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Transportation and economies of scale in recycling low-value materials

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A B S T R A C T

This study investigates the economic incentive-drivers used in various configurations in green supply chains. The configurations of competitive suppliers and integrated transportation are studied for recycled materials with low economic value but high environmental impact. Arguments are embodied in a competitive game that manifests interactions among competing manufacturers, suppliers of virgin materials, suppliers of recycled materials, and the government. Because of market size and technology limitation, long hauling to few remote treatment facilities is observed in practice. Demand-dependent transportation efficiency arisen from economies of scale thus affects the equilibrium states in the game of this recycling system. Managerial insights are provided to encourage the use of low-value recycled materials. A tax-subsidy system is conditionally effective when using recycled materials maintains quality. When quality becomes compromised by mixing recycled materials, we find that integrating suppliers of recycled materials with those of virgin materials can make the tax-subsidy system effective again.

1. Introduction

Issues associated with collecting and recycling resource materials have gained prominence because of increasing environmental concerns. However, private processors have their own business priorities in their choice of recycled materials, and their evaluation is unlikely to accord with social responsibility or laws. Most high value materials have long been collected by highly efficient industrial organizations whether the collection was mandated (TMS, 2013) and most low value materials are left uncollected even if they cause significant consequences to the environment (EARTH911, 2013). Several materials may have insufficient market applications, and several others may even be more expensive than virgin materials, not to mention the extra cost incurred by long distance hauling to remote delicate-processing factories. For instance, mixed rubbers and plastics are costly to recover and require specialized technologies in the process (Mercedes-Benz, 2013). Such materials are often referred to as economically disadvantaged recycled materials (EDRMs) (Hawken et al., 2000). If using recycled materials compromises quality, the process is referred to as *lossy recycling*, whereas if the market value is unaffected, the process is called *lossless recycling*. With most plastic products, properly mixing virgin and recycled plastics does not decrease the selling price but effectively reduces the production cost.

EDRMs, such as most composite material products and construction wastes, have several disadvantages that preclude their use in ordinary production processes (Economist, 2002; Flory, 2009). For example, monetary savings from using

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recycled materials are disproportionate to the increasing in costs as a result of transporting goods from remote locations. Given that the supply sources of EDRMs are highly specialized, EDRMs entail high acquisition and delivery costs and are thus considered low-priority options for material usage. Transporting these scraps for processing is usually not cost-effective. For example, using materials recycled from scraped polystyrene is possible to cut material costs, but they are also costly to obtain from a remote factory, which may be the only source holding the proprietary technology in the country (INEPSA, 2013). Furthermore, in contrast to virgin materials, EDRMs are often consumed in small amounts and require long-distance transportation because of their limited applications in the market. Treating and processing low-value materials typically require specialized technology, which is owned by few factories in a region. Thus, such factories are usually located at remote sites. The trade-off between transportation and economic value surplus becomes a major concern.

A sustainable recycling system requires proper support from the consumption market. For example, the glass recycling program of New York City was suspended in 2002 because its costs outweighed its profit. However, the program was later resumed because potential economic benefits increased (EarthTalk, 2013). Therefore, the success of government policy heavily relies on economic incentives. Consistently used materials are to be collected automatically. Therefore, this study ignores materials with high economic value, such as precious metals. We are interested in low-value materials, which are collected only with strong policy intervention. However, if low value materials are mandatory recycled, the expense must be fully paid by taxpayers or sellers. Enforcement cost is usually high without economic motivation. Without acceptance of market, the taxpayers' money can only command EDRMs to be collected but cannot command them to be consumed and thus creates a stockpiled and unbalanced closed-loop supply chain. The unbalance is partly due to the lack of economic value (Hawken et al., 2000). Moreover, pushing legislation toward highly mandatory standard also drive industries to underdeveloped regions known as *pollution havens* (Eskeland and Harrison, 2003).

Alternatively, governments can take only partial financial responsibility over EDRMs. Proper tax-subsidy with competition yields a cascade effect without fully compensating processors' costs (Sheu and Chen, 2012). Taxation encourages usage, subsidy reduces supply cost, and increased usage implies economies of scale, which renders a highly-efficient transportation networks. Currently, most governments unilaterally conjecture necessary processing costs in terms of cost-accounting and try to cover processors' costs in full. The fund comes from either producers or taxpayers. Because collecting environmental taxes from countless no-brand factories is challenging for non-tax major government agencies, the government must pay the rest of processing cost from the taxpayers' pocket, if the collected tax is insufficient. Fortunately, an instrument of partial financial incentive can be more effective than a full one if satisfactory managerial insights are discovered.

Despite the growing research interest in recycling management, most studies continue to assume that materials are homogeneously composite in economic value and environmental impact and disregard the behavioral differences caused by material heterogeneity and market value variability (Robert L Smith, 1998). This gap presents a research opportunity for the current study, which concerns the use of recycled materials in the industrial market rather than in the consumer market. We focus on the challenge of encouraging the transportation of EDRMs for voluntary consumption by considering effective economic instruments and different configurations of the green supply chain system driven by economic incentives. Expensive direct shipping is usually the only choice for a small quantity of goods. When handling a large volume of goods, applying highly-efficient transportation methods, such as transshipment, becomes possible. Thus, this paper thus investigates the complicated relationship between the use of low-value materials and instruments of government policy when transportation cost is a function of volume.

Given these challenges, our improvements address issues regarding the recycling system for EDRMs not covered in previous literature. In this regard, the current study aims to address the following research questions: How can an EDRM closed-loop supply chain be sustained without artificially mandating the use of EDRMs in final products? How well does an instrument of tax-subsidy policy operate if loss of quality is anticipated when EDRMs are used in final products? Can an integrated transportation and production network enhance the profitability of EDRMs?

Although remarkable progress has been made by pioneering studies in promoting material recycling, several critical issues remain unsolved and thus motivate this study. Savaskan et al. (2004), Nagurney and Toyasaki (2005) and Atasu et al. (2009) modeled a framework for a closed-loop supply chain in a multi-echelon distribution channel that involves various manufacturers and retailers.

Sheu and Chen (2012) and Chen and Sheu (2009) suggested the use of economic instruments in strategic planning for a closed-loop supply chain. Drawing on global green legislation, such as the Waste Electrical and Electronic Equipment Directive, Fleischmann et al. (2002) argued that government standards are at least indispensable in correcting the market failure of EDRMs, promoting awareness of pollution reduction, and imposing responsibility on manufacturers. The use of economic incentives to promote all stages of material recycling has been extensively investigated in environmental economics (Ulph, 1996; Walls and Palmer, 2001; Benchekroun and Van Long, 2002). Given that previous studies rarely considered value and cost in designing incentive mechanisms and thus resulted in unbalanced literature on closed-loop supply chains, we thus focus on the economic issue in the manufacturing market rather than the consumer market and therefore build a quantity competition model for industrial market.

This study also concerns the integrated of transportation into production and distribution. Hall (1996) examined decisions on inventory fulfillment when the integration of production and transportation in a system is considered. Chang (2009) studied fleet management plans that integrate the transportation needs of carriers with order information for decisions on service provision. Lin and Wang (2011) and Friesz et al. (2011) investigated a problem regarding the design of an integrated supply chain network and suggested that downward substitution facilitates the elimination of uncertainty.