Closed Loop Supply Chains: A Systems Dynamics Model for Analyzing Sustainable Business Policies for Shared Partners in a Chain

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Introduction

Research in closed loop supply chains have garnered significant importance, which mainly has a coordinated focus on combining the forward and reverse logistics of the supply chain (Halldorsson 2008, Atasu et al 2008). There are significant areas of interest in various applications, which may include modeling the forward and reverse logistics of clothes and apparel, tracing the lifecycle of a consumer product like a mobile phone, and the manufacture, recycling and remanufacturing of industrial products such as aircraft engines (ReCellular Jan 2007, Enders 2002, Perera 2006). The requirement of companies working within Europe include adherence to legislation such as WEEE (which stands for treatment of Waste from Electric and Electronic Equipment), which have spurred further interest in designing closed loop supply chains. Such businesses frequently have multiple partners along the supply chain, which handle different aspects of the manufacture, refurbish and recycling of electronic products (Debo et al 2006, Georgiadis et al 2006, Aras et al 2006, Vorasayan and Ryan 2006, Bakal and Akcali 2006). These partners may share information resources as well as physical infrastructure, and the viability and business decisions of one determines the profitability of the other partners downstream. This suggests that decisions made by one partner in the supply chain may have important and complex impact on others along the chain (Ferguson et al 2008, Fleischmann et al 2002, Teunter and Vlachos 2002, Thierry et al 1995, van der Laan et al 1999, Blackburn et al 2004). In such situations, it is critically important to model and study these decision parameters on their integrative impact on the partners in the chain, with a major focus on sustainability of processes from a business perspective.

Model

We model a problem scenario of a high value consumer electronic product with a short lifecycle, such as a mobile phone or a laptop. Such products usually have high material cost, and are environmentally unfriendly if disposed off quickly. Recycling has been a relatively new phenomenon in such goods, since margins from recycling are significantly lower than new product sales, leading to few recycling options. Hence such a consumer product, if not designed and marketed with an overall goal of sustainability from an environmental as well as business perspective, may lead to environmentally unfriendly business and supply chain cycles. For such

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a product, a new product manufacturer produces the product that isfirst adopted in the market by "market leaders" and subsequently by "followers". The new product stays in the market for a period of time, where some consumers may return the product before its natural end of life. Such returns are reprocessed and brought back into the market as refurbished products, which may be preferred by "follower" consumers over the new product depending on market conditions. Other returns may be processed for recycling, where components are broken down to their elemental states for a restart of the manufacturing process. Products that are returned at the end of their natural life may be processed for refurbishing or recycling depending on the product design and condition (Figure 1).

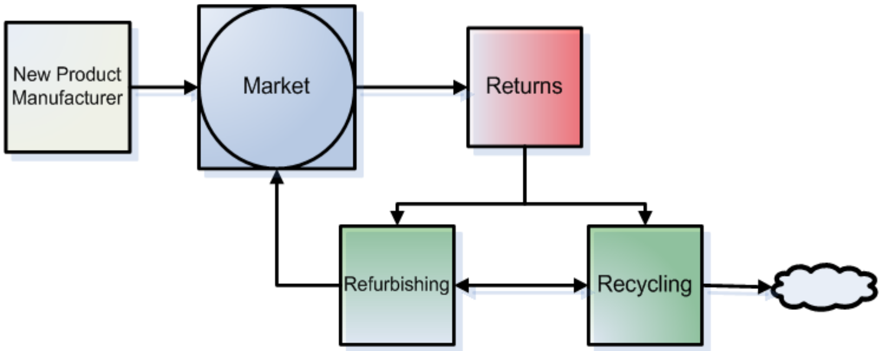

Figure 1: Overall Research Scenario and Model of Shared Resources

Each of these process areas described above presents a complex set of interrelated problems, which can usually be taken in isolation and solved to optimality. For example, marketing and pricing models exist for demand modeling and diffusion of new products in the marketplace; operations models have been proposed for logistics management; product design models suggest the lifecycle and associated costs of new and refurbished products; and consumer behavior research provide a guidance for the attractiveness of new versus refurbished products, and the impact of pricing and product design decisions. However for such a complex and interrelated decision making problem that involve multiple shared resources, an approach that optimizes the different components of the problem space may not provide a generalizable and overarching understanding of the dynamics of the system.

The parameters and decision variables of the model studied here is described in Figure 2. Model parameters include i) rate of innovators or market leaders in the system (alpha), ii) rate of imitators or followers (beta), iii) perceived product depreciation rate relative to new and refurbished products (delta), iv) price of new product (p_n), and v) price of refurbished product (p_r). By definition, innovators buy and use only new products, while imitators may buy and use new or refurbished products. The decision variables include i) return rate of new products by innovators, termed end of life (EOL) return rate for innovators, ii) EOL return rate for imitators, iii) EOL return rate for refurbished products, iii) return to refurbish rate, iv) refurbish to recycle rate, v) leak rate of new products from innovators (return rate before designed end of life), vi) leak rate of new products from imitators, and vii) leak rate of refurbished products.

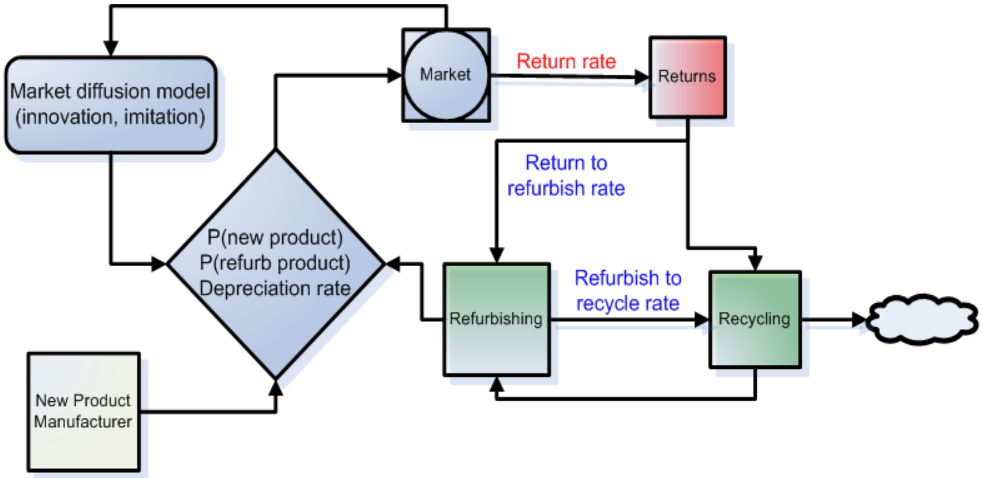

Figure 2: Decision Parameters of the Dynamic Model

The objective of the research is to study the integrative impact of the decision variables on the number of new and refurbished products in the market, the revenue impact on new product manufacturer, refurbisher and recycler, and the profitability and business sustainability of the refurbisher and recycler under various market and product design scenarios. While environmental sustainability of the supply chain is an important consideration, we argue that environmental sustainability goals should be modeled and subsumed into business sustainability, which are the true drivers of decision making for firms. For example, an economically sustainable refurbishing policy for a high-technology consumer product can be engineered to provide environmentally friendly benefits, and not necessarily vice versa.

We propose and implement a system dynamics approach to study the problem space and generate policy insights for managing the overall closed loop chain partners. System dynamics models have been used extensively to study complex phenomena that can be modeled quantitatively and may also contain qualitative constructs. It is well-suited for complex analytical models such as ours which have no closed form solutions, and may have non-linear and multiple level interactions among problem parameters (Sterman 2000, Dutta 2001, Georgiadis and Vlachos 2004, Forrester 1961, Wadhwa and Madaan 2008, Su et al 2009, Spengler 2004). An integrated approach that incorporates quantitative models developed in the literature, along with well-known models of the components of the overall supply chain, would provide rich insights into the decision making process. Our work is unique in addressing a holistic approach that includes initial pricing and sales of products, designing products for remanufacture and specified recycling rates, and looking at a holistic revenue stream of initial retailers, recyclers and remanufacturers.

Results and Discussion

The system dynamics model is validated using both qualitative as well as quantitative approaches. For each component of the model, we define causal loops based on existing literature, and test the partial model results to validate it. For the overall model, we plot the results for various output measures and compare them with those of published models and public data (where available). These provide confidence on the robustness and validity of our model.

Figures 3a and 3b show sales of new products and refurbished products sold to imitators, under price differentials of 0.1, 0.4 and 0.7, and perceived product differentiation between new and refurbished products ranging from 0.1 to 0.9. We see that for a given imitator rate (beta), perceived product differentials have a small positive effect on new product sales, and have a significant negative effect on refurbished product sales. The drop in sales of refurbished products continues even with price differentials that favor the refurbished products ($p_n - p_r$). This suggests that perceived product differentials have a greater influence on refurbished product sales than price advantages. It would be important for product designers and marketers to develop public awareness campaigns for their products that aim to have a high proportion of refurbished sales for sustainable development.

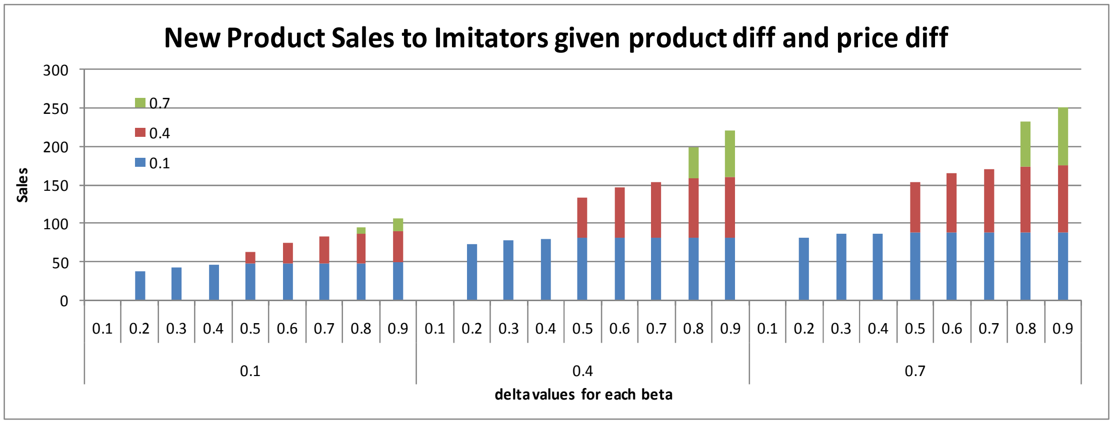

Figure 3a: New Product Sales to Imitators

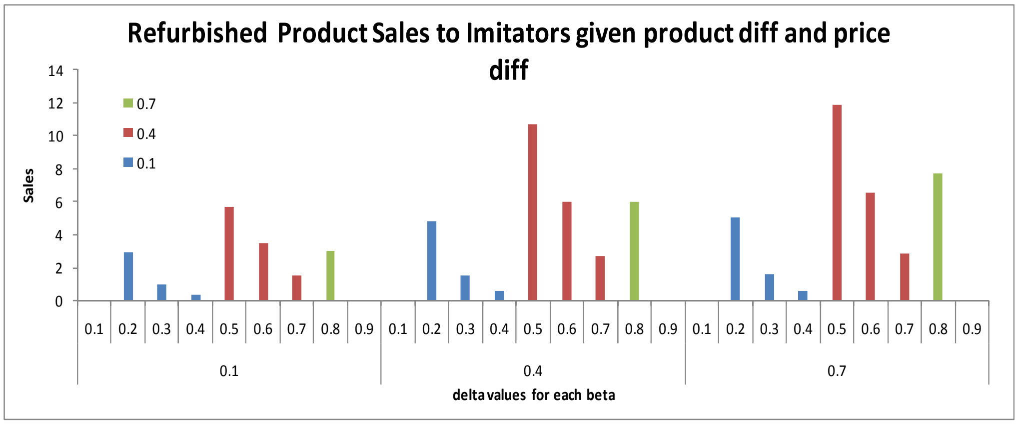

Figure 3b: Refurbished Product Sales to Imitators

We now turn our attention to the refurbish rate from returns and its impact on a sustainable business policy. Figure 4a shows that, as expected, the refurbish rate does not have an appreciable impact on new product sales, however it positively impacts sales of refurbished products, primarily through availability of refurbished products in the market (Figure 4b). As in the previous scenario (Figures 3a and 3b), refurbish sales is negatively affected by the perceived product differential. Hence perceived product differentiation is seen as a significant driver of consumer choice in the marketplace.

We will show additional policy implications of product marketing and design choices on sales and sustainability of all market participants in such markets with shared resources.

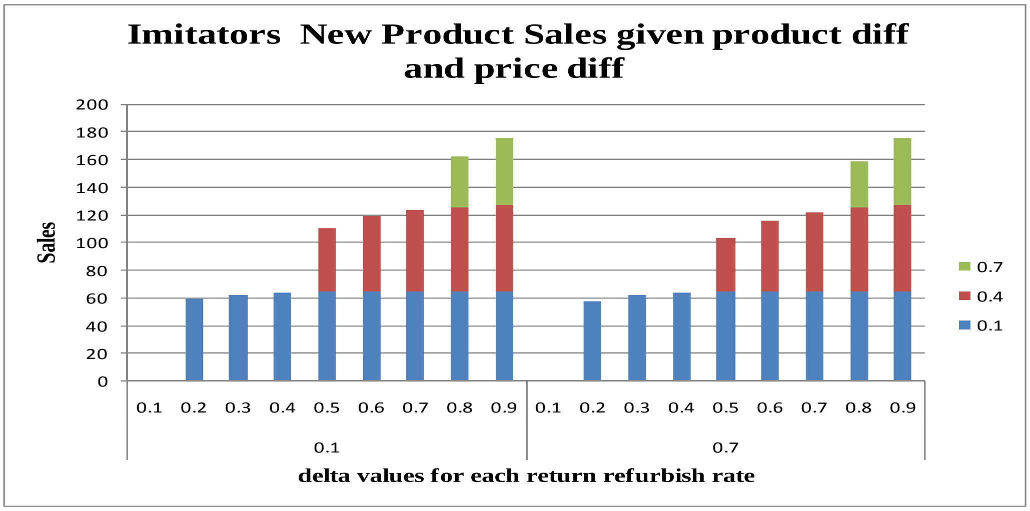

Figure 4a: Impact of Refurbish Rates on New Product Sales to Imitators

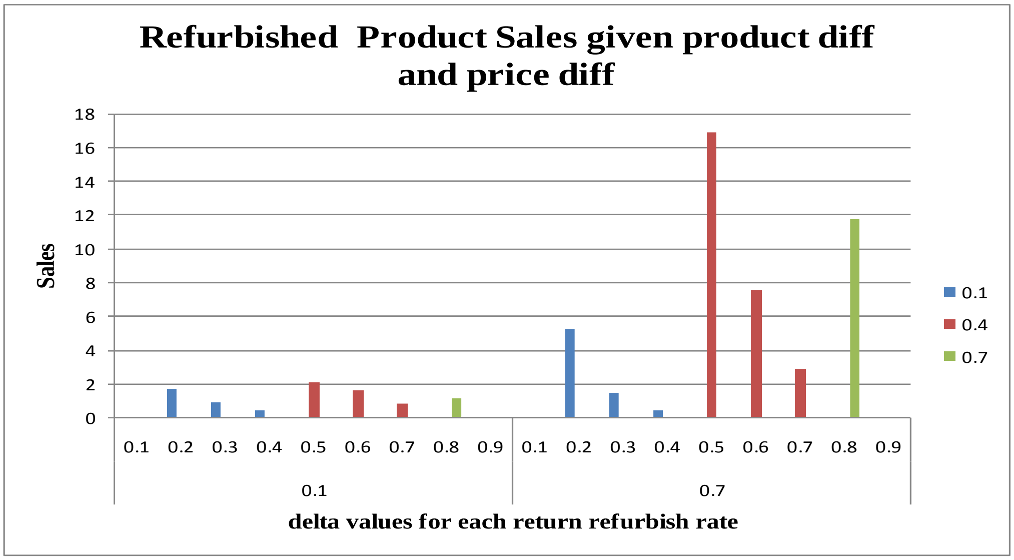

Figure 4b: Impact of Refurbish Rates on Refurbished Product Sales to Imitators