Under Dual Channel Environment, A Quality-Based Price Competition Model For The WEEE Recycling Market

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ABSTRACT

Recently in emerging countries, there have both formal and informal sectors to process waste electrical and electronic equipment (WEEE). Normally, the formal channel consists of recyclers with official qualifications for disassembling WEEE, meanwhile the informal channel is dominated by unregulated recyclers. In this study, we create a quality-based price competition model for the WEEE recycling market to comprise the formal and informal sectors. The results indicate that government subsidy can help the development of the formal sector at a higher quality level of waste, when the quality of waste is high but the government subsidy is not substantial, the informal sector always has a competitive advantage.

INTRODUCTION & LITERATURE REVIEW

The Environmental Protection Agency (EPA) reports that 20–50 million metric tons of e-products per year are being scrapped worldwide. For example, in the US alone, there are 14–20 million personal computers out of use each year. The United Nations Environment Program (UNEP) estimates that millions of used products have been generated every year in China since 2003. The waste electrical and electronic equipment (WEEE) have become a huge pollutant source because these products often contain toxic material or components (Dimitrakakis et al., 2009; Hicks et al., 2005).

In developed countries, dismantling WEEE is strictly controlled and audited by the environmental authorities and carried out by qualified recyclers, while in many developing countries we have both a formal and an informal sector for processing waste electrical and electronic equipment (WEEE). The formal channel involves companies with official qualification for disassembling WEEE. However, there are not a huge amount of used electrical products that are recycled, disposed, and reused in an environmental-friendly manner. The informal recycling sector, which is unregulated, encompasses the disassembly of WEEE using crude and pollutive methods (Chi et al., 2011). In developing economies, it is not unusual to find an informal recycling sector which processes a high volume of e-waste products. For example, in Brazil a formal recycling structure for treatment of WEEE is still in its infancy; with the WEEE recycling rate estimated by the Brazilian Electrical and Electronic Producers Association to be only 2% (Araujo et al., 2012). Similar things happened in both India and China too.

The government in almost every developing country has established related rules and laws to regulate WEEE recycling because of the existence of a vibrant informal recycling sector. Typically, the government provides a subsidy to support these formal recyclers with official qualifications. As an illustration, a recycling management fund is set up in mainland China to provide subsidies to qualified recyclers which took effect in September 2012. The expected outcomes are still unclear since the implementation program is still in its infancy. What role can government subsidy play in promoting the healthy development of the recycling industry? The subsidies will enable qualified recyclers to offer a more competitive acquisition price and thus change the weak position they have been in. Then what level of subsidy is reasonable? How high should a quality threshold of reusing WEEE be set by the government? What is the impact on the dynamics of the recycling industry if remanufacturers buy reused parts from qualified recyclers? Based on these questions, the paper builds a dual-channel model which incorporates quality-based price competition between formal and informal recycling channels in reverse logistics to assist the government in solving these issues.

Previous researchers have focused on reverse logistics management. Likewise, Spicer and Johnson (2004) discuss the role of third party recyclers and compare three kinds of recycling channels – OEM take backs (manufacturers have direct responsibility), pooled take backs (several manufacturers share the responsibility), third-party take back (manufacturer subcontracts to third party for end-of-life product responsibility). Souza (2013) examines strategic issues in OEM remanufacturing and provided a modeling framework to answer the question of whether an OEM should offer a remanufactured product. Savaskan et al. (2004) compare the operation efficiency of different recycling means to provide the theoretical basis for manufacturers, while Savaskan and Wassenhove (2006) add multiple retailers into the channel choice analysis. Ferguson and Toktay (2006) explore how a manufacturer deals with the competition with a third-party recycler who engages in refurbishing and reselling. They show that the manufacturer should recycle and dispose of used products to reduce the impact of the recycler's refurbishing work on the sale of new products. In Vlachos et al. (2007), they develop capacity planning policies for remanufacturing in reverse supply chains. Oraiopoulos et al. (2012) introduce a relicensing method for the original equipment manufacturer (OEM) to influence the scale of the secondary market. Kim et al. (2013) develop a Markov decision model to improve operational costs by coordinating production, remanufacturing and disposal operations.

In summary, previous research has not dealt with the issues of recycling competition between formal and informal sector recyclers with different disposal methods and quality-based acquisition pricing when collecting WEEE products. We distinguish our work from earlier studies as follows: (1) incorporating the quality-based price competition between formal and informal recycling channels; (2) describing different disposal methods in the two channels; (3) exploring the impact of government subsidy, cooperation with remanufacturers, and setting of the quality threshold of recycling in the formal sector.

MODEL DEVELOPMENT

In the WEEE recycling market, there exist two kinds of recycling channels: a formal sector (Channel *A*) which is led by recyclers with official disassembly qualification who collects used products and chooses

one of the three disposal methods of disassembly, recycling reused parts and refurbishing based on the product quality levels, and an informal sector (Channel *B*) which is led by unregulated recyclers who disassemble low-quality used products and refurbish those with high economic value. In Figure 1, both recyclers in the formal and informal sectors sell extracted metals from disassembling WEEE in the raw material market and refurbished products in the secondary market. Only the qualified recycler can cooperate with remanufacturers to sell recycled reused parts because product security and quality assurance are provided in this sector. In practice, the government provides subsidies only to qualified recyclers in the formal sector.

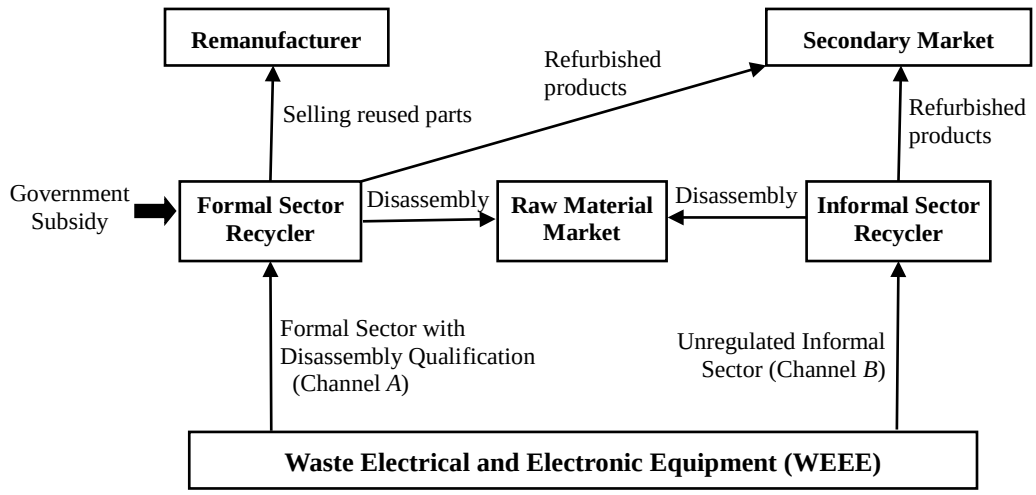


Fig. 1. WEEE flows in formal and informal sectors.

The recyclers in Channels *A* and *B* decide acquisition prices based on the quality of used products and minimum quality point for refurbishing, that is, products with quality beyond this point can be refurbished. In practice, the recycled reused parts must meet the minimum quality requirements set by the government. Therefore, we define τ^* as the quality threshold for reusing WEEE. Note that channel *A* only recycles reused parts from products beyond the lowest quality point.

Since there are a variety of disposal methods, we assume the following relationship $C_{1A} > C_{1B} > C_{2A} > C_{3A} > C_{3B}, P_1 > P_2 > P_3$. We assume that both recyclers are able to assess the quality level when collecting used products. Based on the quality information, recyclers decide the acquisition price, $p_A = f(\theta)$, $p_B = g(\theta)$, which is a continuous function of quality.

$$q_A = q + ap_A - bp_B \tag{1}$$

$$q_{\boldsymbol{B}} = q + ap_B - bp_A \tag{2}$$

τ_A is a demarcation point of quality between refurbishing and recycling reused parts in channel *A*. The profit function of the qualified recycler in Channel *A* is,

$$\pi_A = \int_0^{\tau^*} (P_3 - C_{3A} + s - p_A)(q + ap_A - bp_B)d\theta + \int_{\theta^*}^{\tau_A} \left(P_2 + s - \frac{C_{2A}}{\theta} - p_A\right)(q + ap_A - bp_B)d\theta + \int_{\tau_A}^{1} \left(P_1 - \frac{C_{1A}}{\theta} - p_A\right)(q + ap_A - bp_B)d\theta. \tag{3}$$

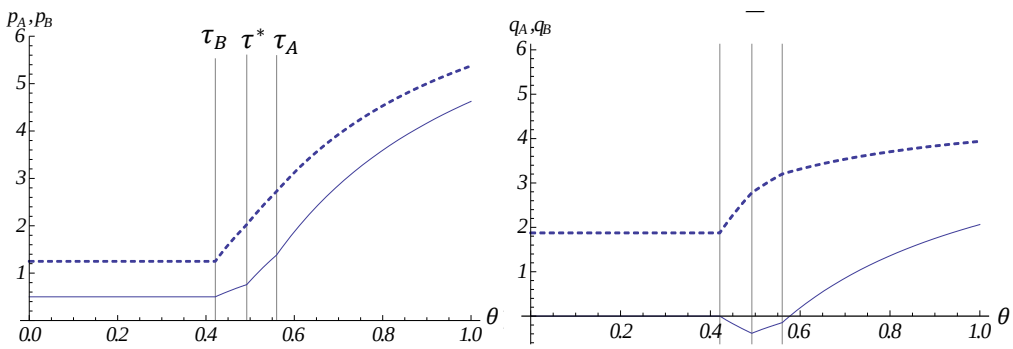
The profit function of the recycler in Channel *B* is,

$$\pi_B = \int_0^{\tau_B}(P_3 - C_{3B} - p_B)(q + ap_B - bp_A)d\theta + \int_{\tau_B}^{1}\left(P_1 - \frac{C_{1B}}{\theta} - p_B\right)(q + ap_B - bp_A)d\theta. \quad (4)$$

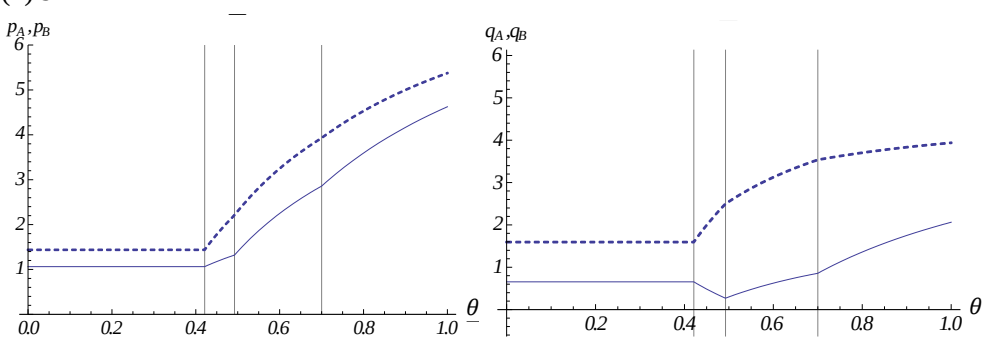
NUMERICAL SIMULATION

We use numerical simulation to show the recycling competition and effects of subsidy in a more graphic way. In Figure 2, the simulation results are presented.

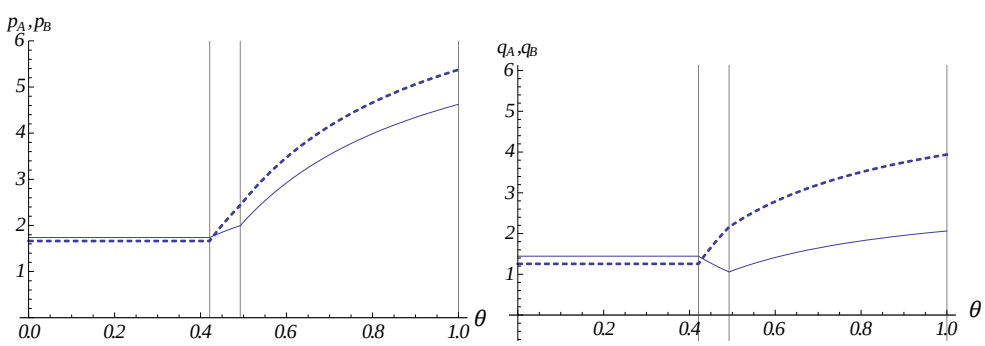
(1) s=0



(2) s=1



(3) s=2.2



(4) s=5

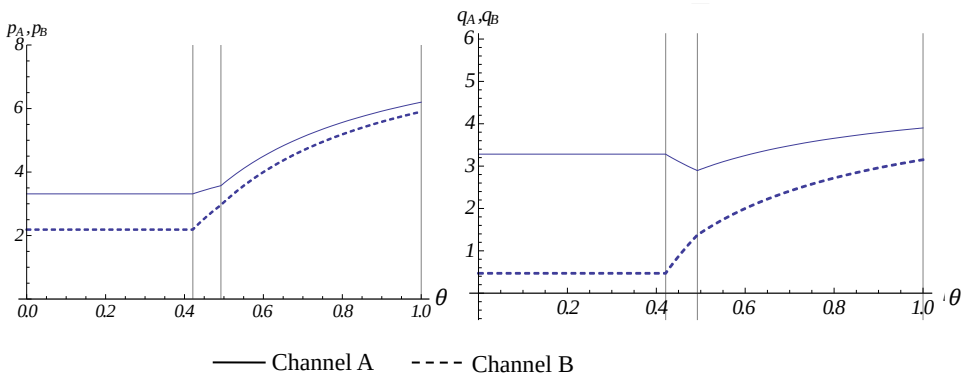


Fig. 2. Variation of acquisition prices and quantities at four subsidy levels.

When there is no subsidy (*s*=0), the acquisition price is always higher in channel *B* than that in channel *A* which only collects a small amount of high-quality products to refurbish. When subsidy rises to *s*=1, the acquisition price and quantity increase obviously in channel *A*, but still are below that in channel *B*. This phenomenon is quite common in current developing countries. Although the government has provided some subsidy, the acquisition prices at all quality levels are always higher in the informal sector. This indicates that the formal sector is still at a competitive disadvantage.

When subsidy rises to s=2.2 (about 88% of disassembly cost of channel *A* in this simulation), $\tau_A = 1$, channel *A* quits from the secondary market and is able to provide higher prices than channel *B* only at the disassembly quality level. It's clear that in the secondary market without competition from channel *A*, it becomes more difficult to impose a restriction on the acquisition quantity of channel *B* which has become monopolistic.

As subsidy continues to rise, channel *A* obtains stronger competitiveness. When subsidy rises to s=5 channel *A* has secured a high market share, but the competing advantage is still not very obvious at very high-quality levels. This proves that the higher the quality level is, the weaker is the effect of subsidy on recycling. The government is supposed to make trade-offs between heavy subsidy and social effects of secondary market. Blindly raising subsidy to crack down on the informal sector will pay an extraordinarily high price and strangle the positive contributions of the secondary market.

CONCLUTION

Our study has examined the recycling of WEEE in a dual channel environment, which is a critical part of supply chain management. Two policy decisions from the government that can help regulate the WEEE recycling industry are: 1) subsidy level provided to formal recyclers by the government, and 2) quality threshold of recycling. We have developed a quality-based price competition model for the WEEE recycling market for the dual channel environment to analyze the industry dynamics and assist the government in making decisions on WEEE recycling policies. Our research finds that government subsidy can promote the development of the formal sector. We show that at a higher quality level of waste, the marginal effect of subsidy is not as strong. When we do not have a substantial government

subsidy and the quality of waste is high, the informal sector always has a competitive edge. Therefore, the government should not set the quality threshold of reusing too high because this will deteriorate recycling competition. In addition, the government subsidy should be set appropriately to restrict the quality of collected products at a high level only suitable for refurbishing in the informal sector. Sustainability is an important issue in supply chain management and handling waste electrical and electronic equipment (WEEE) is very important especially in emerging countries where the formal recycling sector is not well developed. Our paper can be extended in several directions such as introducing penalty risks imposed on the informal sector in the competition model and dynamic analysis in multiple periods.

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