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A Game Model of New and Remanufactured Goods, Brown and Green Consumers, and Market Share Dominance¹

by

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Abstract

The n total consumers in the market for a particular good are made up of b brown and g green consumers so that $b+g=n$. The b brown (g green) consumers are not (are) environmentally conscious and hence they prefer to buy a new (remanufactured) good denoted by N and R respectively. By strategically purchasing or not purchasing the N and the R goods, the brown and the green consumers attempt to create a dominant market share for their preferred good. In this setting, we study three issues. First, we delineate the game between the brown and the green consumers in normal form and then solve for the Nash equilibrium when $n=2$ and $b=1$. Second, we find all the Nash equilibria of this game between brown and green consumers when $n>2$ is an even number and $b=g=n/2$. Finally, we increase the cost of purchasing the new and the remanufactured goods and then study how this increase affects the answers obtained for the above two issues.

Keywords: Brown Consumer, Green Consumer, Market Share, New Good, Remanufactured Good

JEL Codes: D11, Q20, C72

1. Introduction

1.1. Overview

The word “remanufacturing” pertains to an industrial process in which worn-out products are restored to like-new condition. In this regard, Lund (1984) has noted that in remanufacturing, a series of industrial processes, often taking place in a factory environment, leads to the full disassembly of a discarded product. Next, usable parts are cleaned, refurbished, and put into inventory. The product is then reassembled from the old parts—and sometimes with new parts as well—to produce a unit that is fully equivalent and sometimes superior in performance and expected lifetime to the original new product.

Remanufacturing has now become significant in the United States because of two reasons. First, on the regulatory side, in an attempt to reduce harmful environmental outcomes, the Environmental Protection Agency (EPA) has taken some practical steps.⁴ In this regard, it is worth emphasizing the agency’s implementation in 1995 of the “Comprehensive Procurement Guideline.” *Inter alia*, this guideline sought to cut waste and promote resource conservation by making sure that materials collected in recycling programs would be used again to manufacture new products.⁵ Second, there are the actual cost savings experienced by firms. To see this, consider the following three examples from Mitra and Webster (2008). First, these researchers have noted that in 1996, Ford was able to avoid the disposal of more than 67,700 pounds of toner cartridges and thus saved \$180,000 in disposal costs. Second, between 1991 and 1997, Ford collected more than 332,000

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See Beladi *et al.* (2013) for an alternate perspective on governmental activities designed to protect the environment.

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Go to <https://vsc.gsa.gov/green/files/CPG.pdf> for additional details. Accessed on December 10, 2015.

pounds of toner cartridges and hence was able to save \$1.2 million. Finally, in 1995, Union Carbide saved \$75,000 by avoiding disposal costs. Given the growing importance of remanufacturing from both an environmental and a practical standpoint, a growing literature has now begun to examine the nature and the desirability of this industrial process from different perspectives. We now briefly survey this literature.

1.2 Review of the literature

Simplifying matters just a little, we can look at remanufacturing either from the standpoint of firms or from that of consumers. We focus on firms first. Lebreton and Tuma (2006) study remanufacturing in the context of the disposal of 600,000 tons of used tires in Germany. On the basis of their analysis, these authors point to particular factors that are likely to raise remanufacturing rates in this country. Ferrer and Swaminathan (2006) analyze the competition between an original equipment manufacturer (OEM) and an independent operator (IO). In a multi-period setting, the IO may intercept cores of products made by the OEM to sell remanufactured products in future time periods. These authors demonstrate that when the threat of competition increases, the OEM is more likely to fully utilize all available cores and offer the remanufactured product itself, at a lower price.

Atasu *et al.* (2010) ask whether remanufactured products cannibalize new product sales. The analysis conducted by these authors shows that a product portfolio that includes both new and remanufactured products can make it likely for a firm to reach additional market segments and thereby block competition from new low-end products or third-party remanufacturers. New and remanufactured goods are often sold in the same market and hence it makes sense to consider them together in the design of a product line. Aydin *et al.* (2015) adopt this last point of view and propose a new methodology that permits them to calculate the maximum profit and the market share

associated with a product line.

Shi *et al.* (2015) study the stability of the Nash equilibrium arising in the game between an OEM and a remanufacturer. They show that a higher willingness-to-pay (WTP) on the part of consumers can either strengthen or weaken the stability of the pertinent Nash equilibrium. Even so, a higher WTP always hurts the OEM and benefits the remanufacturer. Wu (2015) analyzes a closed-loop supply chain model of an OEM and a remanufacturer who interact in a sales market and in a so called “recycle market.” He shows that the higher competitiveness in the sales market will encourage the remanufacturer to focus the notion of economies of scale in the recycle market and not in the sales market and that this focus benefits both the OEM and the remanufacturer. Finally, Batabyal and Beladi (2015) is the only paper we are aware of that has analyzed the competitive interaction between an OEM and a remanufacturer when the aim of both firms is to use expenditures on product development to capture a dominant share of the market in which they are operating.

This brings us to remanufacturing from the standpoint of consumers. In this regard, note that just as firms can take a variety of marketing actions such as advertising to increase the market share of the goods they produce, by purchasing more or less of a certain good, consumers can also impact the share of a particular market that is held by this same good. As noted by Dalal and Dalal (2014), Anvar and Venter (2014), and Pang *et al.* (2015), this last aspect of consumer behavior is true across a whole host of goods and the goods themselves do not have to be environmental or green in nature. Even so, given the new versus remanufactured goods focus of our paper, the reader should understand that both Gu *et al.* (2015) and Hong *et al.* (2015) have acknowledged the salient role that *consumer* preferences and behavior play in determining the ultimate success of remanufacturing. This acknowledgment notwithstanding, to the best of our knowledge, there are *no* theoretical studies

of the ways in which consumers with different levels of environmental consciousness can, through their purchase decisions, determine whether an OEM or a remanufacturer obtains a dominant share of the market for a good such as a toner cartridge.

Given this lacuna in the literature, we show how consumers can pursue an environmental or green agenda versus a non-environmental or brown agenda through their purchase decisions. Section 2 describes the simple, static game model⁶ in which the n total consumers in the market for toner cartridges⁷ are made up of b brown and g green consumers so that $b+g=n$. The b brown (g green) consumers are not (are) environmentally conscious and hence they prefer to buy a new (remanufactured) good denoted by N and R respectively. By strategically purchasing or not purchasing the N and the R goods, the brown and the green consumers attempt to create a dominant market share for their preferred good. Section 3 delineates the game between the brown and the green consumers in normal (matrix) form and then solves for the Nash equilibrium when $n=2$ and $b=1$. Section 4 finds all the Nash equilibria of this game between brown and green consumers when $n>2$ is an even number and $b=g=n/2$.⁸ Section 5 increases the cost of purchasing the new and the remanufactured goods and then studies how this increase affects the answers obtained in sections 3 and 4. Finally, section 6 concludes and then discusses three ways in which the research described

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See Tadelis (2013, pp. 79-100) for a lucid textbook account of static games.

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To fix ideas, in what follows, we shall think of our remanufacturable good as a toner cartridge. Having said this, we note that the model we analyze and the results we obtain are in no way dependent on the remanufacturable good being a toner cartridge. Other real world examples of brown and remanufactured goods include new and remanufactured cameras, new and remanufactured cell phones, and new and remanufactured diesel engines.

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Our assumption here is that the initial distribution of brown and green consumers in the market under study is symmetrical in the sense that half of all consumers are brown and the remaining half is green. In the absence of any other information about the market under consideration, it seems to us that this is the natural assumption to make about consumer numbers and this explains why we make this particular assumption.

in this paper might be extended.

2. The Theoretical Framework

Consider a particular market in which new and remanufactured toner cartridges (N and R) are available for sale to consumers. The n total consumers are of two possible types. The brown or b consumers do *not* have any explicit environmental objective in mind. Hence they are more interested in purchasing new or the N toner cartridges and in promoting the market for new toner cartridges. In contrast, the green or g consumers would *like to* promote resource conservation in particular and environmental sustainability in general. Therefore, these g consumers are interested in purchasing remanufactured or the R toner cartridges. Clearly, we have $b+g=n$.

The objective of both brown and green consumers is to ensure a *dominant market share* for their preferred kind of toner cartridge. Practically, this means that brown (green) consumers would like to see more than fifty percent of the total number of toner cartridges bought in the market under study to be comprised of new (remanufactured) toner cartridges. For each type of consumer, this dominant market share objective can be accomplished by buying more of the preferred kind of toner cartridges. To this end, suppose that the benefit to each consumer from having his preferred kind of toner cartridge attain a dominant market share is \$4.⁹ If, as a result of individual purchase decisions, there is a tie and new and remanufactured toner cartridges both end up occupying fifty percent market share then the benefit to each type of consumer is \$2. The benefit to either type of consumer when his less preferred kind of toner cartridge attains a dominant share of the market being studied

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This specification implicitly assumes that in addition to the direct utility from consuming a toner cartridge, a consumer also derives utility from knowing that his preferred kind of toner cartridge has attained a dominant market share. The \$4 figure denotes the sum of these two sources of utility. We do not believe that the derivation of utility from these two sources subjects consumers to any kind of informational burden. In this regard, recall that the basic game that we are analyzing in this paper is a static game of *complete* information. Having said this, we acknowledge that there are other ways of modeling this aspect of the problem.

is simply \$0. Finally, purchasing either kind of toner cartridge is costly to the two types of consumers. We begin our analysis by supposing that the cost of purchasing a toner cartridge of either type is \$1.¹⁰

Note that our interest in analyzing strategic behavior on the part of consumers arises from a basic tradeoff confronting them. Specifically, for a consumer of either type, an obvious way to contribute to the dominant market share objective for the preferred kind of toner cartridge is to go ahead and actually purchase it. However, such an action is *costly*. On the other hand, if a sufficiently large number of consumers of either type do actually purchase their preferred kind of toner cartridge then those who do not make a purchase may still accomplish their market share objective by not making a purchase and hence incurring no costs. We now proceed to describe the game between the brown and the green consumers in normal (matrix) form and then solve for the Nash equilibrium when $n=2$ and $b=1$. In game-theoretic parlance, the game we are about to delineate is a static game of complete information and the Nash equilibrium that we shall study is a Nash equilibrium in pure strategies.

3. The Normal Form Game

We begin by emphasizing two points. First, because the subsequent mathematical analysis in this paper is conducted with actual numbers, we recognize that this analysis is somewhat special. Second, this first point notwithstanding, it is important to comprehend that the specific choice of $n=2$ and $b=1$ is primarily for expositional convenience. This means that the arguments we make

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This assumption is altered in section 5 below. We are thinking of the new and the remanufactured toner cartridges as goods that are imperfect but *close* substitutes. This explains why the cost of purchasing a toner cartridge of either type is identical and, more specifically, normalized to \$1. If we were to drop this assumption then the structure of the payoffs in the normal form games to be analyzed below would change and this would complicate the resulting mathematical analysis.

in this paper hold more generally but, as the reader will surely understand, for larger and positive values of both n and b it is difficult to depict the underlying game of interest in matrix form.

The game of interest is between the two types of consumers and the basic decision concerns whether to purchase a toner cartridge or not. To this end, let P denote a decision to purchase and D denote a decision to not purchase a toner cartridge. Then, for the benefit and cost figures given in section 3, some thought tells us that the normal form of the game we are interested in is given by figure 1 below.

Brown Consumer	Green Consumer		
		Purchase (P)	Don't Purchase (D)
	Purchase (P)	(1,1)	(3,0)
	Don't Purchase (D)	(0,3)	(2,2)

Figure 1: Normal form game with \$1 purchase cost

Inspecting figure 1 we see that when both types of consumers purchase their preferred toner cartridge and also when both types do not purchase their preferred toner cartridge, the market outcome is a *tie* and hence the share of the market held by either kind of toner cartridge is exactly one-half. Put differently, neither kind of toner cartridge obtains a dominant share of the market under study. The only difference between the two payoffs $(P,P)=(1,1)$ and $(D,D)=(2,2)$ is the cost of purchasing a toner cartridge. Note that the numerical entries in the individual cells of the matrix in figure 1 represent *net* and not gross payoffs. In addition, the difference between the gross and the net payoff is the \$1 it costs to purchase a toner cartridge of either type. This is why we get

$$(P,P)=(2-1=1,2-1=1) \text{ and } (D,D)=(2-0=2,2-0=2).^{11}$$

If only one type of consumer buys his preferred toner cartridge and the other type does not make a purchase then the purchasing consumer accomplishes his goal of obtaining a dominant market share for his preferred kind of toner cartridge. This discussion and the numerical payoffs in figure 1 together tell us that purchasing a toner cartridge is a *dominant* strategy and therefore $(P,P)=(1,1)$ is the *unique* Nash equilibrium of the game that we have been analyzing thus far. Our next task in this paper is to compute all the Nash equilibria of an extended game between brown and green consumers when $n > 2$ is an even number and $b = g = n/2$.

4. The Extended Game

Generalizing from the section 3 analysis, it ought to be clear to the reader that all consumers purchasing their preferred toner cartridge is clearly a Nash equilibrium in this extended game. Three features of this equilibrium are worth highlighting. First, the outcome is a *tie* and thus the share of the market obtained by either kind of toner cartridge is exactly fifty percent. Put differently, there is no dominance in the market share achieved by either kind of toner cartridge. Second, the payoff to every consumer is \$1. Finally, the claimed Nash equilibrium is, in fact, an equilibrium because if a particular consumer chooses not to make a purchase then his payoff is 0 and his preferred kind of toner cartridge achieves *less* than fifty percent market share.

We now contend that *no* other profile of strategies constitutes a Nash equilibrium. To verify this contention, let us proceed in three steps. In addition, let \hat{b} and \hat{g} denote the number of

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The game between brown and green consumers that we are studying is clearly a two-player finite game. Therefore, as noted in Tadelis (2013, p. 51, emphasis added), this game can be represented “by a matrix that will capture *all* the relevant information of the normal-form game.” This means that it is *not* necessary to specify a separate utility function that generates the payoffs either in figure 1 above or in figure 2 below.

consumers of each type that plan to make purchases. Now in our first step, suppose that an identical number of consumers of each type buy so that the outcome is a tie but some consumers are not making purchases of toner cartridges. In symbols, this means that $\hat{b}=\hat{g}<n/2$. In this case, any one of the consumers who is not purchasing a toner cartridge would prefer to deviate, in the process incurring a cost of \$1 and increasing his payoff from \$2 to \$3 because this consumer would now be altering the outcome of the game. Therefore, this state of affairs *cannot* be a Nash equilibrium.

In the second step, suppose that the number of brown consumers who prefer the new toner cartridge N is at least two more than the number of green consumers who prefer the remanufactured cartridge R . Once again, in symbols we have $\hat{b}\geq\hat{g}+2$.¹² In this case, any one of the b consumers that prefers the new toner cartridge and intends to make a purchase knows that his purchase decision is superfluous and hence this consumer will prefer to not make a purchase and save the cost of purchasing a toner cartridge. As a result, this state of affairs also *cannot* be a Nash equilibrium.

In the third and final step, suppose that the number of brown consumers who prefer the new toner cartridge is exactly one more than the number of green consumers who prefer the remanufactured toner cartridge. In other words, we have $\hat{b}=\hat{g}+1$.¹³ In this case, any one of the g type consumers that does not plan to make a purchase will recognize that a decision to purchase a remanufactured toner cartridge can turn a less than fifty percent market share for remanufactured toner cartridges outcome into a tie or fifty percent market share outcome. Therefore, such a

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Note that a symmetric line of reasoning will apply in the case where $\hat{g}\geq\hat{b}+2$.

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Once again, note that a symmetric line of reasoning will apply in the case where $\hat{g}=\hat{b}+1$.

consumer will want to make a purchase and alter the outcome of the game, thereby giving him a payoff of \$1 instead of \$0. This means that the state of affairs described in this third step also *cannot* be a Nash equilibrium.

With these three steps, we have now covered all the possible strategy profiles and this allows us to conclude that even in this extended game, the *unique* Nash equilibrium involves purchases of preferred toner cartridges by all the n consumers in the market. Our last task in this paper is to study the impact that an increase in the cost of purchasing the new and the remanufactured toner cartridges has on the Nash equilibria of the games that we have analyzed in this and the previous section.

5. An Increase in the Cost of Purchasing Toner Cartridges

As in section 3, we begin with the case where $n=2$ and $b=1$. In addition, the benefit figures remain unchanged from those used in sections 2 and 3. The only difference is that the cost of purchasing a toner cartridge of either kind now is \$3 and not \$1. This increase in the purchase cost substantially alters the payoffs received by the brown and the green consumers. Therefore, using the logic of the discussion employed in section 3, we now have a new normal form game that is given by figure 2 below.

	Green Consumer	
	Purchase (P)	Don't Purchase (D)
Purchase (P)	(-1,-1)	(1,0)
Don't Purchase (D)	(0,1)	(2,2)

Figure 2: Normal form game with \$3 purchase cost

Inspecting figure 2 we see that relative to the situation analyzed in section 3, there is now an important difference. In particular, with a higher purchase cost, buying a toner cartridge is a *dominated* strategy. This fact and the payoffs in figure 2 together tell us that the unique Nash equilibrium for both types of consumers now is to *not* purchase a toner cartridge. What happens when the game is extended to the case studied in section 4, i.e., when $n > 2$ is an even number and $b = g = n/2$? We do not provide all the details but it should be clear to the reader that using the logic of the discussion in section 4, once again we get the result that there is a unique Nash equilibrium in which it is optimal for all the n consumers to *not* purchase a toner cartridge. Put differently, even though brown and green consumers have dissimilar market share objectives for their preferred kind of toner cartridge, if the cost of purchasing these toner cartridges goes up too much then there are no sales of toner cartridges and hence the market for such cartridges essentially breaks down. This completes our analysis of new and remanufactured goods, brown and green consumers, and market share dominance.

6. Conclusions

In this paper, we first described a game model in which the n total consumers in the market for toner cartridges were made up of b brown (g green) consumers who were not (were) environmentally conscious and hence they preferred to buy a new (remanufactured) good denoted by N and R respectively. By strategically purchasing or not purchasing the N and the R goods, the brown and the green consumers endeavored to create a dominant market share for their preferred good. Section 3 delineated the game between the brown and the green consumers in normal (matrix) form and then solved for the Nash equilibrium when $n=2$ and $b=1$. Section 4 found all the Nash equilibria of an extended game between brown and green consumers when $n > 2$ was an even number

and $b=g=n/2$. Section 5 increased the cost of purchasing the new and the remanufactured goods and then studied how this increase affected the answers obtained in sections 3 and 4.

The analysis and the results obtained in this paper are interesting because of three reasons. First, this paper provides the *first* theoretical analysis of the ways in which consumers with different levels of environmental consciousness can, through their purchase decisions, determine whether an OEM or a remanufacturer obtains a dominant share of the market for a good such as a toner cartridge. Second, the results show that equilibrium behavior on the part of consumers involves always buying toner cartridges and this behavior is *independent* of whether the number of consumers in the relevant market is small ($n=2$) or large ($n>2$). Finally, the results show that in a strategic setting, market share considerations from the standpoint of brown and green consumers are driven fundamentally by the *cost* of purchase decisions.

Two implications follow from the results we have obtained in this paper. First, consumers and consumer groups that are interested in using purchase decisions to demonstrating their greenness ought to know that they are more likely to be successful in some markets than in others and the key determinant of success is the cost of making a purchase. Second, by subsidizing the cost of consumer purchases, governments can affect the outcome of these purchases in a noteworthy manner.

The analysis in this paper can be extended in a number of different directions. In what follows, we suggest three possible extensions. First, it would be useful to analyze a game between consumers of the sort analyzed in this paper when the firms that produce the new and the remanufactured goods are able to influence consumer preferences by advertising the relative strengths of their goods. Second, it would be instructive to study what role uncertainty about the quality of both new and remanufactured goods plays in affecting the purchase decisions made by

different types of consumers in a particular market. Finally, since brown and green consumers are unlikely to make a one time purchase of either the new or the remanufactured good, it would make sense to examine a scenario in which the game these two types of consumers play is repeated over time. Studies that analyze these aspects of the underlying problem will provide additional insights into the functioning of markets with remanufacturing and the ways in which such markets can effectively promote the conservation of scarce resources.

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