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A combined input–output/decision making trial and evaluation laboratory method for evaluating effect of the remanufacturing sector development

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ABSTRACT

The increasingly intensive industrial activities in emerging economies like China have caused serious resource depletion and pollution issues. As remanufacturing practices effectively solve common environmental problems in recycling and processing stages by minimizing emissions of wastes, remanufacturing has become an important eco-industry, and it has been gradually adopted in recent years in China. Based on the input–output theory and previous studies, this paper establishes an input–output model with multiple remanufacturing sectors, and develops a combined input–output and Decision Making Trial and Evaluation Laboratory method. Then, using the input–output table of China in 2007, the combined method is used to examine the role of the remanufacturing sector in the national economy as well as its symbiotic effects with other sectors for energy saving and emissions reduction. The results show that the remanufacturing development is far below the average development level of other sectors in China. With the rising market share of remanufacturing, the demand of some energy-intensive and pollution-intensive sectors, including Smelting and Rolling of Metals, and Production & Supply of Electric Power & Heat Power, can be significantly decreased. But the demand of Traffic, Transport and Storage is increased. The results can provide a scientific basis in formulating economic policies to promote the remanufacturing development and the macro adjustment of the industrial structure for the government.

1. Introduction

As the depletion of resources and the deterioration of environment have become serious bottlenecks constraining the economic development (2008), eco-industrial development has become extremely important, especially for a typical developing country, China (Geng et al., 2012, 2014; Wang et al., 2006; Wang et al., 2012a,b; Zhang and Wang, 2014; Zhang et al., 2012). Remanufacturing addresses to achieve greater materials and energy consumption efficiency, and thus it has become an important eco-industry, and its development contributes to resource saving and waste reduction (Geng and Doberstein, 2008). As a result, an increasing number of countries including developing countries have formulated policies to promote remanufacturing practices.

Since the Circular Economy Promotion Law was formally implemented in China on January 1, 2009, remanufacturing, as an important part of circular economy, has gained the significant governmental support and many positive responses from enterprises. However, these recent regulations and policies related to remanufacturing in China are generally voluntary, which mainly provide subsidies for approved remanufacturers as official demonstration projects (Zhu et al., 2011). Several questions remain unanswered. Can indicators and legislations be efficient measures to promote the development of the remanufacturing sector? How to evaluate benefit that remanufacturing promotion can bring to economy and other sectors? Which sectors can have the significant influence on remanufacturing?

Limited studies on remanufacturing focus on examining environmental gains of remanufacturing practices from a company and product life cycle perspectives. For example, Bulmus et al. (2013) discussed material saving in remanufacturing processes at an individual company level. Schau et al. (2011) examined environmental, social and economic costs of remanufactured alternators through their whole life cycle. Actually, the remanufacturing sector development has significant symbiotic relationships with other sectors, especially for those energy-intensive and pollution-

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intensive ones, for alleviation of environmental impacts (Tian et al., 2013). Very few studies examined environmental benefits about remanufacturing at the sector level. Ferrer and Ayres (2000) discussed about the economic effect of a single remanufacturing sector. However, different remanufacturing sectors exist such as vehicle engine remanufacturing as well as machinery and equipment remanufacturing. Moreover, it is still unanswered on how to examine which sectors can significantly reduce their outputs with the rising market share of remanufactured products and service.

To overcome the research gap, the key contribution of this paper is to develop a combined method of input–output (I/O) and Decision Making Trial and Evaluation Laboratory (DEMATEL) to evaluate economic benefits from the remanufacturing sector. Such combined method can overcome the limitation of I/O analysis and the deficiency of the DEMATEL approach. We also extend an I/O model including one single remanufacturing sector to multiple remanufacturing sectors.

This paper firstly reviews remanufacturing in developed countries and China briefly as well as related previous studies in Part 2. In Part 3, we describe the methodology about the development of the combined I/O and DEMATEL method. In Part 4, using the input–output table of China in 2007, we apply the combined method to examine the role of the remanufacturing sector in the national economy as well as its interaction effects with other sectors. Discussion and policy implications are introduced in Part 5 followed by conclusions in Part 6.

2. Background and literature review

2.1. A brief overview of remanufacturing in developed countries and China

In developed countries such as the United States and Germany, remanufacturing has been well-understood, and it has become essential in the national economy. Reasonable regulations are a key factor that promotes the development of the remanufacturing sector in developed countries. As to legislations, the United States issued laws for recycling waste tires which aim to improve the utilization rate as early as 1991. Japan promulgated the 'Basic Environmental Law' effective on November 13, 1993, 'Waste Management Law' effective on July 24, 1971, and 'Law for the Promotion of Utilization of Recyclable Resources' implemented in June, 2001. The European Union issued Waste Electrical and Electronic Equipment Directive for electronics recycling in 2005. These laws, regulations and policies have greatly promoted the development of remanufacturing in developed countries (Nnorom and Osibanjo, 2008).

Compared to developed countries, remanufacturing of China still has a large space to be improved in several areas such as scale, policy and regulation development, and public awareness. Remanufacturing is still in the demonstration stage in China at present, and the total number of 77 remanufacturers is far less than those in developed countries by 2013. Jinan Fuqiang power Co., Ltd. firstly conducted truck engine remanufacturing in China. Accordingly, about 40,000 tons of metal, 72.5 million kWh of electricity and 3000 tons of CO_2 can be reduced by this company if it produces 50,000 remanufactured truck engines every year (Xu, 2010). About 110,000 engines, 60,000 remanufactured gear boxes, and 1 million starters were remanufactured in China in 2009 according to the statistic data publicized by the China National Resources Recycling Association. In terms of policies and regulations, some legislations, like the Cleaner Production Promotion Law implemented since January 1, 2003 and Circular Economy Promotion Law implemented since January 1, 2009 are helpful to form a certain legal foundation for remanufacturing in China, but a complete and perfect legislation system is not developed yet. As for public awareness, Chinese remanufacturing has not yet formed a unified control system in technology and product quality, so poor product and service quality leads to a number of issues about consumer acceptance of remanufactured products (Zhang et al., 2011).

2.2. Literature review

Along with the remanufacturing practices, the research on remanufacturing has gained an increasing attention by scholars all over the world. According to Lund and Hauser (2010), some developed countries such as the United States and German have proved that remanufacturing is a beneficial activity to both economy and environment. Firstly, less materials and energy consumption in remanufacturing brings more environmental benefits than manufacturing (Gutowski et al., 2011). Thus, remanufacturing reduces cost and makes profits for remanufacturers (Heese et al., 2005). Moreover, considering remanufacturability in a life-cycle perspective, Design for Remanufacturing (DfR) can bring more benefits for remanufacturers (Yao et al., 2011). Lastly, as an increasing number of environmental legislations have been enacted, particularly in Europe such as the Restriction of Hazardous Substances and Waste Electronics and Electrical Equipment directives, remanufacturing has become a need for business to meet strict legislations while keep economic profits (Webster and Mitra, 2007).

In terms of the methodologies, limited studies examine the effect of different sectors on economy or environment. Chen (2005) used MARKAL-MACRO, an integrated energy-environment-economy model to examine scenarios for the future energy development and carbon emission in China till 2050. Ferrer and Ayres (2000) used the input–output method to analyze influence of the remanufacturing sector on macro economy and employment of France. Gemechu et al. (2014) applied environmental input–output and price models into direct and indirect effect evaluation of an environmental tax on Spanish products. Dong et al. (2014) used a single-regional-input–output method to calculate the carbon emission from production account and consumption account with a traditional competitive input–output table. Zhu et al. (2014) used a Gray-DEMATEL method to analyze supply chain barriers at both the operational and strategic levels for truck engine remanufacturing in China. Based on the industrial linkage theory, (Yin, 2012) used structured and standardized input–output models to get a quantitative description of inter-industrial relationships. Fang et al. (2009) applied the networked DEMATEL method into linkage analysis of Chinese industries by using different indicators. In conclusion, the I/O related method is most used in the macro-economic or environmental analysis. A DEMATEL related approach is appropriate for the complicated relationships mapping. This study develops a combined I/O and DEMATEL method to describe the complicated linkage relationships between the remanufacturing sector and other sectors by using a prominence–casual graph.

3. Method

3.1. A brief introduction of the I/O method and the DEMATEL approach

3.1.1. The I/O method and its application in remanufacturing evaluation

The I/O method was first put forward by Leontief, an American economist, in 1936, and it was used to analyze a number of dependencies relationships in the American economic system

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