression techniques to determine the exogenous variables to explain the efficiency scores (Perez-Reyes and Tovar, 2009; Pombo and Taborda, 2006). However, care must be taken of the bias in DEA efficiency calculation and the correlation problem in regression analysis by employing a bootstrapping technique (He and Weng, 2012; Simar and Wilson, 2007). Instead, the one-step estimation method in SFA introduced by Reifschneider and Stevenson (1991) estimates simultaneously the parameters of the stochastic frontier function and the inefficiency model, which resolved the problem of biased and inconsistent estimation.

Generally speaking, this study employs an unbalanced data of forestry industry set that consist of 31 Chinese administrative areas over the period from 1998 to 2014 and estimates the stochastic frontier by using translog production function and incorporating heterogeneities. Our contributions are as follows. First, in order to get a comprehensive efficiency measure of the forestry industry, we consider the economic and ecological output of the forestry industry in China by employing the output distance function, which has not been found in other related literature. Second, we incorporate control and environmental variables in the production function