STRATEGIC ANALYSIS OF PRODUCT RECOVERY MANAGEMENT BY USING SYSTEM DYNAMICS APPROACH

Beril Üzmez, Necati Aras, Yaman Barlas
Industrial Engineering Department
Bogazici University
34342 Bebek Istanbul Turkey
+90 535 355 99 53
beril.uzmez@boun.edu.tr, arasn@boun.edu.tr, ybarlas@boun.edu.tr

Abstract

In this study, by using system dynamics approach we aim to investigate the profitability of a company if it is engaged in remanufacturing, which is the most advanced form of product recovery. Our motivation is to find out whether investing in remanufacturing is advantageous for a company/sector in terms of long term profitability and, what should be the quality and price levels of the remanufactured and newly manufactured products. The model shows that a company involved both in new and remanufactured versions of the same product, endogenously generates interesting customer-base dynamics. Different from the studies in the literature that deal with micro level models, we analyze the effects of being involved in remanufacturing of electronic products on the profitability of the firm at macro level, by taking into account the government incentives for the firms that perform product recovery.

Keywords: Reverse logistics; Remanufacturing; Product recovery; Green business

Introduction and Problem Background

With improving technology, environmental consciousness level and involvement in product recovery have become more of an issue for a company’s brand image in addition to the quality and price of the products. Since production quantities and consumption of natural resources and waste to landfill increase steadily, product recovery becomes a necessity for the preservation of the environment. Therefore, governments in developed countries enforce the firms for initiating product recovery activities via several legislations. However, it is important to emphasize that product recovery does not help only to the environmental sustainability but also to the profitability of the companies. Therefore, it can be a viable strategy for the economic welfare of a company. Product recovery includes alternative options such as remanufacturing, recycling, repairing and refurbishing.

In the literature, there are some studies that consider operational processes to analyze the effects of product recovery on the environment. Most of them also include legislations and green image factors. Capacity augmentation for remanufacturing or recycling has been also analyzed. Mont et al. (2006) develop a model with a leasing and reconditioning scheme and test its financial viability in their study. They choose a specific product, baby pram, to investigate because of its three characteristics: (i) it has a high recovery value at the end of its lifecycle, (ii) it has a large secondary market, and (iii) the lifetimes of its modules are very different. At the end of the financial analysis for 48 months, the authors deduce that leasing and reconditioning alternative provides more profit per baby pram. Kerr and Ryan (2001) aim to quantify the life cycle environmental benefits achieved by incorporating remanufacturing into a product system, based on a study of Xerox photocopiers in Australia. They compare the lifecycles of four types of photocopy machines. The results show that when the product is designed for disassembly and remanufacturing, economical and environmental savings are increased more compared with the case where the product is not designed for disassembly and remanufacturing. They also find out that remanufacturing decreases resource consumption and waste. Another study has been done by Kamath and Roy (2007) where they propose to provide necessary information to make a decision about capacity augmentation. Firstly, they provide making efficient decisions by making loop dominance analysis to find the dominant loops for capacity augmentation. Moreover, they analyze the effect of initial capacity by changing model the parameters. Consequently, they claim that the information feedback based methodology is general enough to be useful in designing decision support systems for capacity augmentation. Another study about capacity planning is done by Vlachos et al. (2007). They suggest making an efficient capacity planning by considering economic and environmental factors. They evaluate the total supply chain profit as the measurement of policy effectiveness. They also mention three strategies for capacity planning: Leading capacity strategy, trailing capacity strategy, and matching capacity strategy. They conclude that the most suitable strategy is leading capacity expansion strategy to improve reverse channel operations. Moreover, the effect of environmental parameters on product recovery is analyzed by Georgiadis and Vlachos (2004). Firstly, they examine the effects of the green image awareness of customer, its effects on demand and the effects of environment legislations on the collection rate. Then they compare capacity planning policies. The results show that while leading and matching remanufacturing capacity adding strategies increase the green image and demand of the product, the trailing strategy has a negative effect on the green image and demand. The study which is done by Georgiadis and Besiou (2008) has a same modeling approach with the aforementioned study. The main difference is that this study includes recycling instead of remanufacturing. They consider 4 types of market behavior since reuse index and green image depend on the market behavior. They examine the effects of different legislations on different variables. The study done by Georgiadis and Vlachos (2004) aims to develop integrated forward-reverse dynamic logistic models that include both quantitative and qualitative variables, time delays for each activity, and uncertainty in variables. They realize that the total cost increases because of the starting interest on remanufacturing capacity adding, but after reaching the final capacity, the cost per unit product decreases. In 2009, Poles and Cheong analyze the relationship between the factors which affect the uncertainty of return rates like return index and residence time. They examine different combinations including different residence time remanufacturing batches. They conclude that total production cost, residence time and return index have more effect on production and stock activities than the effects of firm strategy.

Model Description

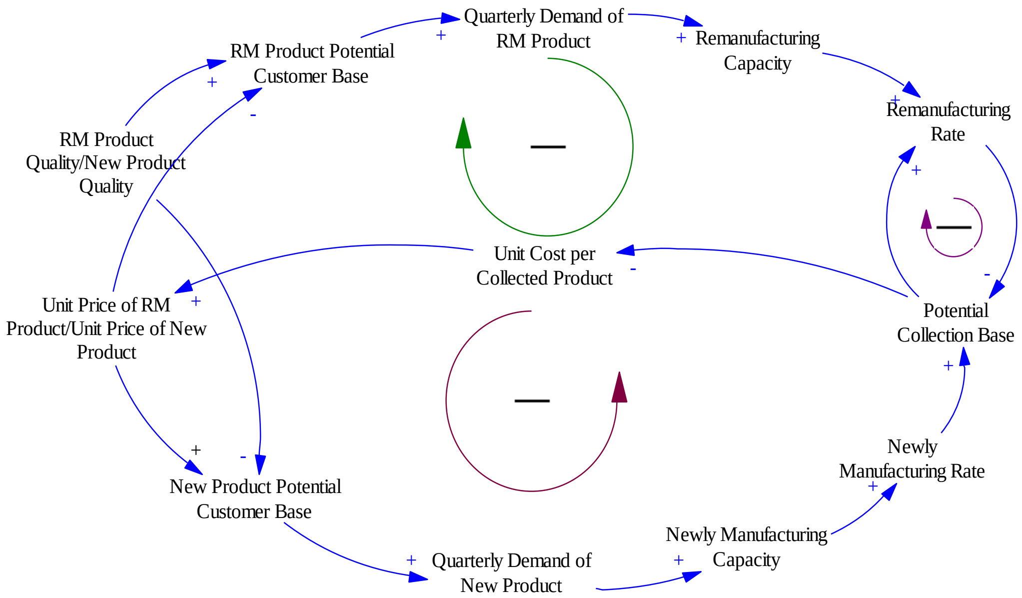
Although real data are not used in the model, the parameters, initial values and delays are set to realistic values by adhering to the ratios of the unit costs of remanufactured and newly manufactured electronic products such as personal computers. The value of the usage time, unit prices, quarterly increase in sales based on market growth, initial customer base, recollection percentage of used products, and profit margins are assigned on the basis of US data found in the reports of the Gartner Group. The values of the unit costs of new and remanufactured products are set to reasonable values. Namely, the unit cost and the selling price of a remanufactured product is taken as half of that of a new product. Moreover, increase in the prices due to inflation or decrease in the prices based on the introduction of new products to the market is ignored based on the assumption that they counterbalance each other.

In contrast to the former studies, we are tackling the question of whether investing on remanufacturing in the long term is profitable or not for a firm/sector. We aim to suggest policies for product recovery management by analyzing the system at a macro level for a long period of time such as 25 years. The model tries to give an answer to the following questions: (i) What are the effects of the customer perception of the product quality and price on the profitability of remanufacturing, the customer base of remanufactured product and the customer base of new product? and (ii) If a firm producing laptop and desktop computers starts remanufacturing, under what conditions does it incur positive profit in the long term?

Overview of The Model

The model is constructed for a computer firm which has 20 percent market share and is flexible to increase or decrease its remanufacturing and newly manufacturing capacity. The time interval is selected as a quarter year and the model is analyzed for 100 quarter years. It is assumed that each firm can collect only its own used product. We assume that there are two types of products of the firm available in the market: new products and remanufactured ones. Customers prefer the product depending on various factors such as Remanufactured (RM) Product Quality/New Product Quality, Unit Price of RM Product/Unit Price of New Product and Availability of RM Product in the Market. The competition takes place not only between the products of the firm, but also between the products of the firm and those available in the market.

At the beginning, the firm manufactures only new products, and the initial values of RM product customer base, expected sales of RM products and RM capacity are set to 1. This also helps to avoid the division by zero that can occur for the ratio of the demand to the sales for RM products. The qualities are identified as constant values at the beginning and they do not change during the simulation. It is assumed that the minimum value of the quality ratio of remanufactured and new product is 50% by considering the real life. This assumption is provided by determining appropriate range values of the effect function of the quality ratio. There is a similar assumption for the ratio of prices as well.



Basic Causal Loop Diagram of The Model

In the causal loop diagram, we can observe the following. If the remanufactured product is more advantageous than the new product for customers at the beginning, the remanufactured product customer base increases and new product customer base decreases due to the migration of customers to the remanufactured product. The increase in the remanufactured product customer base leads to an increase in its quarterly demand and remanufacturing capacity, and thus the remanufacturing rate. The increase in the remanufacturing rate results in an increase in the consumption level of the potential collection base. To put it in other words, the decrease in the sales of the new product as a result of the migration of customers to the remanufactured product leads to a decrease in its demand, manufacturing capacity and thereby the manufacturing rate. The decrease in the manufacturing rate results in a reduction in the inflow of potential collection base. Therefore, after a while, although the demand of remanufactured product is high, the decrease in the potential collection base starts to restrict the remanufacturing rate. The consequence is that the remanufactured product demand cannot be satisfied. Moreover, the decrease in the potential collection base increases the unit cost per collected product and the unit price of remanufactured product. Thus, purchasing new products begin to be more advantageous for customers and the migration between the new and remanufactured product potential customer bases change in the opposite direction until the potential collection base reaches the sufficient level to enable remanufacturing.

Several scenarios are analyzed by changing the quality ratios of remanufactured and new product of the firm and those of the market, because the differences between the qualities and prices are the main effects which determine the profile of the products and so the customer bases of these products.

In Figure 1, the migration between the customer bases of the firm, which is called stealing customer rate, is determined by the additive effects of non-availability of remanufactured products, quality and price ratios of remanufactured and new products of the firm. The competition between the products of the firm and those of the market are considered for new products and remanufactured products separately. The price and quality ratios of new products of the firm and those in the market determine the feeding rate of new product customer base. The same review goes for the remanufactured products too. The customer bases determine the quarterly demands of the products by being multiplied with demand per quarter per person. In real life, there is a green image factor resulting from remanufacturing and it is obvious that the green image factor increases not only the feeding rate of remanufactured product customer base, but also the feeding rate of new product customer base. The fraction of the green image for increasing the inflow of new product customer base is taken as nearly half of the fraction for remanufactured product customer base. The contributions of the green image are determined by the multiplication of remanufactured product customer base with these fractions separately.

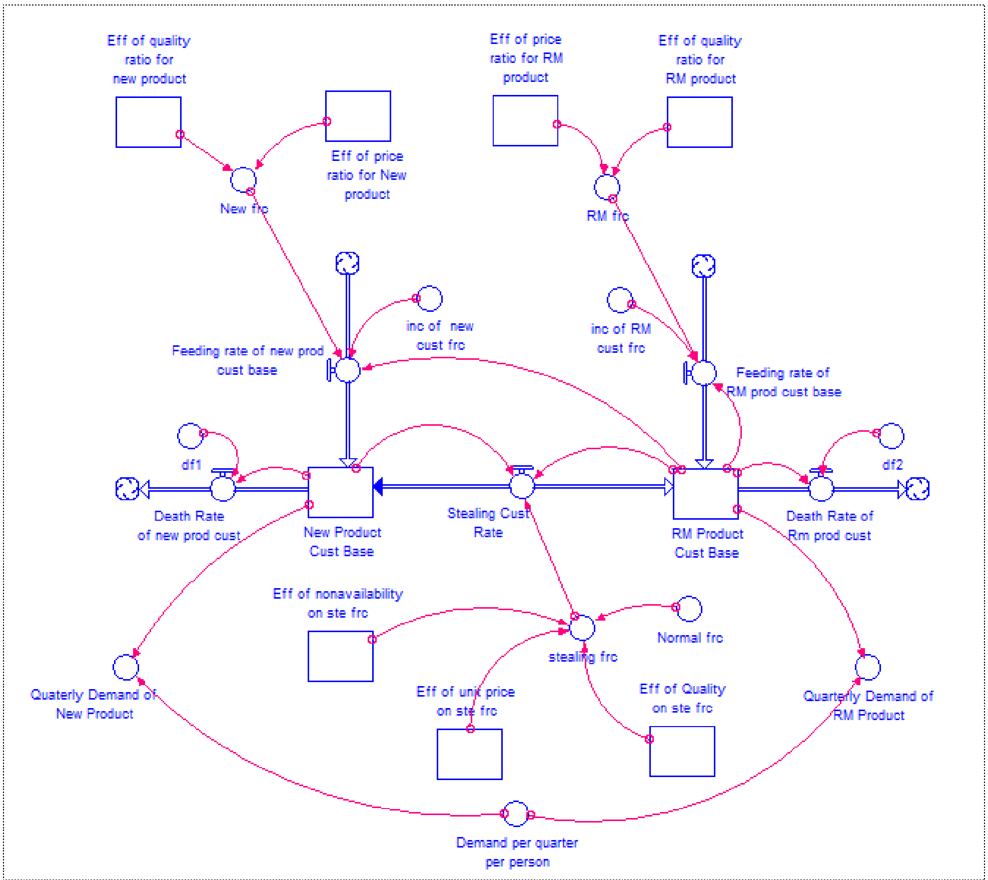


Figure 1: The Transition Between the Customer Bases

Production rates of remanufactured and new products are identified by different constraints. For remanufacturing, the capacity is determined by considering the expected sales, which is identified by the previous quarterly demand of the remanufactured products and the potential amount of collectable product (Figure 2). The minimum of the remanufacturing capacity, quarterly demand of remanufactured product and potential amount of collection base determines the remanufacturing rate. It is assumed that all remanufactured products are sold. The potential amount of collection base is a critical constraint for remanufacturing, since although the demand increases, there are some cases in which the demand cannot be satisfied due to the insufficient amount of collected used products and/or remanufacturing capacity. In this case, the effect function of non-availability of remanufactured product on stealing fraction, of which input is ratio of demand and sales of remanufactured product, leads to a decrease in the advantage of remanufactured product and the stealing customer rate flow in the same direction or it may even change its direction depending on the effects of quality and price ratios, because if the demand is not satisfied, after a while it leads to customer transition to other product customer base in real life. Therefore, it is the most important negative loop which balances the system. There are several factors balancing the system in the long term. Therefore, system dynamics is an appropriate approach since we aim to show the effects of several factors on the system behavior simultaneously and analyze the variables such as customer behavior, sales and profit of the firm during the long term.

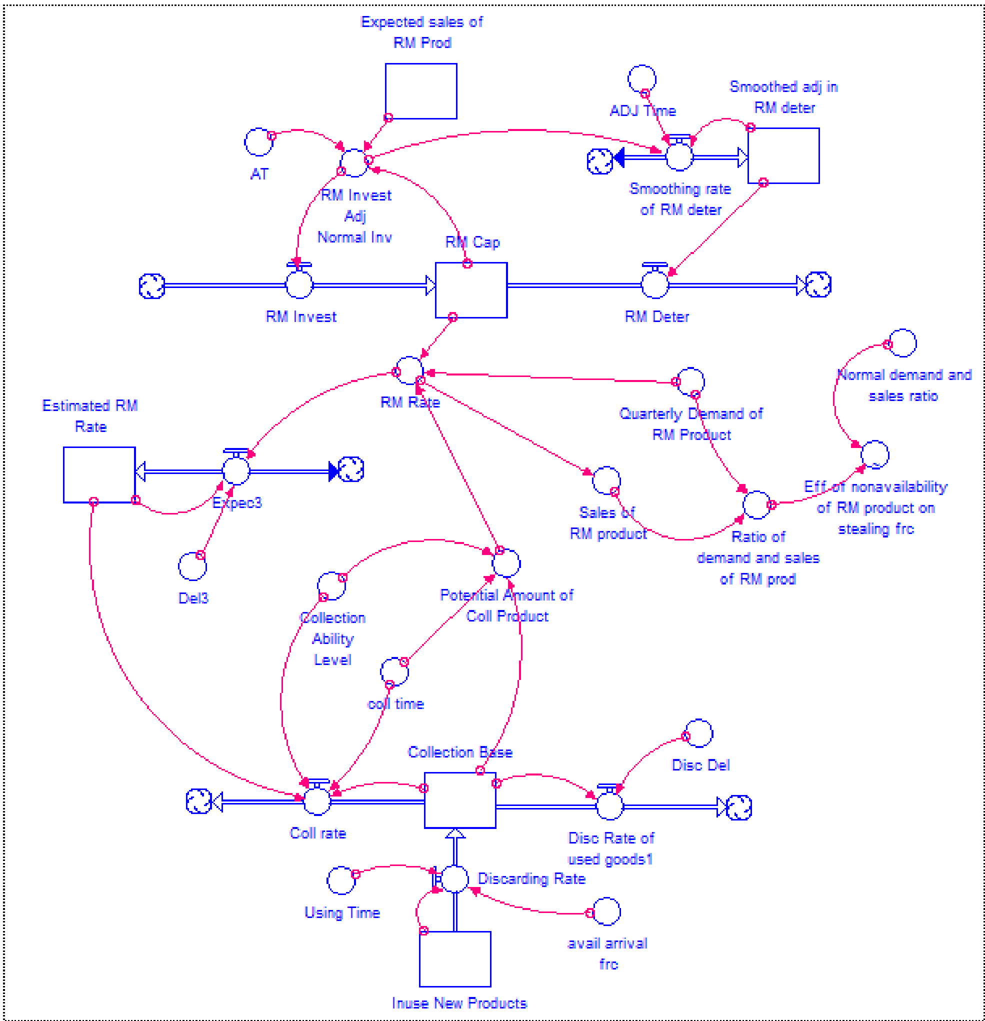


Figure 2: The Factors Determining RM (Remanufacturing) Rate

The effect function of product non-availability is not used for new product since the minimum of the current capacity, which is determined by the expected sales of new product, and the current demand determines the rate of new production(newly manufacturing) (Figure 3). Therefore, the capacity reaches the goal of demand even though there is a delay. The small difference resulting from the delay is ruled out in the model. It is assumed that all new products are sold in a quarter year so inventories are not considered. The products which are sold only by that firm are going to the potential collection base stock as a used product after a 3 year residence time or usage period by the customer.

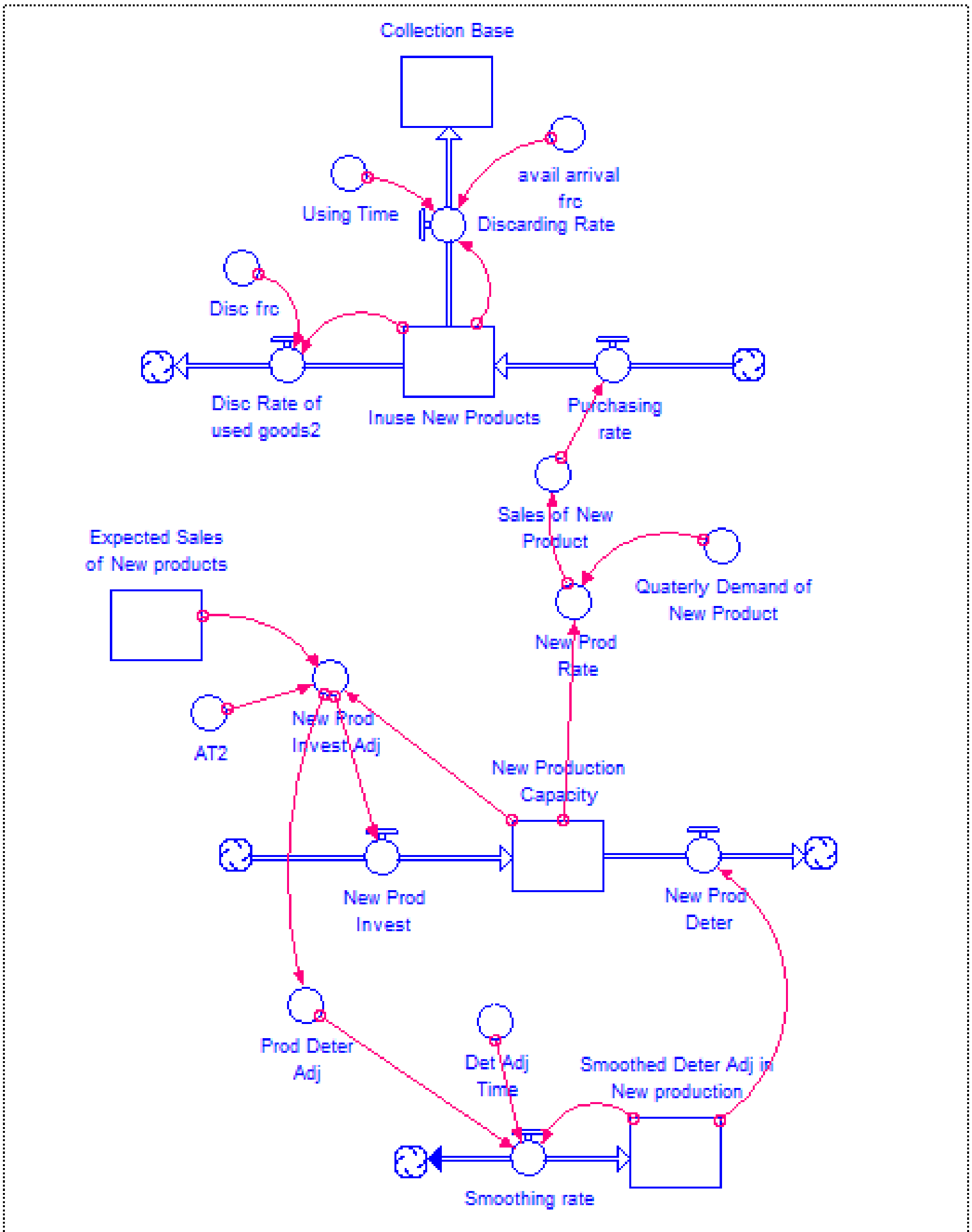


Figure 3: The Factors Determining New Production (Newly Manufacturing) Rate

In addition to the effects of the qualities of remanufactured and new products, the important factors determining the unit prices and the customer behavior are the unit costs of the remanufactured and new product (Figure 4). The prices of remanufactured and new product are determined by the multiplication of the unit production costs of these products with 110%, since the profit percentage per unit product is assumed as 10%. For remanufacturing, “Unit Cost of RM product” is determined by the addition of unit manufacturing cost per RM product and average unit cost of RM investment. The investment cost for increasing “RM Capacity” is reflected on the unit cost by the ratio of “Total RM Investment Cost” and “Total Sales of RM product” and it is named as “Average Unit Cost of RM Investment”. Unit manufacturing cost per RM product is identified by considering energy consumption cost per RM product (Cost per joule*Energy per RM product), raw material cost per RM product (Amount of Raw Mat per RM product*Cost per Raw material) and cost per collected product. Although the energy consumption cost and raw material cost per unit product are constant, cost per unit collected product may change depending on the ratio of current potential collection base and reference collection base. If remanufactured product is chosen by customers since it is more advantageous, it leads to a decrease in the new product customer base, hence in the new product demand. If the collection base descends below the nominal collection base, which is assumed as a reference, after a while unit cost per collected product increases. The increase in the unit cost per collected product leads to an increase in the unit price of the remanufactured product and it may make the remanufactured product disadvantageous in some conditions. This situation decreases the collection base and results in an increase in the unit collected product cost. Therefore, it is another negative feedback loop since it balances the system. If the collection base increases, unit cost per collected product decreases again. This change has an effect on the unit cost of remanufactured product and so the unit price of it. The unit cost of new product is determined by the same way, but collection cost does not take part in the equation determining the unit cost per new product.

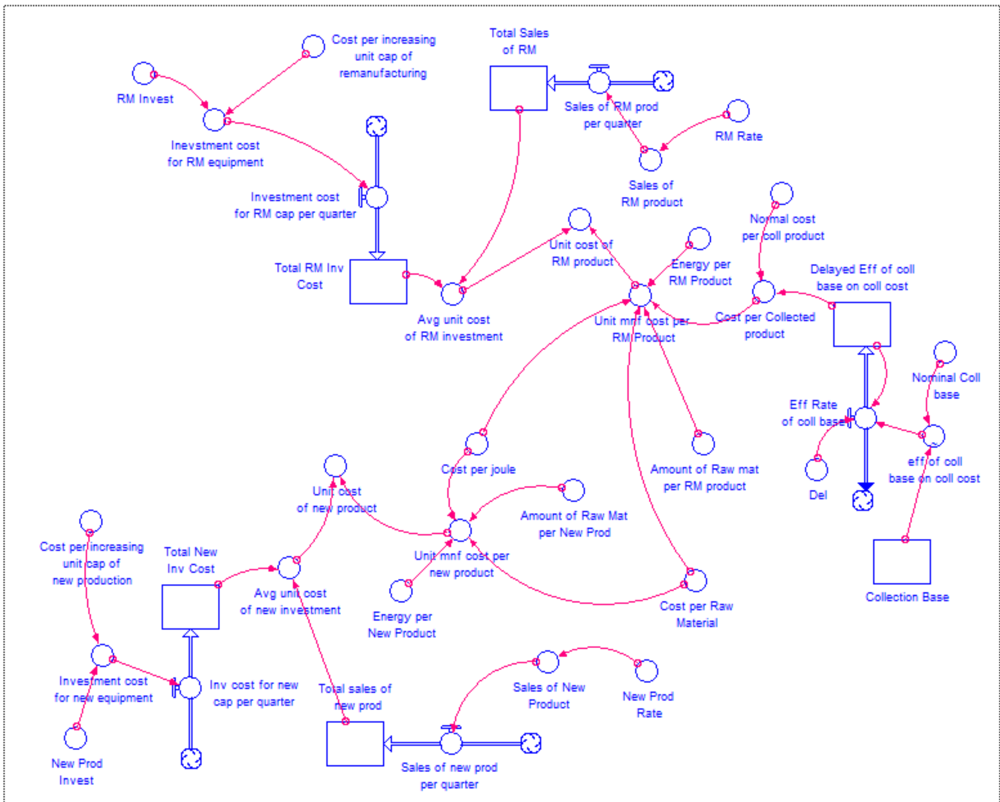


Figure 4: Unit Costs of Remanufactured and New Products

In Figure 5, the total expenditures result from the investment for increasing capacities and total production cost of the new and remanufactured products. The profit of the firm is determined by the subtraction of the total expenditures from the incomes of the product sales and the reduction of the capacities. Then the total profit of the firm is determined by the subtraction of the corporation tax from the profit. Moreover, the tax credit, which has been applied as an incentive of government for the investment of remanufacturing, is subtracted. Depending on the incentive, 20% of the investment cost of remanufacturing capacity expansion is subtracted from the corporation tax.

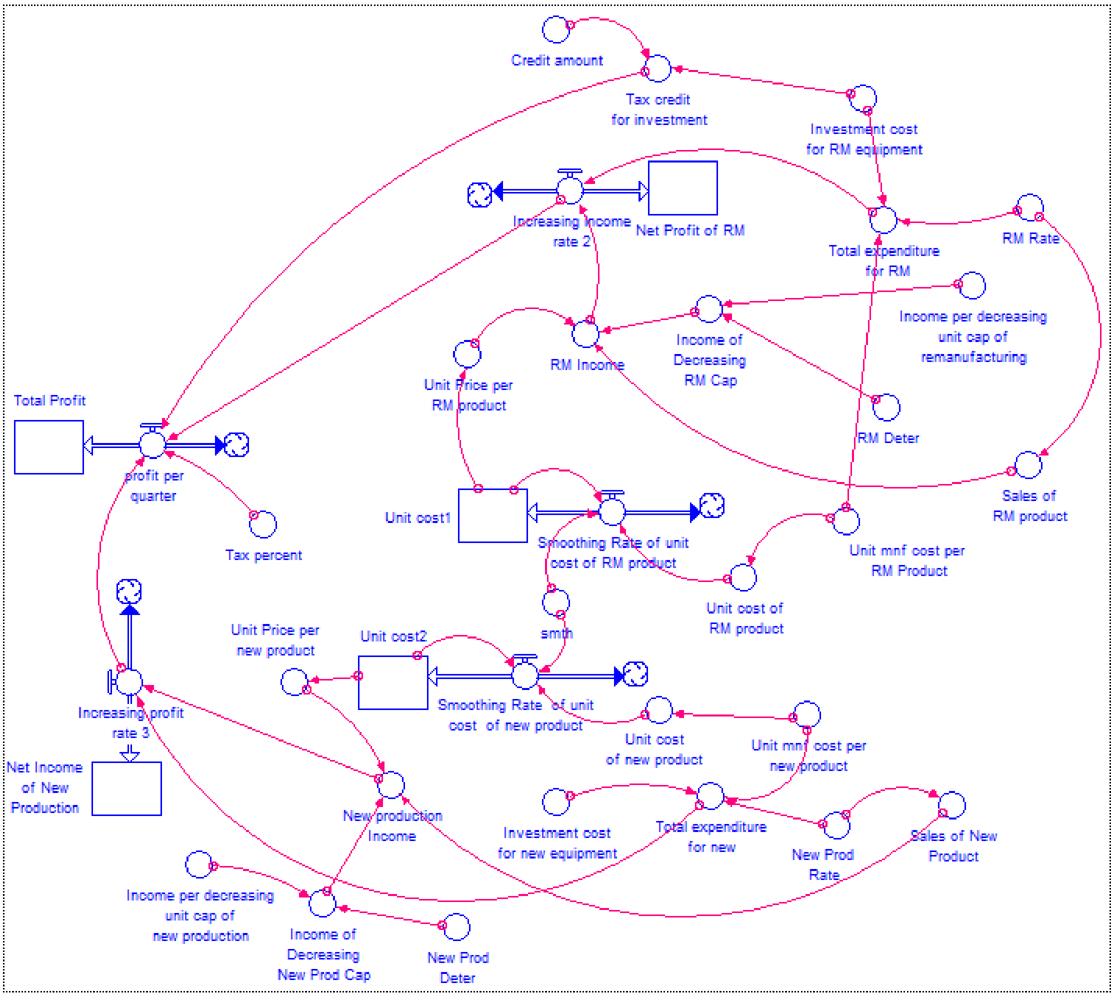


Figure 5: The Corporation Tax, Tax Credit Incentive and Total Profit

The figures are the separated and simplified versions of the model and the whole model is shown in Appendix.

In this study, fluctuations of customer bases, the factors affecting the stealing rate (migration rate) between the new product and the remanufactured product customer bases, satisfaction rate of demand of remanufactured product and the total profit of the firm are analyzed for different scenarios by changing the quality ratios.

Validation of the Model

Model validation includes two steps: Structure Validation and Behavior Validation. Since our model is hypothetic, that is we do not use real data, we only apply structure validity tests to check whether the structure of the model is a meaningful description of the real relations that exist in the system. The validity of the model behavior is also evaluated below in terms of its meaningfulness. In the model, all the parameters, variables and delays have real life counterparts. The dimensions of the equations are consistent. Moreover, the behavior of the system is analyzed for the extreme conditions and it is deduced that the results and the behavior of the system are consistent with real life.

Results and Discussion

The model analysis is shown in three steps. The first step includes the analysis of the change in the customer bases and the behavior of the whole system depending on the given quality values and the changing unit prices of the products. The second step includes the analysis of the total profit of the firm for different quality ratios. Finally, the third step includes the sensitivity analysis of some parameters.

Step 1: Analysis of the System Behavior

The qualities of new product and remanufactured product of the market are not important for the transition behavior between the customer bases of new product and remanufactured product of the firm. They only have an effect on the amount of the customer transition between market and customer bases separately. Therefore, in this analysis step, the quality of new and remanufactured product of the market is set to the same values with those of the firm respectively. The analysis and results justify our hypothesis, namely an excessive decrease in the demand of new products has a negative effect on the remanufacturing rate because of the unsatisfactory potential collectable used product base. This situation causes an increase in the unit cost of collected product and increases the unit price of remanufactured product. Moreover, the increasing gap between the sales and the demand leads to an increase in the rate of non-availability of remanufactured (RM) product, hence the effect of non-availability of RM product on stealing fraction increases since the customers do not wait to buy a product forever if the product does not exist in the market. This situation may change the customer behavior if quality ratio of new and remanufactured product does not have an enough effect on customer behavior opposite to the disadvantage of price and non-availability of RM product.

The customer behavior is determined by the effect of quality and price ratios of remanufactured and new products and the effect of non-availability of remanufactured product. The ratios of the qualities are determined as constant values at the beginning. Therefore, the change in the unit price of remanufactured product and the non-availability of remanufactured product may result in fluctuations of the customer bases. The examples of customer behaviors of new and remanufactured (RM) products in different constant quality ratios of remanufactured and new products are shown in Figure 6, Figure 11, and Figure 16. In the extreme condition, that is when the qualities of remanufactured and new products are equal, remanufactured product is preferred since its price is lower than the new product price. The customer base of remanufactured (RM) product increases (Figure 6); hence the quarterly demand of RM product increases (Figure 8). On the other hand, collection base, which is the potential collectable used product stock, decreases since the demand and sales amount of new products decrease (Figure 7). Therefore, after a while, the collection base starts to restrict remanufacturing rate since the rate of remanufacturing is decided based on the minimum of the remanufacturing capacity, quarterly demand of remanufactured product and the current collection base.

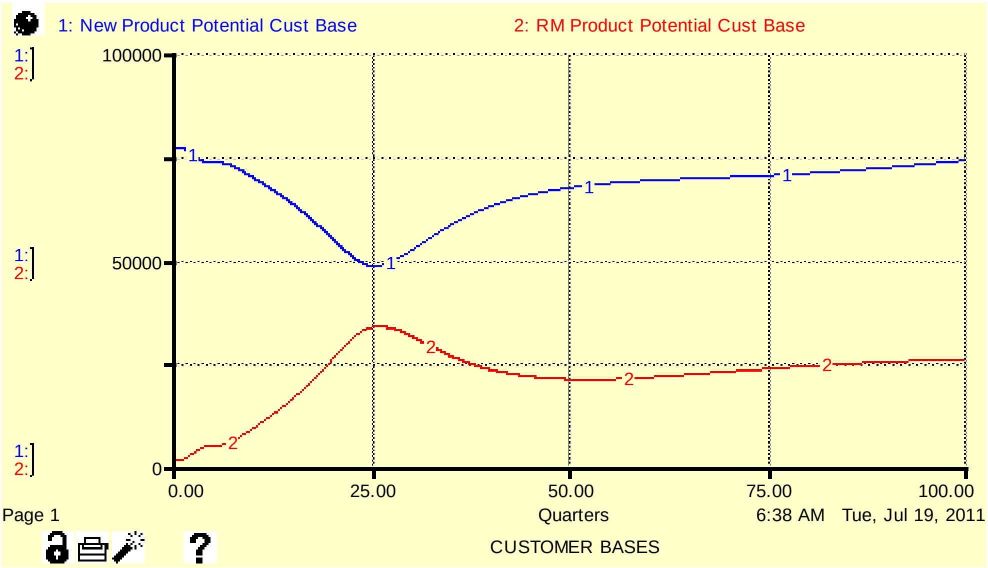


Figure 6: The New Product Customer Base and the RM Product Customer Base When the Qualities of the Products Are Equal

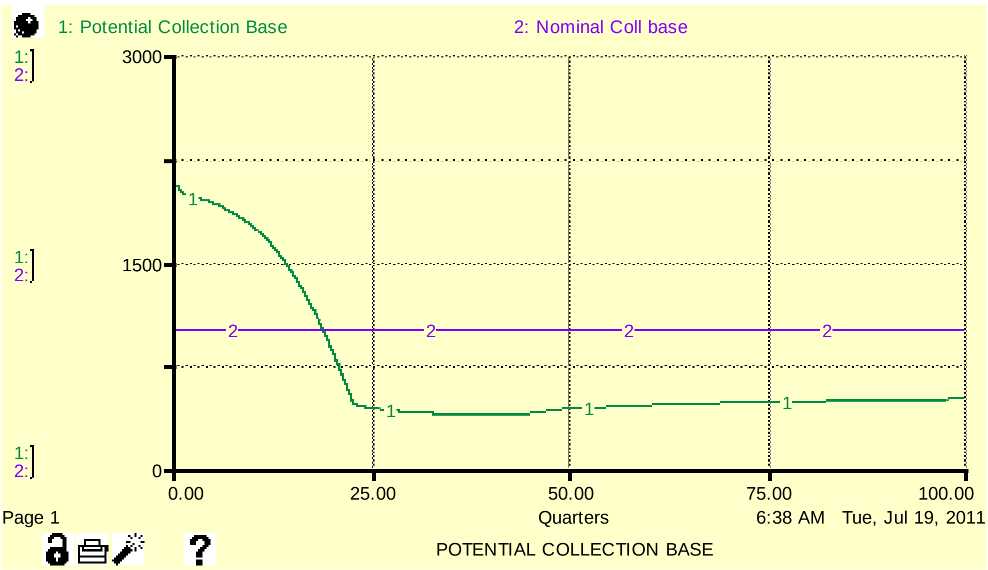


Figure 7: Current Collection Base versus Nominal Collection Base When The Qualities of the Products Are Equal

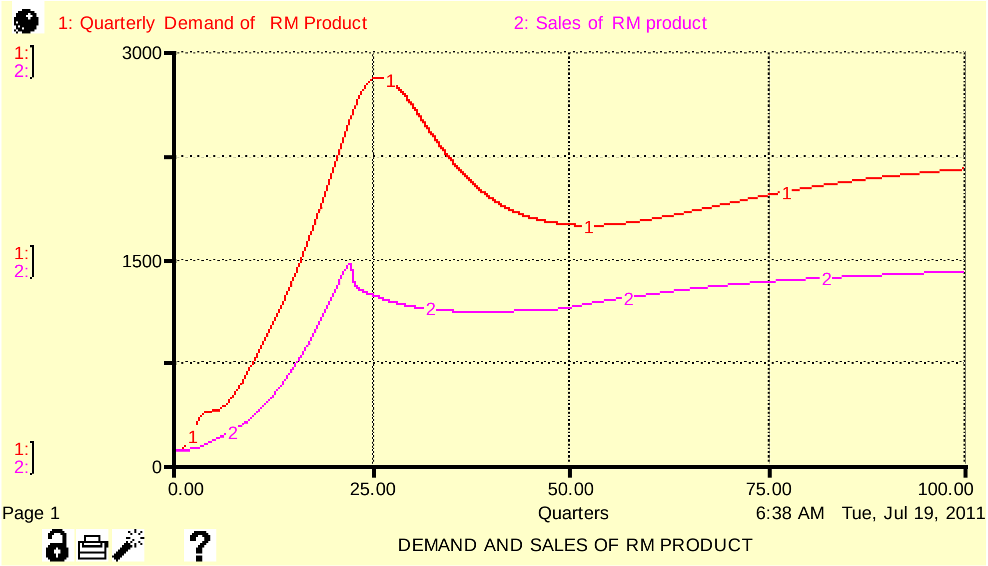


Figure 8: Sales and Quarterly Demand of Remanufactured (RM) Product When the Qualities of the Products Are Equal

The unit price of remanufactured product increases depending on the increasing unit collection cost per used product since current collection base goes down below nominal collection base, which is a reference value for collection base (Figure 7 and Figure 9).

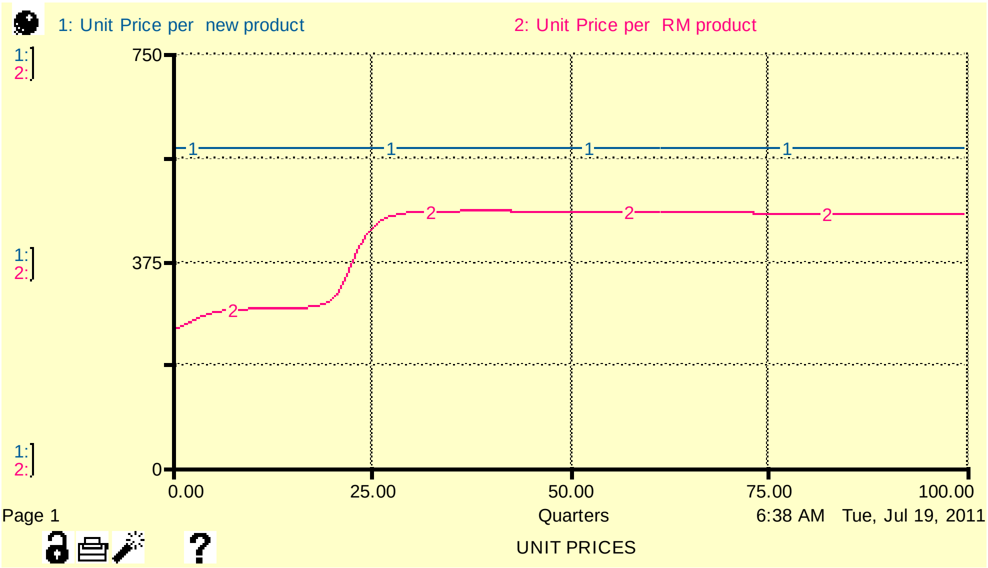


Figure 9: Unit Price of New product and Unit Price of Remanufactured Product When the Qualities of the Products Are Equal

Moreover, insufficient collection base results in the increase of the gap between quarterly demand and sales of remanufactured product (Figure 7 and Figure 8). It leads to a decrease in customer base of remanufactured product since the effect of non-availability of RM product on stealing fraction increases when the gap between the amount of demand and sale of RM product increases (Figure 10). Figure 10 indicates effect of ratio of prices of remanufactured and new product on stealing fraction, effect of non-availability of remanufactured product on stealing fraction, effect of ratio of qualities of remanufactured and new product on stealing fraction, stealing fraction, in numerical order.

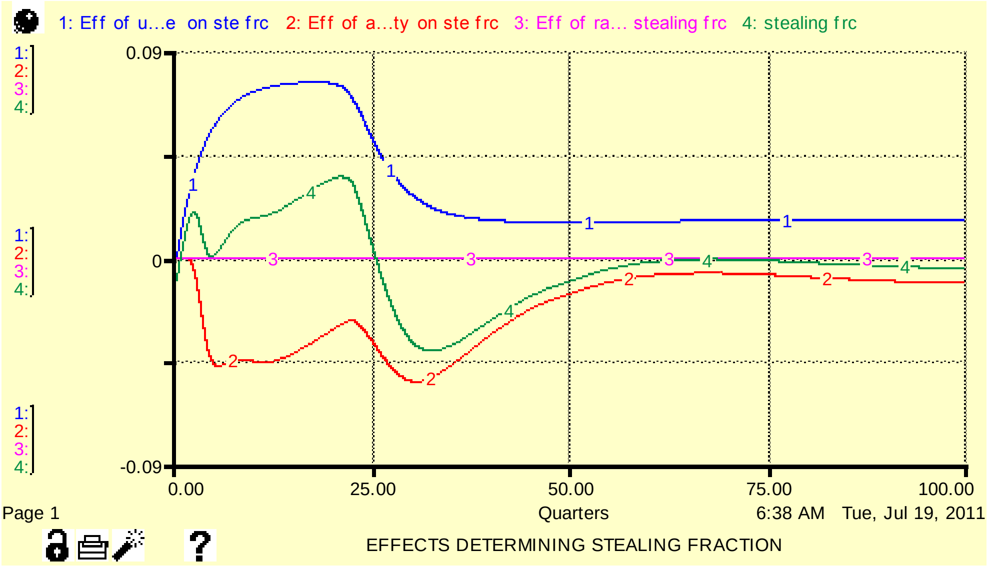


Figure 10: Stealing Fraction, Effect of Non-availability of RM Product, Effect of Quality Ratio of RM Product/New Product and Effect of Price Ratio of RM Product/New Product on Stealing Fraction When the Qualities of the Products Are Equal

The system is investigated for different quality ratios since we believe that quality perception of customers about remanufactured products may change the customer behavior and so the behavior of other variables. The results which are shown in Figures 11-20 support our hypothesis. When the quality ratio is 60% or 75%, RM product customer base increases at the beginning (Figure 11 and Figure 16).

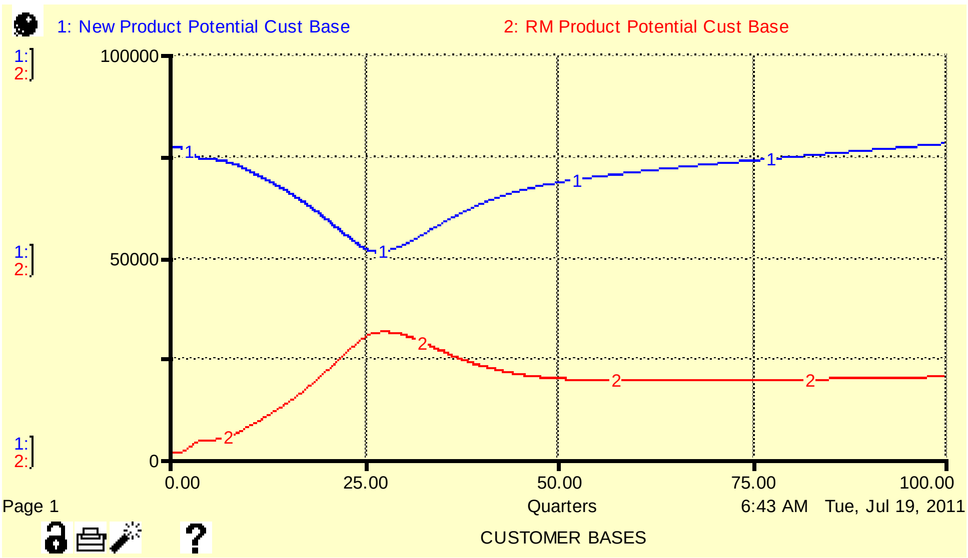


Figure 11: The New Product Customer Base and the RM Product Customer Base When the Quality Ratio of RM Product and New Product is 75%

However, increasing rate of customer base of remanufactured (RM) product is less than the first case since the quality of new product is higher than that in the previous case. It makes the decrease in the customer base of new product slower and the decrease in the collection base slows down as well. Nonetheless, after a while, remanufacturing rate is not able to satisfy the demand of RM product. For instance, when the quality ratio is 75%, the collection base restricts the RM rate again but later than usual in the first case because of the slower decrease in the collection base (Figure 12 and Figure 13).

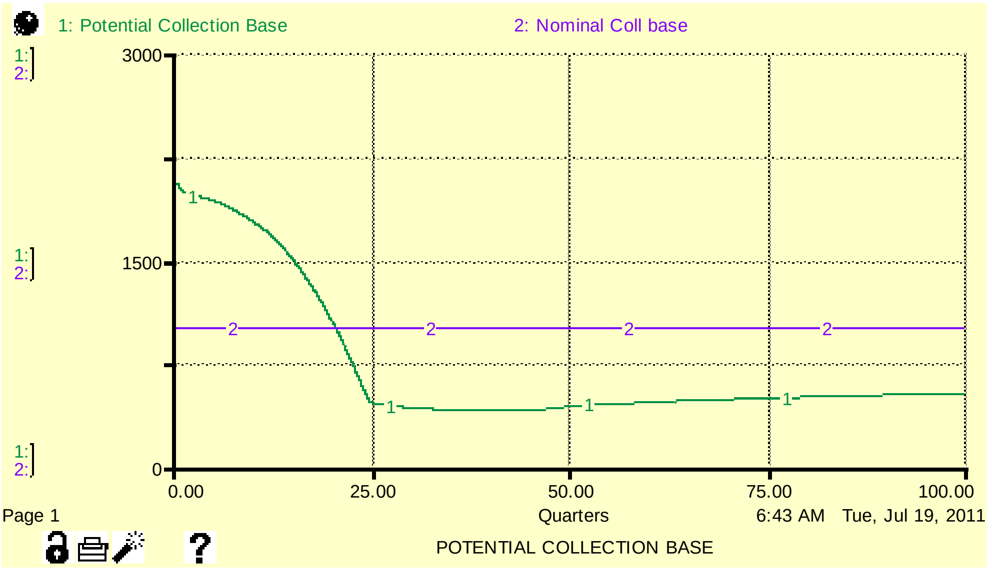


Figure 12: Current Collection Base versus Nominal Collection Base When The Quality Ratio of RM Product and New Product is 75%

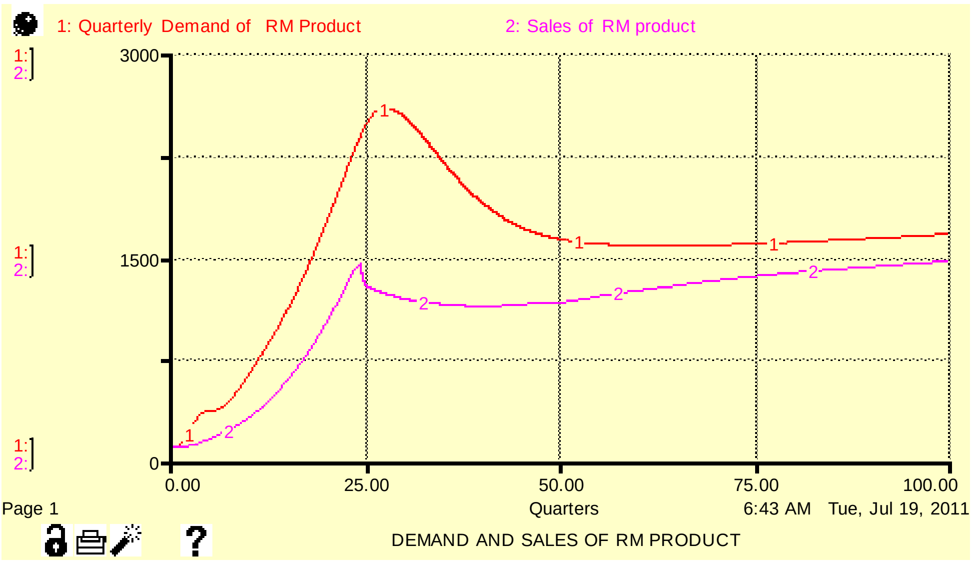


Figure 13: Sales and Quarterly Demand of Remanufactured (RM) Product When the Quality Ratio of RM Product and New Product is 75%

Therefore, in contrast to the first case, it leads to a less increase in the negative effect of non-availability of RM product and unit price of RM product (Figure 14 and Figure 15).

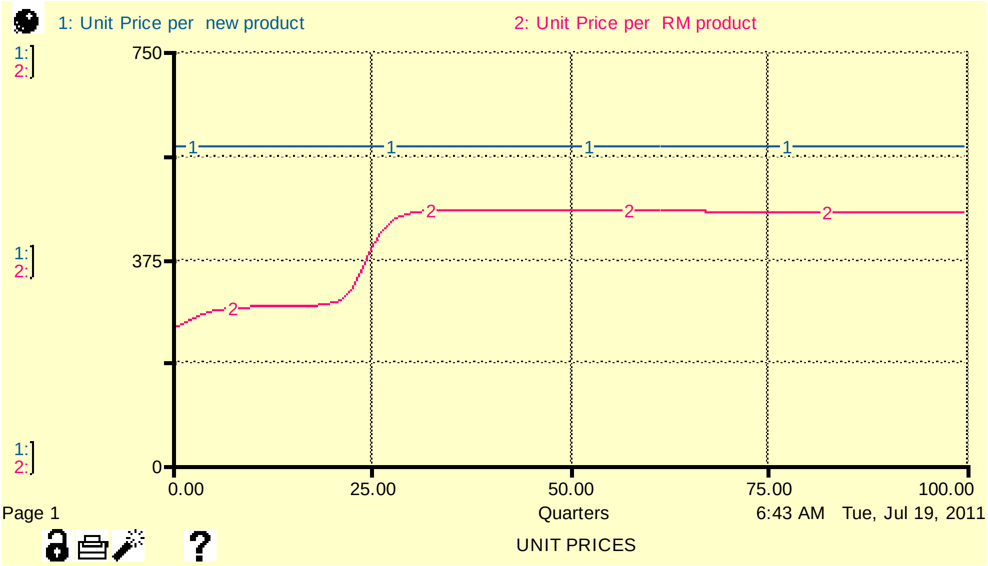


Figure 14: Unit Price of New product and Unit Price of Remanufactured Product When the Quality Ratio of RM Product and New Product is 75%

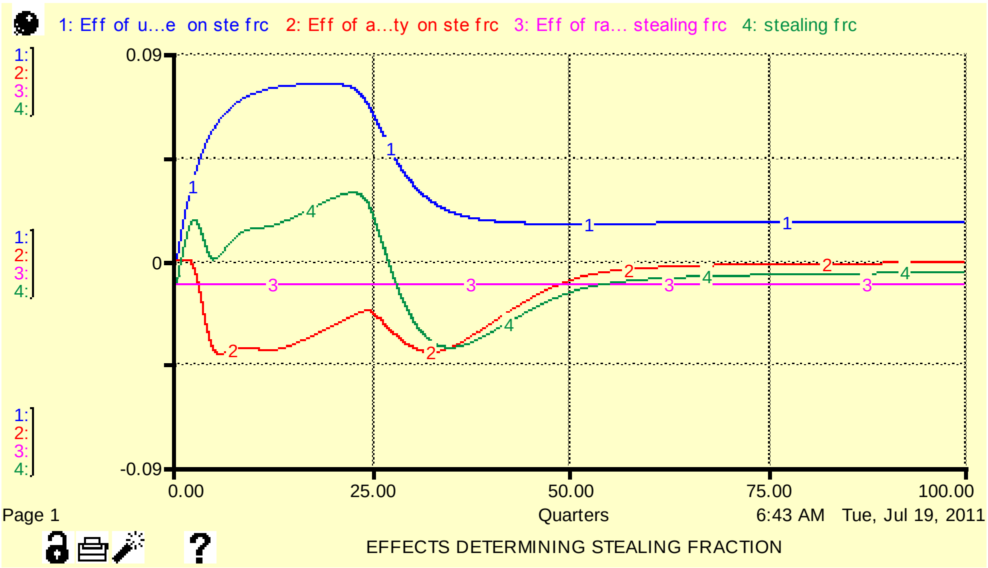


Figure 15: Stealing Fraction, Effect of Non-availability of RM Product, Effect of Quality Ratio of RM Product/New Product and Effect of Price Ratio of RM Product/New Product on Stealing Fraction When the Quality Ratio of RM Product and New Product is 75%

When the quality ratio is 60%, in contrast to the cases in which the qualities are equal and the quality ratio is 75%, the collection base goes down below the nominal collection base later (Figure 17) because of the slower increase in the customer base and demand of remanufactured product. Moreover, increase in the gap between sales and quarterly demand of RM product is less than those in the previous cases as well (Figure 18). This situation makes the negative effect of non-availability of remanufactured product less. However, the unit price of new product increases after 28th quarter since the collection base decreases and goes down below the nominal collection base (Figure 17, Figure 19 and Figure 20). Remanufactured product potential collection base decreases until the potential collection base reaches the sufficient amount to satisfy the remanufactured product demand. After it reaches the sufficient amount, remanufactured product customer base starts to increase while new product potential customer base is decreasing because of the migration to the remanufactured product (Figure 16, Figure 17 and Figure 18). Another reason leads to increase in the remanufactured product potential customer base is the decrease in the unit price of remanufactured product depending on the potential collection base (Figure 17 and Figure 19). Therefore, it can be deduced that the potential collection base has an effect on customer stealing rate (migration rate) through its effect on the unit price and quarterly demand satisfaction of remanufactured product (Figure 20).

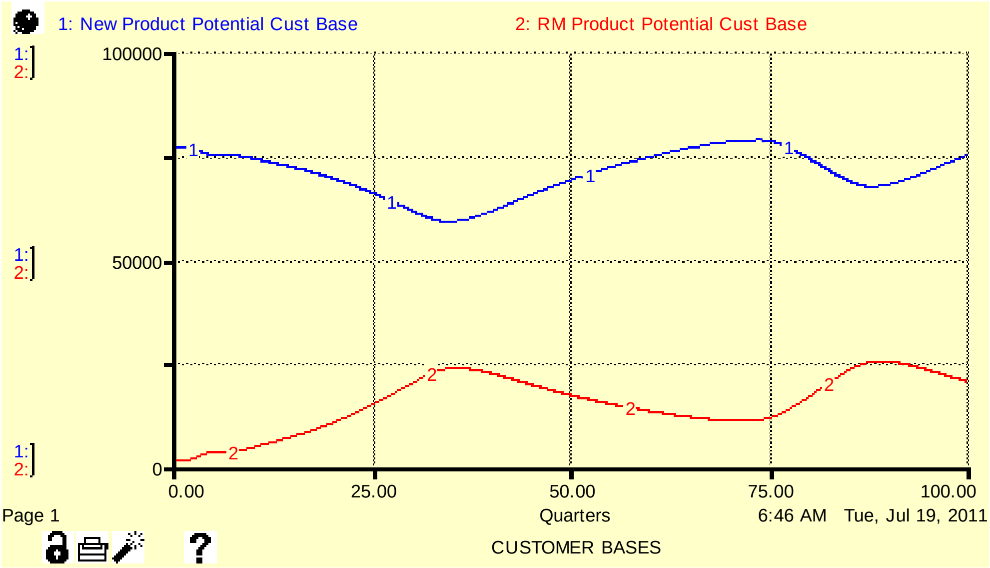


Figure 16: The New Product Customer Base and the RM Product Customer Base When the Quality Ratio of RM Product and New Product is 60 %

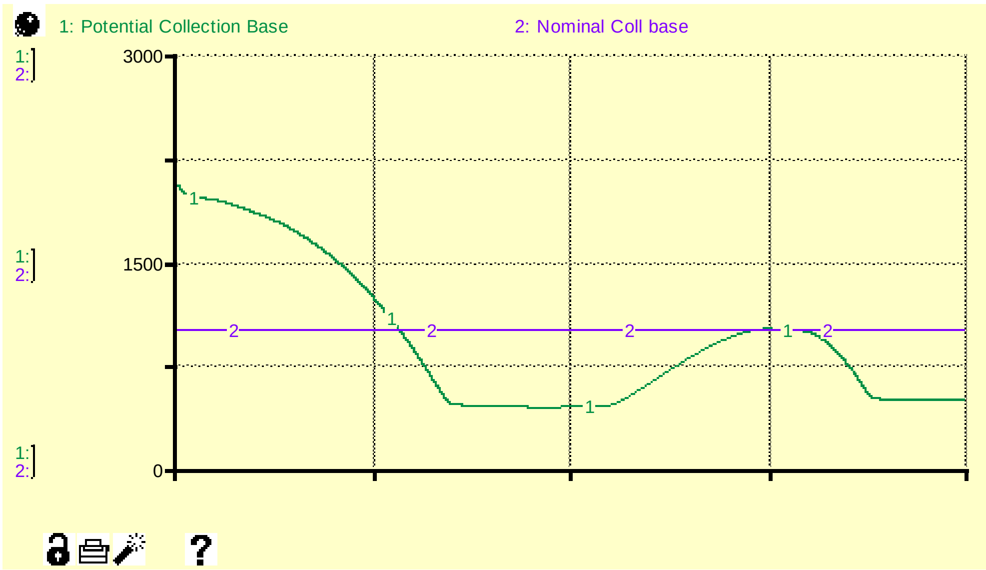


Figure 17: Current Collection Base versus Nominal Collection Base When the Quality Ratio of RM Product and New Product is 60 %

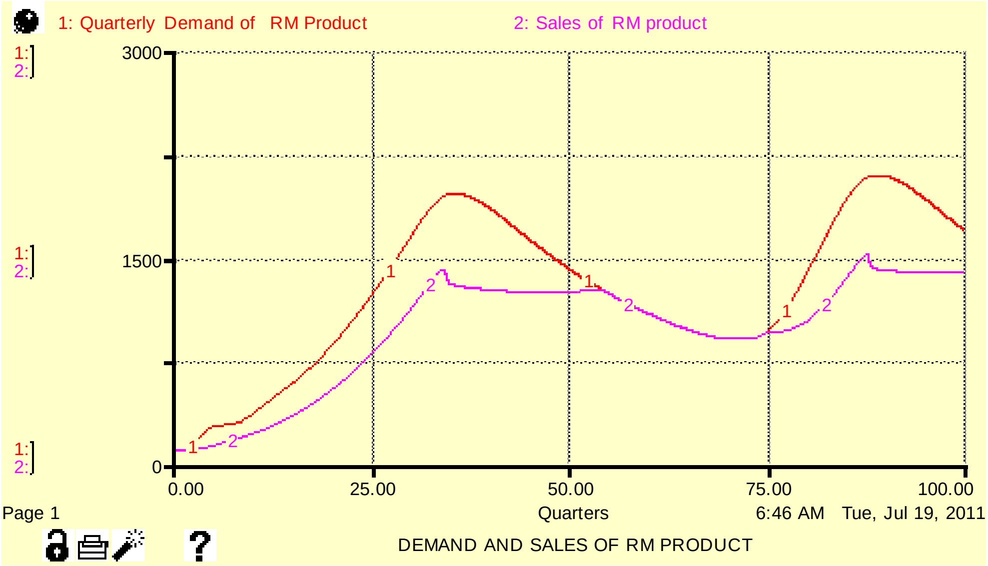


Figure 18: Sales and Quarterly Demand of Remanufactured (RM) Product When the Quality Ratio of RM Product and New Product is 60 %

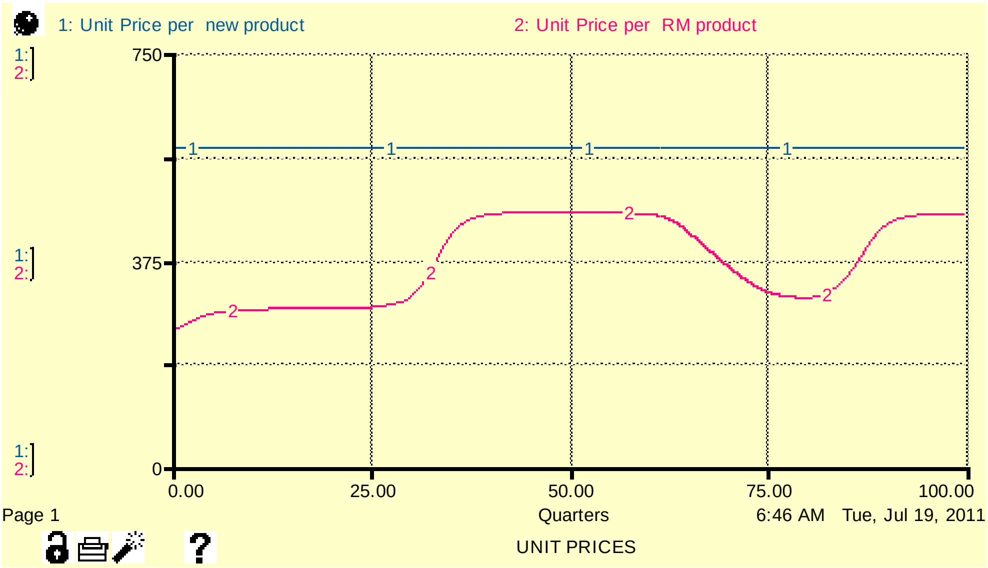


Figure 19: Unit Price of New product and Unit Price of Remanufactured Product When the Quality Ratio of RM Product and New Product is 60 %

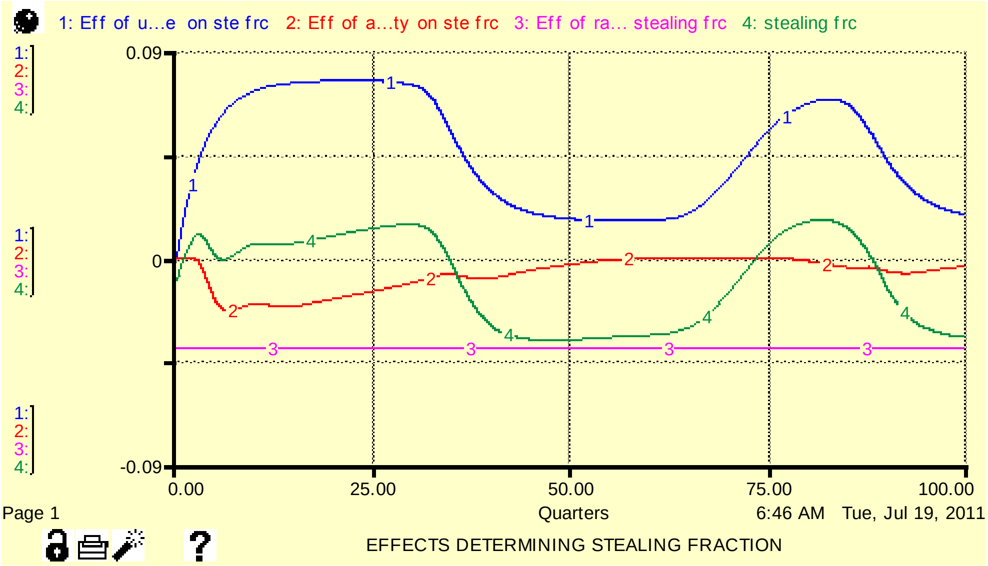


Figure 20: Stealing Fraction, Effect of Non-availability of RM Product, Effect of Quality Ratio of RM Product/New Product and Effect of Price Ratio of RM Product/New Product on Stealing Fraction When the Quality Ratio of RM Product and New Product is 60%

The most important result obtained from the analysis is that when the remanufactured product is much more advantageous than the new product, its demand increases for a while. However, the remanufactured product cannot maintain its advantage forever, since the firm needs collectable used product base to remanufacture, but the sales of new product decreases and it cannot provide sufficient amount of used products. Therefore, the system balances itself through two ways: the increasing unit collected cost and so unit price of remanufactured, backlogged quarterly demand of remanufactured product.

Step 2: Total Profit Analysis of the Firm

It is assumed that the price of the firm's new product is equal to that of the market. The same assumption goes for the remanufactured product too. In Table 1, the columns show the value of the qualities of the products. It is assumed that the quality value can change between 1 and 10.

The first case is the extreme case which is that the qualities of the products are same. In other cases, the gap between the qualities gets larger. It shows that although the qualities of the products of the firm are same with the qualities of the products of the market, the gap between the qualities of remanufactured and new product of the firm has an incredible effect on the total profit. When the gap between the qualities of new and remanufactured products of the firm decreases, the transition of the customers from the new product customer base to the remanufactured product customer base increases. Therefore, since the price and unit profit of the new product is higher than those of the remanufactured product, it decreases the total profit.

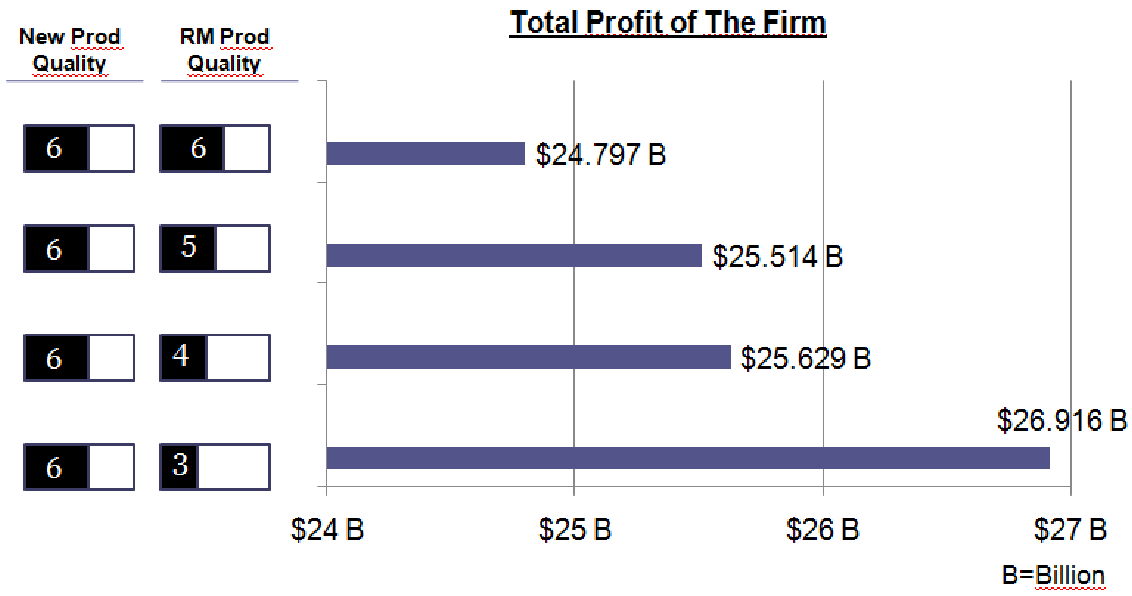


Table 1: Cumulative final profits in 25 years, in different scenarios

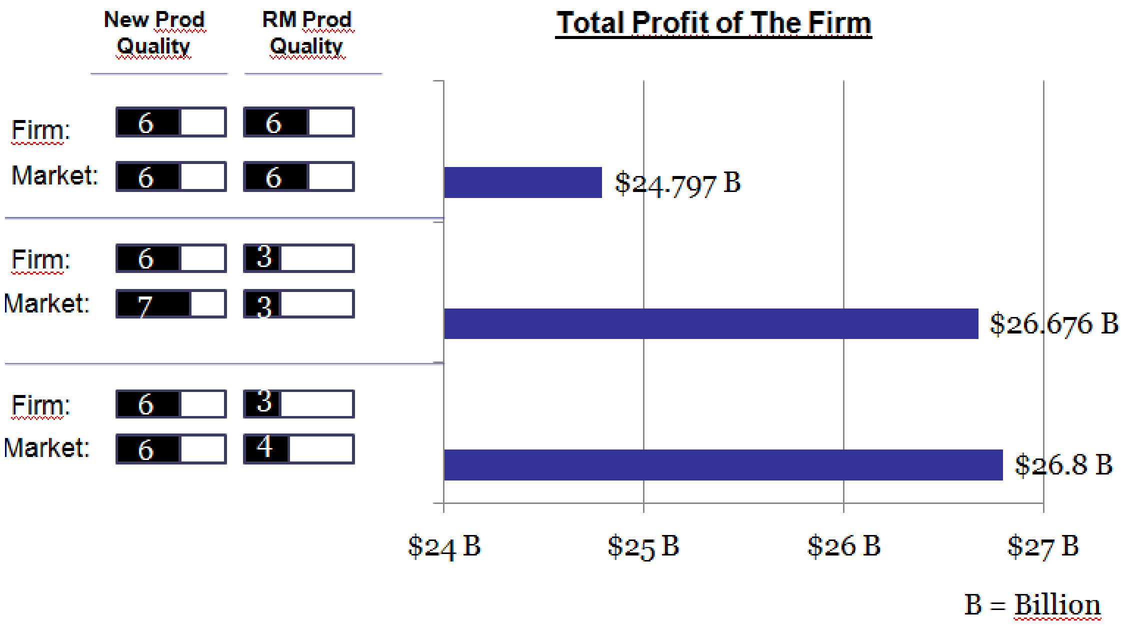


Table 2: Cumulative final profits in 25 years, in different scenarios by considering the competition in the market

Table 2 shows that although the remanufactured product quality of the firm is lower than that in the market in the third case, or the new product quality of the firm is lower than that in the market in second case, the profit is higher than the first case since the gap between the quality of remanufactured and new product of the firm is larger than the first case. It shows that although the remanufactured product quality of the firm is lower than that in the market, the firm can increase its profit by enlarging the quality gap between its new product and remanufactured product. Furthermore, although the qualities of the products of the firm are same as the qualities of the products in the market, the gap between the qualities of remanufactured and new product of the firm has an incredible effect on the total profit. When the gap between the qualities of new and remanufactured products of the firm decreases, the transition of the customers from the new product customer base to the remanufactured product customer base increases. Therefore, since the price and unit profit of the new product is higher than those of the remanufactured product, it decreases the total profit.

Step 3: Sensitivity Analysis with Some Parameters:

3.1: Green Image:

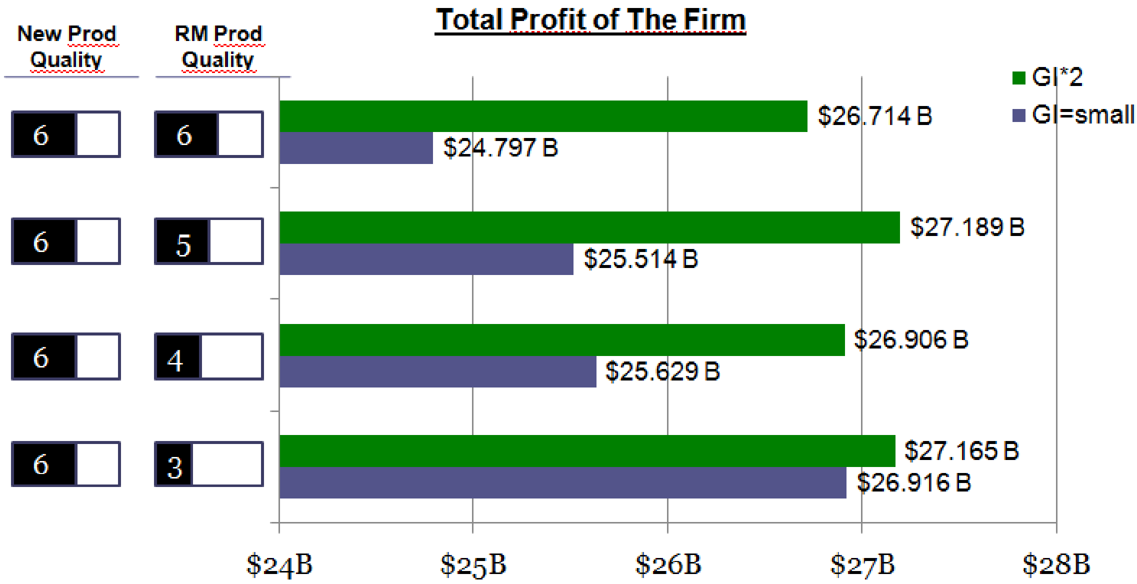


Table 3: Cumulative final profits in 25 years for different green image values

In table 3, if the green image of the firm is higher than that assumed in the base case scenario, the firm's total profit gets higher since the positive effect of the green image on the customers is much more than the base case. When the prices and qualities of the firm's new product and products in the market are equal and none of the firms performs remanufacturing, the total profit is $ 25.950 billion. Therefore, if it is also compared with the base case and the case where the firm is not involved in remanufacturing, remanufacturing is always more profitable since the green image is higher for a firm that remanufactures. But in the base case, remanufacturing is more profitable than the case where the firm is not involved in remanufacturing only when the gap between the qualities of the firm's products gets larger.

3.2: Collection Rate of Used Products:

It is obvious that the collection rate of used products has an important role on the remanufacturing rate. Therefore, different cases are compared with the base case in which the fraction of collected used products is 32%.

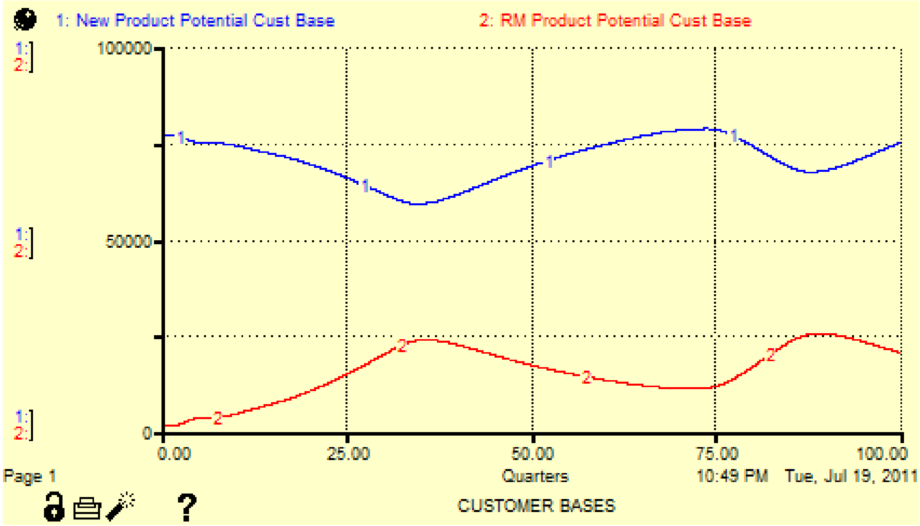


Figure 21: The Case when the Fraction of Collected Used Products is 32%

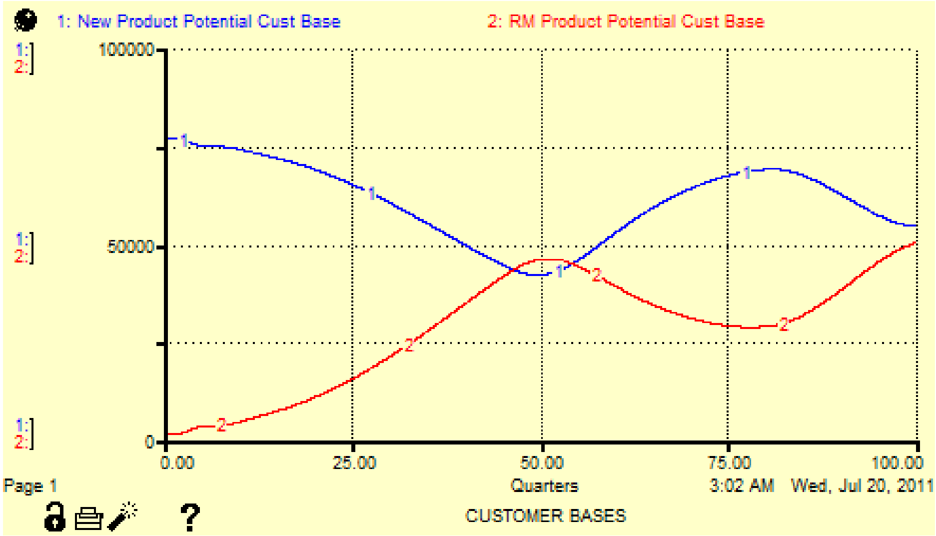


Figure 22: The Case when the Fraction of Collected Used Products is 70%

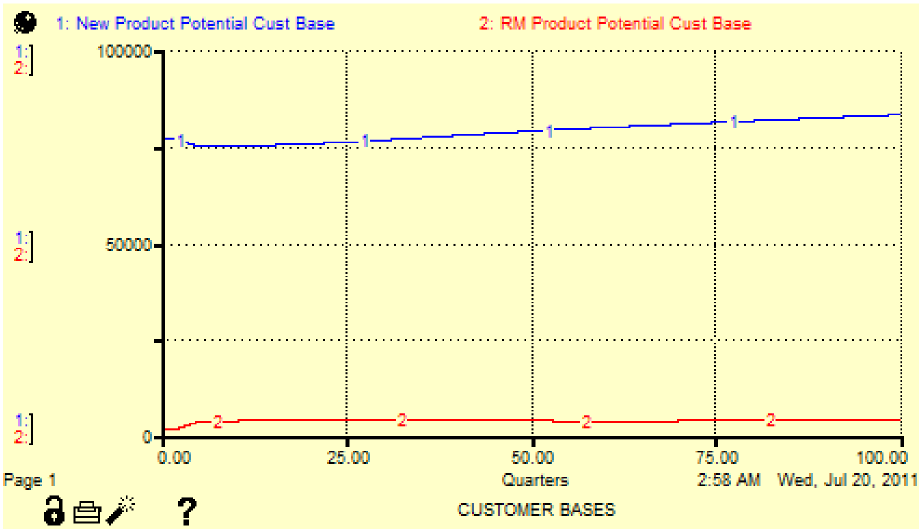


Figure 23: The Case when the Fraction of Collected Used Products is 15

The results show that fraction of collected used products is an important factor restricting the remanufacturing rate and thereby the demand satisfaction. Therefore, the remanufactured product of the firm in the second case reaches a higher value compared to the base case since the demand can be satisfied for a longer duration of time. However, in the third case, since the fraction of collected used products is very low, the demand for remanufactured products cannot be satisfied.

Concluding Remarks and Future Work

The analyses show that the gap between the quality of the firm's new product and remanufactured product is an important factor to increase the total profit. Remanufacturing can be a good strategy to gain customers as long as it does not lead to stealing customers from the same firm's new product customer base. Since there is a migration between the new product customer base and remanufactured product customer base, remanufacturing is useful not only for remanufactured product customer base but also for new product customer base. The effect of remanufacturing on profitability also depends on customer awareness and so perceived green image of the firm. Moreover, the firm can increase its profit by enlarging the gap between the qualities of its new and remanufactured product even if the quality of its product is worse than that of the market. The interaction between the manufacturing and remanufacturing rates is important since collection of used products is a necessity for remanufacturing.

In the future work, the dependence of total profit of the firm on the profit margins of the products will be investigated. Moreover, the effect of the different levels of government incentives on the total profit will be analyzed. The case where the firm can collect used products produced by other firms will be considered as well.

References

Mont O, Dalhammar C, Jacobsson N. A new business model for baby prams based on leasing and product remanufacturing. Journal of Cleaner Production 2006;14 (17): 1509–1518.

Kerr W, Ryan C. Eco-efficiency gains from remanufacturing; A case study of photocopier remanufacturing at Fuji Xerox Australia. Journal of Cleaner Production 2001; 9:75–81.

Kamath N B, Roy R. Capacity augmentation of a supply chain for a short lifecycle product: A system dynamics framework. European Journal of Operational Research 2007, 179, 334-351.

Vlachos D, Georgiadis P. Iakovou E. A system dynamics model for dynamic capacity planning of remanufacturing in closed-loop supply chains. Computers & Operations Research 2007; 34(2):367-394.

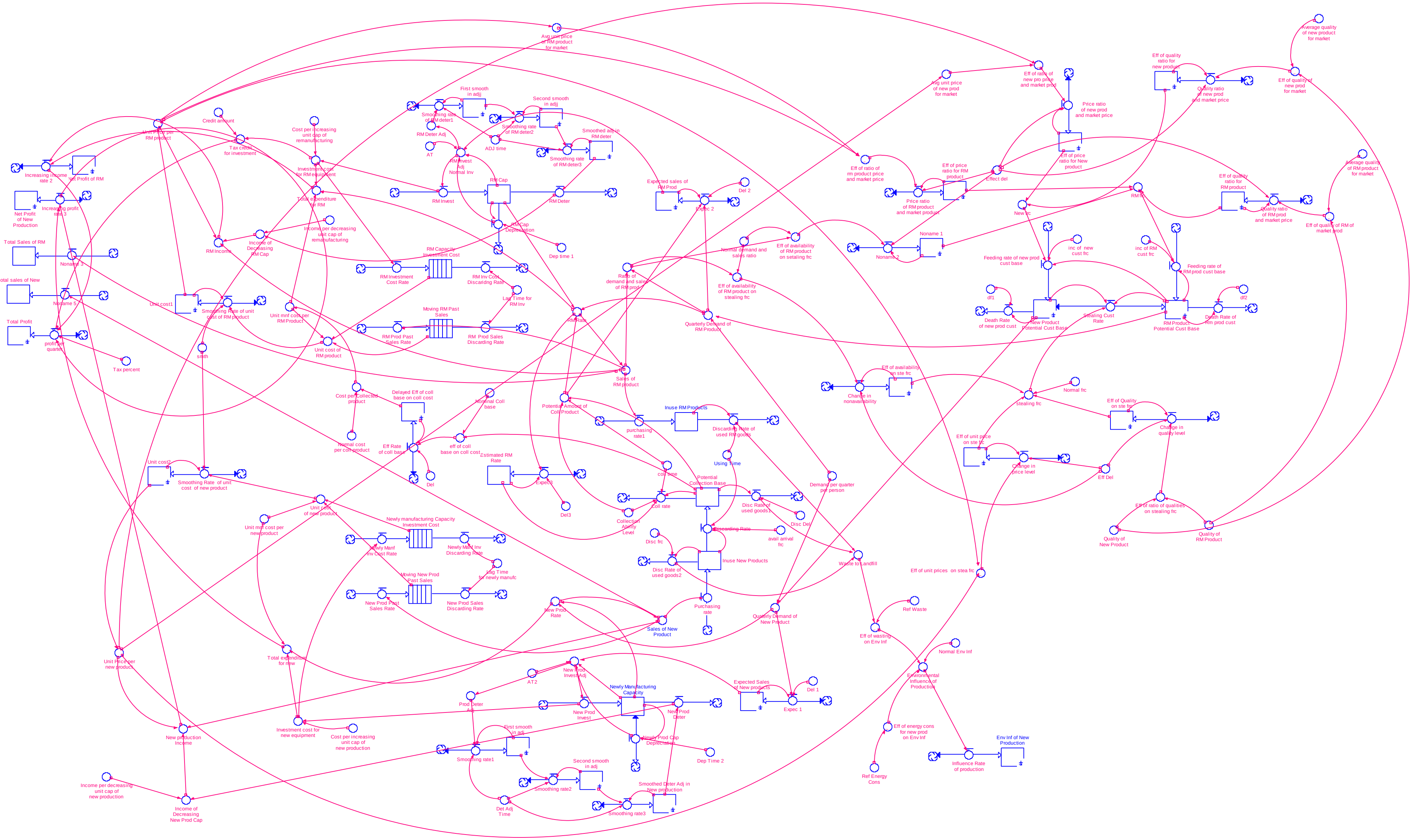
Georgiadis P, Vlachos D. The effect of environmental parameters on product recovery. European Journal of Operational Research 2004;157(2):449–464.

Georgiadis P, Besiou M. Sustainability in electrical and electronic equipment closed-loop supply chains: a system dynamics approach. Journal of Cleaner Production 2008;16(15):1665–1678.

Georgiadis P, Vlachos D. Decision making in reverse logistics using system dynamics. Yugoslav Journal of Operations Research 2004;14(2): 259–272.

Poles R, Cheong F. A system dynamics model for reducing uncertainty in remanufacturing systems. Pacific Asia Conference on Information Systems 2009.

Appendix



Stock-Flow Diagram of Recovery Management Model for a Computer Firm