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# Key Factors in the Market for Remanufactured Products

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Measures to extend the economic lives of products—such as remanufacturing carried out by *closed-loop supply chains*—are receiving increased attention because of various economic and regulatory factors. In this paper, we examine drivers of price differentials between new and remanufactured products using data on purchases made on eBay. Our analysis shows that seller reputation significantly explains the price differentials between new and remanufactured products. We also find that products remanufactured by original equipment manufacturers or their authorized factories are purchased at relatively higher prices than products remanufactured by third parties. However, in the presence of these reputation signals (seller reputation and remanufacturer identity), we find that stronger warranties are not significantly associated with higher prices paid for remanufactured products. Our work contributes to the closed-loop supply chain research stream in operations management by empirically examining market factors that have not been studied before.

*Key words*: environmental operations; empirical research; closed-loop supply chains; remanufacturing; seller reputation; eBay; OM-marketing interface; OM-information systems interface
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## 1. Introduction

Measures to extend the economic lives of products are receiving increased attention in both research and practice because of a combination of economic and regulatory factors. One such measure is remanufacturing—a $53 billion industry in the United States alone (Hauser and Lund 2003)—which involves the following steps carried out by *reverse* or *closed-loop* supply chains (CLSCs): product acquisition, reverse logistics, inspection and possible product disposal, remanufacturing or refurbishing of the product to a defined operating and aesthetic standard (comparable to a corresponding new product), and remarketing (Blackburn et al. 2004).

Prior operations management (OM) literature has studied various strategic and tactical issues pertinent to CLSCs with product remanufacturing (Corbett and Kleindorfer 2001a, b; Guide and Van Wassenhove 2006a, b; Kleindorfer et al. 2005). This body of literature, as critiqued by Guide and Van Wassenhove (2006a) and Atasu et al. (2008), is predominantly analytical in nature. They stress the need for empirical research to quantify the parameters used in analytical models and expand the scope of phenomena treated in the OM literature on CLSCs. More recently, Guide and Van Wassenhove (2009) note that research has "barely begun" to investigate market-related issues and that a lack of understanding of prices and markets poses barriers to the viability of remanufacturing efforts, "no matter how well the operational system is designed" (p. 16). They also note the opportunity for such work to lead industry practice because industry has long operated under common wisdom rather than systematic empirical studies. Furthermore, such work would enable the development of more sophisticated and relevant analytical models.

In this paper, we examine the extent to which factors such as seller reputation, remanufacturer identity, and warranty strength influence the prices at which remanufactured products are purchased relative to the prices of corresponding new products. Using data on purchases of remanufactured and new products on eBay within the "Electronics" category—a category where remanufacturing activity is significant as are the end-of-life environmental impacts of products—we find that the reputation of sellers of remanufactured products as well as their identity (i.e., whether original equipment manufacturer (OEM)/authorized factory or third party) significantly explain observed price differentials between corresponding new and remanufactured products. In contrast, we find that warranty strength has no significant effect on observed

price differentials. To complement our findings, we report on price differentials across different product categories.

Our findings have several implications. Understanding the significance and magnitude of the effect of seller reputation on the prices paid for remanufactured products would provide input to shorter-term pricing decisions and longer-term reputation-building decisions of sellers of remanufactured products. Establishing both the significance and magnitude of the price premiums commanded by products remanufactured by OEMs or their authorized factories versus those remanufactured by third parties would provide input to OEMs and third parties assessing the viability of engaging in remanufacturing. Finally, because warranties may be expensive to honor, sellers and remanufacturers would benefit from knowing whether stronger warranties meaningfully boost the prices paid for remanufactured products when reputation signals are present. Overall, these findings are pertinent to CLSC research and practice because the viability of remanufacturing hinges on the prices at which consumers actually purchase remanufactured products, relative to the prices of new products.

The remainder of this paper is organized as follows. In §2, we discuss the related literature and introduce our hypotheses. We provide a discussion of the research site and our data collection methodology in §3. Section 4 describes the operationalization of the variables considered in our study, and §5 presents our model specification. Section 6 discusses our results, and §7 concludes with the implications of our study.

## 2. Related Literature and Hypotheses

Several recent reviews of CLSC research in OM have highlighted the need for an empirical treatment of market factors (Atasu et al. 2008; Guide and Van Wassenhove 2006a, 2009; Souza 2008). Apart from Hauser and Lund (2003), who conduct a firm-level survey to gain an understanding of the general business and market demographics of firms that remanufacture products, to the best of our knowledge, the only published field-based empirical work on market factors in CLSCs is by Guide and Li (2010). They administer ascending-price eBay auctions for two products—a consumer product (Bosch Skil® jigsaw) and a commercial product (Cisco™ network security device) through a single user ID with 100% positive feedback, thereby keeping reputation constant. From auctions of 10 remanufactured and 20 new versions of each of the two products, they show the significantly lower price/willingness to pay (WTP) for the remanufactured versions of both products. Further, by examining the bid histories of the products, they find insignificant evidence of cannibalization (overlap in bidders) across the new and remanufactured versions of the consumer product but some evidence of cannibalization for the commercial product.

Building on this work, we gather rich transaction-level data to empirically investigate research questions that have not been addressed before. We contribute to the literature by examining different *factors that explain the purchase price differentials* between new and remanufactured products, including *seller reputation*, whether the *OEM/authorized factory or a third party* undertakes the remanufacturing, and whether the *warranty* offered for the remanufactured product is comparable to that for a corresponding new product. Finally, we report on how price differentials vary by product category.

Breidert et al. (2006) classify the methods available to estimate WTP into four groups: secondary market data, experiments (including field and laboratory experiments), direct surveys, and indirect surveys. Guide and Li (2010) employ field experiments, whereas we use secondary market data on products transacted in the field. The laboratory experiment approach has been used in recent papers to examine other market factors pertinent to CLSCs. For example, Agrawal et al. (2012) conduct experiments on student participants to assess how the presence of remanufactured versions affects the perception of the OEM's new product. They find that the presence of OEM-remanufactured versions decreases the WTP for the new product, whereas the presence of third-party-remanufactured versions increases the WTP for the new product. Ovchinnikov (2011) conducts a choice-based conjoint study on student participants to understand consumers' relative preferences for new and remanufactured products. With the price of the new product being fixed, high-end consumers have an inverted U-shape product-switching behavior as a function of remanufactured product price—at a very low remanufactured product price, fewer high-end consumers switch to the remanufactured version because of suspicions of low product quality.

Our work also relates to the literature on "secondary market" products. However, the empirical literature on secondary markets focuses entirely on used products. Unlike used products, remanufactured products are purportedly identical to new products in terms of product performance because of the processes of disassembly, servicing, and testing performed on them. Thus, observations for used products would not obviously carry over to remanufactured products. Specifically, the significance and magnitudes of the effects hypothesized below are pertinent to the viability of remanufactured products and have yet to be established.

### 2.1. Seller Reputation

Akerlof (1970) posits that in the presence of buyer uncertainty about product or service quality, reputable

sellers should enjoy a price premium through credible communication of quality. Inferior quality should incur a loss that deters opportunistic behavior; otherwise, reputable sellers would be driven from the market. Furthermore, Shapiro (1983) shows that the price premium afforded by superior reputation makes it optimal for reputed sellers to continue delivering high-quality products instead of myopically choosing inferior quality. In nonstatic markets, reputation systems provide valuable information to potential buyers about the trustworthiness of sellers and also help deter opportunistic behavior.

The advent of publicly viewable reputation mechanisms, such as that on eBay, initiated empirical work on the effect of seller reputation on prices paid for used products, such as coins, baseball cards, and so forth, for which reference or book prices are available (Ba et al. 2003, Dellarocas 2006, Resnick and Zeckhauser 2002, Resnick et al. 2006). This literature has highlighted that a seller's reputation can be measured along two dimensions—positive and negative—and has examined the roles of both reputation dimensions in influencing the prices paid (see Resnick et al. 2006 for a review). The literature also discusses why negative reputation may receive greater emphasis than positive reputation and uses counts of positive and negative feedback for the seller as separate measures of positive and negative reputation, respectively (Houser and Wooders 2006, Lucking-Reiley et al. 2007, Resnick and Zeckhauser 2002, Standifird 2001).

Findings for the effect of seller reputation on prices paid for used products are mixed. Negative reputation has been shown to have either a detrimental effect (e.g., Houser and Wooders 2006, Lucking-Reiley et al. 2007) or no effect (e.g., Bajari and Hortaçsu 2003, Livingston 2005) on used product prices. The effect of positive reputation is mixed as well, with results indicating either no effect (e.g., Eaton 2007, Lucking-Reiley et al. 2007) or a positive effect (e.g., Melnick and Alm 2002). However, although used products may face the moral hazard problem in the presence of buyer uncertainty about the seller's *type* (see Dellarocas 2005), the moral hazard problem is likely to be greater in the case of remanufactured products as a result of (1) the additional effort (unobservable to the buyer) involved in disassembling, servicing, and testing remanufactured products to a defined operating and aesthetic standard; and (2) the expectation that remanufactured products should be comparable in performance to new products. Therefore, notwithstanding the mixed results for used products, we expect that seller reputation would significantly explain price differentials for remanufactured products (recall that we use the term "price differential" to denote the relative difference between the reference price of a corresponding new product and the purchase price of the remanufactured product). Thus, we hypothesize the following:

Hypothesis 1A (H1A). *Negative seller reputation for remanufactured products is positively associated with price differentials.*

Hypothesis 1B (H1B). *Positive seller reputation for remanufactured products is negatively associated with price differentials.*

### 2.2. Remanufacturer Identity

Analogous to uncertainty about the seller of a remanufactured product, uncertainty about the remanufacturing process (including disassembly, servicing, and testing) could also be a buyer concern. The remanufacturing process could be complex and may require capital investments. Analytical models either assume that consumers have a higher preference for an OEM-remanufactured than a third-party-remanufactured product (e.g., Ferrer and Swaminathan 2006) or that consumers do not differentiate between them (e.g., Ferguson and Toktay 2006). However, to the best of our knowledge, there are no empirical studies that examine this relationship. We expect lower price differentials for products remanufactured by OEMs or their authorized factories because these entities are expected to be equipped with the resources (facilities and knowledge) to ensure that the remanufactured product conforms to the defined standard. Thus, we hypothesize the following:

Hypothesis 2 (H2). *Products that are remanufactured by OEMs or their authorized factories are associated with lower price differentials.*

### 2.3. Warranty Strength

Pertinent to the discussion of seller reputation and remanufacturer identity is whether consumer safeguards in the form of warranties can translate into higher purchase prices for remanufactured products. If so, remanufactured products that are accompanied by warranties comparable to corresponding new products should command lower price differentials than remanufactured products that are not backed by such warranties. The literature on used products has reported mixed findings on the relationship between warranties and price premiums. For example, Pavlou and Dimoka (2008) find a positive relationship between warranties and prices. In contrast, Dewally and Ederington (2006) find no statistical evidence for this relationship. They discuss how warranties may be cumbersome for buyers to pursue and could be offered on the fly, whereas reputation is built over time. Applying an analogous reasoning, in the presence of reputation signals (seller reputation

and remanufacturer identity), remanufactured products that are accompanied by warranties comparable to corresponding new products might not necessarily have lower price differentials than remanufactured products not backed by such warranties. However, for reasons similar to those discussed for seller reputation in §2.1, the effect of warranties on the prices paid for remanufactured products can be expected to be more pronounced than that observed for used products. Thus, we hypothesize the following:

Hypothesis 3 (H3). *Remanufactured products with stronger warranties are associated with lower price differentials.*

OEMs and third parties face various operations and marketing challenges in offering remanufactured products (Ferguson 2010). Establishing the significances and magnitudes of the effects of seller reputation, remanufacturer identity, and warranty strength on the purchase price differentials between new and remanufactured products would provide valuable input to their shorter-term pricing and warranty decisions as well as their longer-term entry and reputation-building decisions.

## 3. Data

eBay is a prominent marketplace—both in general (e.g., Frei and Rodriguez-Farrar 2005) and specifically for remanufactured products (Hanks and Sinclair 2006, Parlikad and McFarlane 2005). OEMs and third-party remanufacturers or resellers sell significant volumes of remanufactured products on eBay. eBay allows collection of data on completed transactions, such as positive and negative seller reputation, seller incumbency, and prices paid by buyers; thus it is an ideal research site for our work. We use both commercial and custom-developed software to extract detailed data on purchases of remanufactured and new products on eBay to test our hypotheses.

Our data set includes transaction-level data on remanufactured and new products sold during the first two weeks of August 2009 in the eBay product category of "Electronics," across all listing types (both fixed and nonfixed price listings). The products covered in this category include GPS systems, home audio (e.g., amplifiers, receivers), home video (e.g., televisions, DVD players), portable audio (e.g., MP3 players), vehicle electronics (e.g., satellite radio receivers, car alarms), and other products such as outdoor radios and calculators.

To obtain a list of purchased remanufactured products (also referred to as "completed items/listings/transactions" and uniquely identified by eBay's item numbers) during our sampling period, we used keywords identified in the remanufacturing literature (e.g., Hauser and Lund 2003) as search criteria, namely, "remanufactured," "refurbished," "rebuilt," and "reconditioned." For exposition, we generally refer to items spanning these keywords as "remanufactured" products. We cleaned this list to eliminate listings that included the aforementioned keywords but that were not relevant. As is typically the case, information on the specific source (or history) of the *core* for a remanufactured product in our sample is not available. However, potential sources that the sellers mentioned span various supply chain stages and include initial inspection failures, vendor returns, floor models, warranty returns, shipping damages, and end-of-use returns.

To compute price differentials, we identified all new products sold in the "Electronics" category on eBay during the same period. Within this set of sold new products, we identified those that exactly matched the remanufactured products. This process involved an extensive effort to ensure that the identified new products were exact matches (e.g., model number, version, etc.). For our data set, we excluded remanufactured products that did not have a corresponding new unit purchased as well as new products that did not have a corresponding remanufactured version purchased. For the main analysis, we excluded repeated buyer–seller combinations to avoid potential violation of the i.i.d. assumption in our regressions; we arbitrarily included the first occurrence of a buyer-seller combination in the case of repetitions (however, we later test the robustness of our results to the inclusion or exclusion of repeated buyer–seller combinations). Our resulting data set includes 250 remanufactured product transactions and 1,979 new product transactions, in which there is at least one corresponding new product for each remanufactured product in our data set, and vice versa.

For each of these transactions, we simultaneously extracted seller and product/transaction-related data from eBay using our custom software program. In addition, because online buyers care about *delivered* prices (i.e., sale price plus shipping cost to be paid by the buyer), we gathered data on the shipping cost for each item. For the most part, the items in our data set had "standard" shipping rates to be paid by buyers, irrespective of destination. In cases where the shipping cost was "calculated" based on the destination, to control for the potential dependence on the buyer's location, we used the postal code of the first author to determine the shipping cost. Where multiple shipping options were available, we chose the least expensive option.

We compute the reference price for a remanufactured product as the average of the delivered prices of all corresponding new products. For each remanufactured product in our sample, we also collect the following data: (1) whether the entity that remanufactured the product was the OEM/its authorized

factory or a third party, (2) whether the duration of the warranty for the remanufactured product was the same as that for a corresponding new product, and (3) whether the remanufactured product was sold by an "authorized" seller.

## 4. Variable Descriptions

We measure our dependent variable *PRICE DIFFERENTIAL* as the difference between the average delivered price of the corresponding new products and the delivered price of the remanufactured product, as a fraction of the average delivered price of the corresponding new products. Thus,

$$\begin{aligned} &\textit{PRICE DIFFERENTIAL} \\ &\quad \div \big(\text{Average Delivered Price}_{\text{New}} \\ &\qquad - \text{Average Delivered Price}_{\text{Remanufactured}}\big) \\ &\qquad \cdot \big(\text{Average Delivered Price}_{\text{New}}\big). \end{aligned}$$

This measure has a theoretical range of $(-\infty, 1)$. Note that negative values of *PRICE DIFFERENTIAL* are theoretically possible because there may be certain seller- or transaction-related dimensions (such as seller reputation or listing end times, introduced in §§4.1 and 4.2) that may lead a remanufactured product to be purchased at a higher price than a corresponding new product. We next discuss the independent variables that we expect to be associated with price differentials. Table 1 provides descriptive statistics of our variables.

### 4.1. Seller-Related Variables

*Seller Reputation.* eBay's feedback mechanism allows buyers to leave positive, neutral, or negative feedback, along with textual comments. eBay reports the counts of each type of feedback received by sellers in the last 12 months. Using prior literature as a basis in which feedback counts are used as measures of reputation (e.g., Houser and Wooders 2006, Lucking-Reiley et al. 2007, Standifird 2001), we use the total number of neutral and negative feedback counts as a measure of *SELLER NEGATIVE REPUTATION* and the number of positive feedback counts as a measure of *SELLER POSITIVE REPUTATION*. We combine the neutral and negative feedback counts because market participants perceive neutral feedback negatively (Cabral and Hortaçsu 2010, Resnick and Zeckhauser 2002). Having two separate measures for positive and negative reputation enables us to capture their potentially different effects (Houser and Wooders 2006, Lucking-Reiley et al. 2007, Resnick and Zeckhauser 2002, Standifird 2001).

*Remanufacturer Identity.* We assign *OEM_AUTHORIZED* a value of 1 if the product was remanufactured by the OEM or its authorized factory and 0 otherwise.

*Seller Type.* We assign *AUTHORIZED SELLER* a value of 1 if the remanufactured product was sold by an authorized seller and 0 otherwise.

*Seller Incumbency.* To account for the potential effect of a seller's tenure in the marketplace on its perceived reputation and, hence, on prices paid, we include *SELLER INCUMBENCY* as an independent variable. We measure seller incumbency as the number of days from the time of the seller's registration with eBay to the start time of the product listing.

### 4.2. Product- or Transaction-Related Variables

*Warranty Strength of the Remanufactured Product.* Because the duration of the warranty offered for a remanufactured product could affect its purchase price, we include the indicator variable *WARRANTY STRENGTH*, which equals 1 if the warranty duration for the remanufactured product was the same as that for a corresponding new product and 0 otherwise.

*Demand Factors.* We control for two demand factors that could influence the prices paid for remanufactured products: (1) *QUANTITY AVAILABLE*, measured as the available quantity of the remanufactured item as listed by the seller, which is visible to potential buyers, and (2) *DEMAND PROXY*, measured as the number of new units of a product sold during our sampling period, which would reflect the popularity of the product.

*Selling Fees.* eBay charges an insertion fee when an item is listed for sale. eBay also charges upgrade fees for embellishments to the listing, such as visual enhancement of the item page and longer listing durations. When the transaction between a seller and a buyer is completed, eBay charges a final value fee to the seller as a tiered percentage of the item's sale price. Because a seller likely incorporates the cost of sale into the price at which it lists an item and also because listing embellishments provided in return for selling fees could translate into marketing benefits for the seller, we employ *SELLING FEES* as a control, measured as the sum of all fees paid to eBay by the seller of the remanufactured product.

*Listing End Time/Day.* Prior research has discussed the possibility that the ending time of an eBay listing may be associated with the price paid (Lucking-Reiley et al. 2007, Simonsohn 2010). A reason is the potentially closer attention buyers pay during weekends or nighttime (nonwork) hours. Accordingly, we include two binary temporal controls: (1) *WEEKEND*, which captures whether the listing end time was on a weekend (Saturday or Sunday), and (2) *NIGHTTIME*, which captures whether the listing end time was during night hours (6 P.M.–6 A.M.).

**Table 1 Descriptive Statistics and Correlations** ($N = 250$)

| Variable | Mean | Std. dev. | Min | Max | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) *PRICE DIFFERENTIAL* | 0.27 | 0.19 | −0.40 | 0.70 | 1.00 | | | | | | | | | | | | | | | |
| (2) *SELLER POSITIVE REPUTATION* ('000s) | 32.70 | 34.67 | 0.00 | 71.53 | 0.43*** | 1.00 | | | | | | | | | | | | | | |
| (3) *SELLER NEGATIVE REPUTATION* ('000s) | 0.91 | 1.01 | 0.00 | 2.07 | 0.44*** | 0.99*** | 1.00 | | | | | | | | | | | | | |
| (4) *SELLER INCUMBENCY* ('000s) | 2.07 | 0.99 | 0.006 | 4.08 | −0.12* | 0.06 | 0.05 | 1.00 | | | | | | | | | | | | |
| (5) *OEM_AUTHORIZED* | 0.24 | 0.43 | 0.00 | 1.00 | −0.23*** | −0.51*** | −0.50*** | 0.07 | 1.00 | | | | | | | | | | | |
| (6) *AUTHORIZED SELLER* | 0.55 | 0.50 | 0.00 | 1.00 | 0.34*** | 0.82*** | 0.81*** | 0.10 | −0.21*** | 1.00 | | | | | | | | | | |
| (7) *WARRANTY STRENGTH* | 0.04 | 0.19 | 0.00 | 1.00 | −0.09 | −0.17*** | −0.17*** | −0.04 | 0.19*** | −0.21*** | 1.00 | | | | | | | | | |
| (8) *QUANTITY AVAILABLE* | 1.80 | 3.40 | 1.00 | 36.00 | −0.27*** | −0.15** | −0.19*** | −0.02 | 0.09 | −0.03 | 0.04 | 1.00 | | | | | | | | |
| (9) *DEMAND PROXY* | 15.69 | 62.32 | 1.00 | 860.00 | −0.04 | −0.05 | −0.05 | −0.15** | 0.07 | −0.07 | −0.02 | −0.02 | 1.00 | | | | | | | |
| (10) *SELLING FEES* | 6.89 | 12.10 | 1.01 | 156.30 | −0.38*** | −0.28*** | −0.29*** | −0.09 | 0.00 | −0.23*** | 0.03 | 0.14** | 0.01 | 1.00 | | | | | | |
| (11) *CATEG_GPS* | 0.16 | 0.37 | 0.00 | 1.00 | −0.14** | −0.30*** | −0.36*** | −0.16** | 0.38*** | −0.10 | 0.09 | 0.13** | −0.04 | 0.11* | 1.00 | | | | | |
| (12) *CATEG_HOME AUDIO* | 0.24 | 0.43 | 0.00 | 1.00 | 0.17*** | 0.52*** | 0.54*** | −0.02 | −0.32*** | 0.40*** | −0.11* | −0.13** | −0.12* | −0.20*** | −0.25*** | 1.00 | | | | |
| (13) *CATEG_HOME VIDEO* | 0.09 | 0.29 | 0.00 | 1.00 | −0.49*** | −0.30*** | −0.29*** | 0.03 | 0.04 | −0.35*** | 0.01 | 0.08 | −0.05 | 0.31*** | −0.14** | −0.18*** | 1.00 | | | |
| (14) *CATEG_PORTABLE AUDIO* | 0.42 | 0.49 | 0.00 | 1.00 | 0.30*** | 0.09 | 0.11* | 0.02 | −0.22*** | −0.04 | 0.01 | −0.20*** | 0.19*** | −0.12* | −0.38*** | −0.48*** | −0.27*** | 1.00 | | |
| (15) *CATEG_VEHICLE ELECTRONICS* | 0.03 | 0.18 | 0.00 | 1.00 | −0.03 | −0.16*** | −0.16** | −0.01 | 0.16** | −0.20*** | 0.09 | 0.26*** | −0.03 | 0.09 | −0.08 | −0.10 | −0.06 | −0.15** | 1.00 | |
| (16) *WEEKEND* | 0.25 | 0.43 | 0.00 | 1.00 | 0.00 | −0.17*** | −0.17*** | −0.03 | 0.08 | −0.24*** | −0.06 | 0.01 | 0.03 | 0.03 | 0.05 | −0.00 | 0.07 | −0.06 | 0.05 | 1.00 |
| (17) *NIGHTTIME* | 0.67 | 0.47 | 0.00 | 1.00 | 0.06 | −0.09 | −0.10 | 0.05 | −0.09 | −0.18*** | 0.05 | −0.07 | 0.05 | −0.04 | −0.03 | −0.09 | 0.08 | 0.14** | −0.06 | −0.09 |

***$p < 0.01$; **$p < 0.05$; *$p < 0.10$.

*Subcategory Controls.* Although all the products in our data set are from eBay's electronics category, we employ categorical variables to control for the extent to which price differentials may be sensitive to product subcategory. The subcategories we assign to the items correspond to the product subcategories under which the items were listed on eBay. These include GPS systems, home audio (e.g., amplifiers, receivers), home video (e.g., televisions, DVD players), portable audio (e.g., MP3 players), vehicle electronics (e.g., satellite radio receivers, car alarms), and "other" (e.g., outdoor radios, calculators). We arbitrarily chose "other" as the reference subcategory.

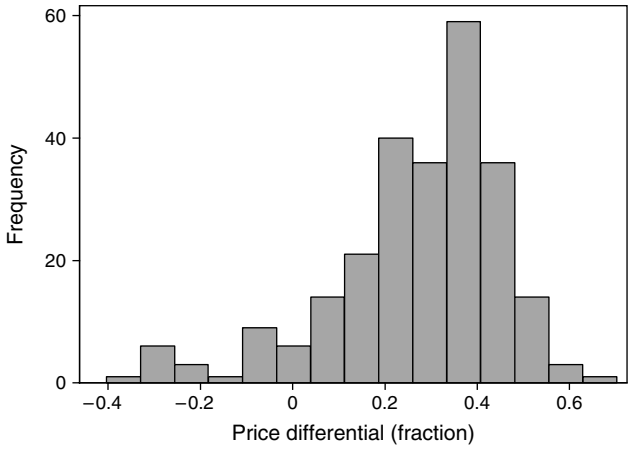
## 5. Empirical Model and Diagnostics

The relationships between our dependent variable and noncategorical exogenous variables are nonlinear. For example, although we expect higher levels of positive (negative) seller reputation to be associated with lower (higher) price differentials, we anticipate diminishing effects. Similarly, although we anticipate that higher selling fees for remanufactured products are associated with lower price differentials, we expect this behavior to diminish as selling fees increase. Therefore, we perform logarithmic transformations of the noncategorical independent variables in our model. Our empirical model is of the form

$$\begin{aligned} f(&PRICE\ DIFFERENTIAL) \\ &= \alpha_0 + \alpha_1 \ln(SELLER\ POSITIVE\ REPUTATION) \\ &\quad + \alpha_2 \ln(SELLER\ NEGATIVE\ REPUTATION) \\ &\quad + \alpha_3 \ln(SELLER\ INCUMBENCY) \\ &\quad + \alpha_4(OEM\_AUTHORIZED) \\ &\quad + \alpha_5(AUTHORIZED\ SELLER) \\ &\quad + \alpha_6(WARRANTY\ STRENGTH) \\ &\quad + \alpha_7 \ln(QUANTITY\ AVAILABLE) \\ &\quad + \alpha_8 \ln(DEMAND\ PROXY) \\ &\quad + \alpha_9 \ln(SELLING\ FEES) \\ &\quad + \alpha_{10_{a,\ldots,e}}(PRODUCT\ SUBCATEGORY) \\ &\quad + \alpha_{11}(WEEKEND) + \alpha_{12}(NIGHTTIME) + \varepsilon. \end{aligned}$$

The distribution of *PRICE DIFFERENTIAL*, which has a theoretical range of $(-\infty, 1)$, is shown in Figure 1. We employ a log-normal model with the transformation $(-1) \times \ln(1 - PRICE\ DIFFERENTIAL)$ of the dependent variable. The Box–Cox specification test and the Ramsey RESET test indicated suitability of the log-normal model (Box and Cox 1964, Ramsey 1969). This transformation is also directionally consistent with *PRICE DIFFERENTIAL*. The results of this regression are presented in column A of Table 2. We also employ two alternative models as robustness checks: (1) We employ a Tobit regression (Tobin 1958), where the upper bound of *PRICE DIFFERENTIAL* is 1. Although there is no censoring of the dependent variable in our case because the outcomes are observable, we employ a variation in the Tobit family (corner solutions model) that enables us to model a bounded dependent variable (Kennedy 2008). To account for heteroskedasticity in this model, we use a heteroskedasticity-consistent estimator (Breusch and Pagan 1979, White 1980). Results of the Tobit regression are presented in column B of Table 2. (2) Because more than 90% of our observations have price differential values greater than 0, we perform a regression with a logit transformation of *PRICE DIFFERENTIAL*. Results of this regression are included in column C of Table 2. Note that the logit transformation results in the loss of 24 observations that have negative price differentials. For both these alternative models, the directions of the coefficients of our main independent variables are consistent with those from the log-normal regression.

**Figure 1** **Distribution of Price Differential**




To test for multicollinearity, we computed the variance inflation factor (VIF) and the condition index for each independent variable. The maximum VIF is 7.31 (below the suggested threshold value of 10; Belsley et al. 1980), and the maximum condition index is 10.65 (below the suggested threshold value of 30; Belsley et al. 1980), suggesting that multicollinearity is not a significant concern.

## 6. Discussion

### 6.1. Regression Results

The mean price differential between new and remanufactured products in our data is 26.81%. We perform a $t$-test to verify whether the price differentials are significantly greater than zero. The test statistic ($t = 22.58$, $p < 0.01$) strongly indicates positive price differentials, validating the finding in Guide and Li (2010). Factors such as buyer uncertainty about remanufactured product quality or even ex ante perceptions of lower quality might explain the lower prices at which remanufactured products are purchased relative to corresponding new products. This is despite the possibility

**Table 2 Parameter Estimates**

| | | Dependent variable: *PRICE DIFFERENTIAL* | | |
|---|---|---|---|---|
| | | Column A | Column B (robustness check) | Column C (robustness check) |
| Variable | Parameter | Log-normal regression (std. errors in parentheses) $N = 250$ | Tobit regression (robust std. errors in parentheses) $N = 250$ | Logit regression (std. errors in parentheses) $N = 226$ |
| *SELLER POSITIVE REPUTATION* (log) | $\alpha_1$ | −0.047*** (0.015) | −0.033** (0.014) | −0.029*** (0.008) |
| *SELLER NEGATIVE REPUTATION* (log) | $\alpha_2$ | 0.043** (0.017) | 0.028* (0.015) | 0.038*** (0.009) |
| *SELLER INCUMBENCY* (log) | $\alpha_3$ | −0.015 (0.013) | −0.012 (0.012) | 0.0003 (0.007) |
| *OEM_AUTHORIZED* | $\alpha_4$ | −0.108*** (0.036) | −0.074** (0.035) | −0.049** (0.021) |
| *AUTHORIZED SELLER* | $\alpha_5$ | 0.103** (0.049) | 0.092** (0.042) | −0.008 (0.028) |
| *WARRANTY STRENGTH* | $\alpha_6$ | −0.006 (0.061) | 0.012 (0.036) | −0.050 (0.034) |
| *QUANTITY AVAILABLE* (log) | $\alpha_7$ | −0.049** (0.022) | −0.043*** (0.014) | −0.045*** (0.014) |
| *DEMAND PROXY* (log) | $\alpha_8$ | −0.045*** (0.012) | −0.026** (0.010) | −0.036*** (0.007) |
| *SELLING FEES* (log) | $\alpha_9$ | −0.141*** (0.020) | −0.103*** (0.020) | −0.074*** (0.012) |
| *CATEG_GPS* | $\alpha_{10a}$ | 0.015 (0.064) | 0.013 (0.044) | 0.023 (0.035) |
| *CATEG_HOMEAUDIO* | $\alpha_{10b}$ | −0.195*** (0.072) | −0.123** (0.048) | −0.144*** (0.040) |
| *CATEG_HOMEVIDEO* | $\alpha_{10c}$ | −0.211*** (0.071) | −0.199*** (0.060) | −0.128*** (0.045) |
| *CATEG_PORTABLEAUDIO* | $\alpha_{10d}$ | 0.010 (0.068) | 0.007 (0.049) | −0.007 (0.038) |
| *CATEG_VEHICLEELECTRONICS* | $\alpha_{10e}$ | 0.019 (0.084) | 0.021 (0.056) | 0.039 (0.049) |
| *WEEKEND* | $\alpha_{11}$ | 0.050* (0.026) | 0.045** (0.020) | 0.010 (0.015) |
| *NIGHTTIME* | $\alpha_{12}$ | 0.055** (0.024) | 0.041** (0.019) | 0.044*** (0.013) |
| *INTERCEPT* | $\alpha_0$ | 0.926*** (0.129) | 0.682*** (0.122) | 0.587*** (0.071) |
| Model fit | | $F(16,233) = 29.52$*** | $F(16,234) = 17.27$*** | $F(16,209) = 16.10$*** |

***$p < 0.01$; **$p < 0.05$; *$p < 0.10$.

that remanufactured products could be more reliable than new products as a result of the cumulative testing and diagnostics performed on them (Atasu et al. 2008).

Further, to investigate whether the mean price differential we observe is sensitive to the product category considered, we collected additional data on prices of corresponding remanufactured and new products purchased on eBay across all product categories (following similar steps as described in §3) and found variations in mean price differentials across categories (see Table 3). Although beyond the scope of our study, we conjecture that factors such as product complexity, rate of technological obsolescence, production volumes, and the availability of substitutes may explain these variations.

The results for our main (log-normal) model, presented in column A of Table 2, indicate significant effects of both negative and positive seller reputation on the price differentials between corresponding new and remanufactured products. Specifically,

**Table 3 Price Differentials by Product Category**

| Category | Mean price differential (%) |
|---|---|
| Business and industrial | 28.75 |
| Cameras and photo | 18.65 |
| Cell phones and PDAs | 30.45 |
| Computers and networking | 42.71 |
| Electronics | 20.44 |
| Home and garden | 35.19 |
| Video games | 30.97 |

we find that greater negative seller reputation is significantly associated with higher price differentials (coefficient $\alpha_2 = 0.043, p < 0.05$), whereas greater positive reputation is significantly associated with lower price differentials (coefficient $\alpha_1 = -0.047, p < 0.01$), providing support for H1A and H1B. Furthermore, we observe a difference in the magnitudes of these two effects: (1) Using the regression estimates in column A of Table 2 and with all the other independent variables set at their means (see the appendix for a detailed explanation of how we estimate the magnitude effects mentioned below), we find that an increase in negative seller feedback by 10 units from the mean is associated with a 0.48% increase in price differential. In contrast, an increase in positive seller feedback by 10 units is associated with a 0.01% decrease in price differential. (2) An increase in negative seller feedback by 100 units from the mean is associated with a 2.97% increase in price differential, whereas an increase in positive seller feedback by 100 units is associated with a 0.12% decrease in price differential. (3) An increase in negative seller feedback by one standard deviation around the mean is associated with a 14.88% relative increase in price differential, whereas an increase in positive seller feedback by one standard deviation around the mean is associated with a 12.94% relative decrease in price differential. Thus, in terms of magnitude, we find a stronger effect of negative than of positive seller reputation. Therefore, sellers with poor reputation must provide significant price breaks to encourage purchases of remanufactured products from them. In addition, we find evidence that consumers pay relatively higher prices for products remanufactured by OEMs or their authorized factories than for those remanufactured by third parties (coefficient $\alpha_4 = -0.108, p < 0.01$), providing support for H2. In terms of magnitude, with all the other independent variables set at their means, we observe a 7.93% decrease in the price differential for a change in *OEM_AUTHORIZED*, from 0 to 1. However, we find no significant effect of the warranty strength for the remanufactured product (coefficient $\alpha_6 = -0.006, p = 0.917$); i.e., H3 is not supported. This suggests that seller reputation and the identity of the remanufacturer may dominate in mitigating buyer uncertainty about remanufactured product quality, notwithstanding other buyer safeguards.

With respect to the other independent variables, we find that higher selling fees for remanufactured products are strongly associated with lower price differentials (coefficient $\alpha_9 = -0.141, p < 0.01$). This suggests that sellers are likely to adjust prices to account for increases in the cost of sale or that sellers are likely to accrue marketing benefits from features provided (by eBay) in return for the selling fees, such as a favorable listing display. Our somewhat counterintuitive finding that a greater quantity of a remanufactured product available from the seller is associated with a lower price differential (coefficient $\alpha_7 = -0.049, p < 0.05$) could be because buyers may perceive this as evidence of a more established seller. Alternatively, competition from the higher available quantity of the remanufactured product may lead sellers of new units to lower their prices. We find that the proxy for product demand is negatively associated with price differential (coefficient $\alpha_8 = -0.045, p < 0.01$), suggesting that remanufactured versions of more popular products need to be discounted less. Also, we find that remanufactured products from authorized sellers are associated with higher price differentials (coefficient $\alpha_5 = 0.103, p < 0.05$). A possible reason for this could be that authorized sellers may offer both new and remanufactured versions of products and may therefore wish to differentiate them through listing prices. Finally, we find that remanufactured product listings that end during a weekend day (Saturday or Sunday) or during nighttime hours are associated with higher price differentials (coefficients $\alpha_{11} = 0.050, p < 0.10$; and $\alpha_{12} = 0.055, p < 0.05$, respectively). This could be attributed to the closer attention possible for buyers to assess the competitiveness of a product listing and alternative offerings during weekends or nighttime (nonwork) hours.

### 6.2. Robustness Tests

**6.2.1. Alternative Measurement of *PRICE DIFFERENTIAL*.** We estimated a specification in which we computed *PRICE DIFFERENTIAL* using the *lowest* delivered price among corresponding new products instead of the *average* price. Although average price is a more robust reference price, the use of the lowest price allows us to include additional controls for attributes related to the new product, including positive and negative seller reputation, seller incumbency, selling fees, quantity available, and listing end day/time. We find consistent directions of our main independent variables.

**6.2.2. Causal Effect of Negative Reputation.** Between the two types of reputation we examine, prior research has posited a more pronounced role of *negative* reputation in influencing prices paid (Houser and Wooders 2006, Lucking-Reiley et al. 2007, Resnick and Zeckhauser 2002, Standifird 2001). As discussed in §6.1, we too observe that an increase in negative seller reputation is associated with a larger change in price differential as compared with positive seller reputation. Accordingly, we use negative seller reputation as the *treatment* for causal inference. We employ potential outcomes analysis (e.g., Dehejia and Wahba 1999, Heckman et al. 1997, Rubin 1974)—specifically, *propensity score matching* (Rosenbaum and Rubin 1983, Rubin

and Thomas 1996)—to examine the causal effect of negative reputation on price differential (details of this analysis are included in the online appendix, which is available at http://msom.journal.informs.org/). The two widely adopted outcome measures after propensity score matching are the average treatment effect (ATE) and the average treatment effect on the treated (ATT), which are defined as ATE = E[Outcome (treatment) − Outcome (no treatment)], and ATT = E[Outcome (treatment) | $T = 1$] − E[Outcome (no treatment) | $T = 1$], where T is the treatment indicator and E represents the expected value. Thus, ATE is the expected difference in outcomes (price differential) with and without treatment (high negative seller reputation), and ATT is the difference between expected outcomes with and without treatment for the transactions that actually received the treatment. We find that the average effect of applying the treatment (ATE) is an increase in price differential of 24.83% when compared with the control group. Further, we find ATT to be a price differential of 28.36%, suggesting a causal effect of negative reputation.

**6.2.3. Alternative Measurement of Reputation.** We explored replacing the two separate measures of seller reputation with a single percentage measure of positive reputation (i.e., percentage of positive feedback). When this single reputation score is employed (in place of the separate negative and positive reputation measures) in our regression model, we observe failure of two model specification tests—the Cox–Pesaran–Deaton test (at $p < 0.05$) and the Ramsey RESET test (at $p < 0.05$) (Cox 1962, Pesaran 1974, Pesaran and Deaton 1978). Failure of these tests suggests that (1) parameter estimates from this regression are likely to be biased and inaccurate (Kennedy 2008), and (2) the mean square error of the regression is likely to be over- or underinflated, depending on the extent of bias. Nonetheless, a statistically significant non-parametric rank correlation and rejection of the null hypothesis that price differential and percentage of positive feedback are independent (at $p < 0.01$) indicate a consistent result.

**6.2.4. Intragroup Correlations.** We performed two kinds of tests of intragroup correlations. First, to examine if there is any possible bias because of the inclusion of multiple products from certain sellers, we re-estimated the regression parameters, allowing for intragroup correlations (clustered errors) across sellers, products, seller and product, and buyers. We observe only minor changes in the significances of our independent variables. Second, we tested the inclusion and exclusion of repeated buyer–seller combinations. The inclusion of all repeated buyer–seller combinations adds eight observations to our sample (i.e., $N = 258$), and the distribution of the dependent variable *PRICE DIFFERENTIAL* does not change significantly (sample mean of 26.88%; median of 30.53%) compared with the distribution in our main analysis (sample mean of 26.81%; median of 30.99%). The exclusion of all repeated buyer–seller combinations results in five fewer observations (i.e., $N = 245$); again, the distribution of the dependent variable does not change significantly (sample mean of 26.71%; median of 30.97%). Further, the signs of the parameter estimates in both cases (inclusion and exclusion of all repeated buyer–seller combinations) are consistent with those in Table 2.

## 7. Conclusions

Our work contributes to the OM literature on CLSCs by empirically examining market factors that explain the purchase price differentials between new and remanufactured products, including seller reputation, the identity of the remanufacturer (whether OEM/authorized factory or a third party), and warranty strength. These factors have not been empirically studied before.

Our results suggest that seller reputation is important for remanufactured products. In our study, an increase in positive seller feedback by 10 units from the mean is associated with a 0.01% decrease in price differential, and a 10 unit increase in negative seller feedback is associated with a 0.48% increase in price differential. Therefore, in remanufactured product markets, it is important for sellers to build and communicate their reputation. Reputation mechanisms, such as that on eBay, can provide signals about product or service quality and help mitigate uncertainties faced by potential buyers of remanufactured products. Online marketplaces also provide opportunities for the seller to provide rich information regarding the product offering. For example, eBay allows questions for the seller, and the seller's responses to be displayed on the item page so that all potential buyers can see the information.

We find evidence that consumers pay relatively higher prices for products remanufactured by OEMs or their authorized factories (a 7.93% lower price differential) than for those remanufactured by third parties. OEMs tend to be wary of remanufacturing products because of operational hurdles and cannibalization with their new products on the one hand, and a lack of knowledge of consumers' perceptions of remanufactured products and their willingness to pay on the other. However, the price premium commanded by products remanufactured by OEMs or their authorized factories should offset this cannibalization concern. Further, we find that stronger warranties are not significantly associated with higher prices paid for remanufactured products, suggesting that seller reputation and the identity of the

remanufacturer may dominate in mitigating buyer uncertainty about remanufactured product quality, notwithstanding other buyer safeguards.

Both research and practice will benefit from related future work. First, our analysis focused on a single product category ("Electronics"). Future research could replicate the analysis across different product categories, which typically vary along dimensions such as product complexity, rate of technological obsolescence, production volumes, and the availability of substitutes. For example, our additional cross-category data on prices of corresponding remanufactured and new products purchased on eBay shows evidence of variations in price differentials across categories (see Table 3). Second, although we accounted for several market-specific aspects, our study focused on an online market in which buyers are unable to directly observe products before their purchase decision. Compared with a physical marketplace, an online setting likely involves greater buyer uncertainty about product quality and, hence, a possibly enhanced importance of seller reputation. Although remanufactured products are not often sold to end customers in brick-and-mortar stores, future research could examine whether our results hold in physical marketplaces as well. Third, buyer uncertainty about remanufactured product quality is likely to drive the importance of seller reputation, remanufacturer identity, and warranty strength in the prepurchase stage. However, after the buyer receives the remanufactured product and has the opportunity to experience it, the performance of the remanufactured product should assume importance over ex ante concerns. Preliminary findings (available from the authors) from feedback data on products purchased on eBay suggest that satisfaction levels for remanufactured products are at least comparable to those for new products. Empirically establishing whether the satisfaction levels are indeed comparable is pertinent to the continuing viability of offering remanufactured products. Though not intended to be exhaustive, we believe that these are noteworthy trajectories for future OM research.

## Electronic Companion

An electronic companion to this paper is available as part of the online version that can be found at http://msom.journal.informs.org/.

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## Appendix. Estimation of Magnitude Effects Reported in §6

1. We start with the estimated regression parameters (column A of Table 2) and our regression model.

2. From the prediction equation $\hat{y} = \boldsymbol{\beta}X$, we estimate the value of the dependent variable *PRICE DIFFERENTIAL* (*PD*) at the means of all the independent variables (note that all noncategorical independent variables are log-transformed). Thus, we obtain $\hat{y} = -\ln(1 - PD) = 0.33744$ or, $PD = 1 - e^{-\hat{y}} = 0.28640$.

3. To test the effect of changing positive seller reputation, we keep the remaining independent variables at their mean values and increase the positive seller reputation measure (i.e., positive seller feedback) alone by 10 units; note that [mean positive seller feedback + 10] is log-transformed.

4. We then calculate the changed predicted value of the dependent variable. With the increase in positive seller feedback from its mean by 10 units, we obtain $\hat{y} = -\ln(1 - PD) = 0.33727$ or, $PD = 1 - e^{-\hat{y}} = 0.28628$.

5. Thus, we associate the change in price differential of $0.28628 - 0.28640 = -0.00012$, or a 0.01% decrease, to the increase in positive seller feedback by 10 units from its mean value.

6. We perform a similar procedure for negative seller reputation by keeping all other independent variables (including positive seller reputation) at their means.

7. For a 10-unit increase in negative seller feedback, we observe a change in predicted price differential from 0.28640 to 0.29117, i.e., an increase of 0.48%.

8. We repeat the above steps to assess the effects of a 100-unit increase in positive and negative seller feedback from the mean values.

9. We also repeat the above steps to assess the effects of a 1 standard deviation (s.d.) increase around the means (mean − 0.5 s.d. to mean + 0.5 s.d.) of positive and negative seller feedback. We report the changes in price differential relative to the price differentials at the [mean − 0.5 s.d.] baseline. This is because of different price differential values at [mean − 0.5 s.d.] for positive and negative seller feedback.

10. For the effect of *OEM_AUTHORIZED*, we keep the remaining independent variables at their mean values and calculate the change in price differential for a change in OEM_AUTHORIZED from 0 to 1. With $OEM\_AUTHORIZED = 0$, we obtain $\hat{y} = -\ln(1 - PD) = 0.36379$ or, $PD = 1 - e^{-\hat{y}} = 0.30497$. For $OEM\_AUTHORIZED = 1$, we obtain $\hat{y} = -\ln(1 - PD) = 0.25579$ or, $PD = 1 - e^{-\hat{y}} = 0.22570$. Thus, the change in price differential is 0.07927, or 7.93%.

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