# Understanding the Role of Trade-ins in Durable Goods Markets: Theory and Evidence 

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# UNDERSTANDING THE ROLE OF TRADE-INS IN DURABLE GOODS MARKETS: THEORY AND EVIDENCE 


#### Abstract

The act of trading in a used car as partial payment for a new car resonates with practically all consumers. Such transactions are prevalent in many other durable goods markets ranging from golf clubs to CT scanners. What roles do trade-ins play in these markets? What motivates the seller to set up a channel to facilitate trade-ins? Intuitively, accepting a trade-in would appear to stimulate demand for the producer's product, but facilitating the resale of these used goods that substitute for new goods might also increase cannibalization. Although such transactions involve billions of dollars, we know little about this practice from the extant research literature.

This paper develops an analytical model that incorporates key features of real-world durable goods markets; a) co-existence of new and used goods markets, b) consumer heterogeneity with respect to quality sensitivity, c) firms who anticipate the cannibalization problem arising from the co-existence of new and used goods, and d) lemons problems in resale markets, whereby sellers of used goods are better informed than buyers about the quality of their particular item.

In our analysis, a trade-in policy amounts to an intervention by the firm in the used good market, which reduces inefficiencies arising from the lemons problem. It motivates owners to purchase new goods and reduces their proclivity to hold on to purchased goods because of the low price the latter would fetch in a lemons market.

We also show that trade-in programs are more valuable for less reliable products because of the more acute lemons problem. Such programs increase the average quality of used goods offered for resale, which in turn increases used goods prices as well as the volume of transactions in the resale market. Trade-in programs are also more valuable for products that deteriorate more slowly, because the near-new quality of a used good allows it to compete more effectively for new good purchases.

We test the key predictions of the model about price and volume of trade by assembling a dataset of transactions of US automobile consumers, and find broad support for our model. In particular, we find that a consumer buying a automobile with a trade-in receives an average discount of $\$ 644$ (net of the value of the traded vehicle), and that this discount is larger for more unreliable make-models $(\$ 1,217)$ as well as for make-models that deteriorate slower $(\$ 1,251)$. The volume of used good trade is larger for more reliable make-models as well as for faster deteriorating make-models.


Keywords: Durable goods, Trade-ins, Adverse Selection.

## 1. INTRODUCTION

While the act of trading in a used car to buy a new car resonates with most consumers, trade-in transactions are common in many more markets than is appreciated ${ }^{1}$. Indeed, a substantial fraction of transactions in many product markets, ranging from golf clubs to CT scanners, involve a trade-in. The goods taken in trade are sometimes discarded, as in 'buyback programs' for software (Fudenberg and Tirole 1998), but are quite commonly sold in resale markets that operate alongside the first sale markets. Despite the prevalence of trade-in sales, the rationale for accepting trade-ins remains virtually unexplored in the literature and there is no empirical work examining this phenomenon.

We seek to close this gap in our knowledge, by building and testing a formal model of trade-in transactions in this paper. Our analysis centers on markets where durable goods deteriorate with age, but where the product technology itself is static ${ }^{2}$. Our model captures key features of durable goods markets, including the co-existence of new and used goods markets, consumer heterogeneity with respect to quality sensitivity, firms who anticipate the cannibalization problem arising from the co-existence of new and used goods, and lemons problems ${ }^{3}$ in resale markets.

We show that trade-in programs mitigate the lemons problem, and hence increase the producer's profits. Intuitively, consumers want to match their assets to their own level of desired quality, but the lemons problem induces them to hold on to their previously purchased goods because of the sub-par prices for used goods in these situations. A new good discount ${ }^{4}$ offered for a purchase with a trade-in counteracts this tendency. We show that as the quality uncertainty increases, the magnitude of the trade-in discount increases, while the volume of used good trade, the quality of used goods offered, as well as used good price all decline. On the other hand, as

[^1]the rate of deterioration increases, the magnitude of the trade-in discount decreases, while the volume of used good trade and the quality of used goods offered increase.

Our paper expands on extant work in several ways. First, we employ an infinite period model structure and a stationary equilibrium concept accompanying it that helps us reveal the unique role of trade-ins as a device to mitigate the lemons problem. Second, our model is more comprehensive than extant work in that we accommodate the cannibalization arising from the co-existence of new goods and used goods markets, as well as customer heterogeneity and information asymmetry. Finally, we offer the first empirical evidence about trade-ins by testing a number of refutable predictions from our model.

The remainder of the paper is organized as follows. In Section 2 we review the extant work on durable goods, with a view to disclosing the gaps in our knowledge about trade-in programs and resale markets. Section 3 presents our model, while Section 4 presents the analysis and results. Section 5 presents our empirical tests of the refutable implications of the model. Section 6 concludes the paper with a discussion of the limitations and possible extensions of the work.

## 2. LITERATURE

There is a large literature on durable goods markets stretching back over three decades, and a number of marketing practices have been studied, including vertical coordination (Desai et al. 2004), dual channels (Purohit 1997; Purohit and Staelin 1994), trade promotions (Bruce et al. 2005), end consumer promotions (Bruce et al. 2006) and leasing contracts (Desai and Purohit 1998). However, trade-in practices have received very limited attention.

Ackere and Reyniers (1995) develop a two-period model to show that a discriminatory discount offered to myopic consumers in trade-in transactions will induce more new good purchases in the second period. However, when the producer can commit to prices intertemporally, or when consumers are forward-looking, this rationale for trade-ins vanishes. Adda and Cooper (2000) evaluated a policy intervention similar to trade-ins, whereby French provincial authorities gave owners a one-shot subsidy to scrap their old cars and to buy new ones. Their principal finding is that forward-looking consumers shift purchases forward to take advantage of the discount. This work reminds us of the need to model forward-looking
consumers in durable goods markets. Some work has focused on the psychology of trade-in transactions. Purohit's (1996) laboratory experiments show that consumers faced with two deals that are financially equivalent will nevertheless favor the deal that overpays them for their traded-in good. Similarly, Okada's (2001) study of consumers' decisions to sell their used good uncovered a similar bias towards one's current possessions.

The work leaves open a number of gaps in our understanding of trade-in policies that are seen more clearly when we consider the broader work on durable goods markets. Three gaps are of special significance. First, Coase (1972) pointed out that a durable goods producer who wishes to capitalize on customer heterogeneity in willingness-to-pay, and charge a high price in an initial period followed by a lower price in the following period faces a time commitment problem. Consumers will anticipate this price discrimination strategy, and balk at paying the high initial price. In effect, the producer cannot realize his monopoly status. Any contract or institution that enables a producer to commit credibly to prices or quantities over multiple periods solves the problem, and re-establishes his monopoly status. A large number of commitment devices have been uncovered, including leasing (Desai and Purohit 1999), planned obsolescence, and long-term contracts (Bulow 1982; Fudenberg and Tirole 1998).

Recall the Ackere and Reyneirs (1995) result discussed above where trade-ins play a role when the producer cannot commit, but this vanishes with commitment. Given the larger body of work on commitment, we can see that trade-ins in the Ackere and Reyneirs model are yet another commitment device, and are thus indistinguishable from the other commitment devices. In order to uncover any unique properties of trade-ins, we need to work out of a setup where producers can commit inter-temporally. Waldman (2003) reaches a similar conclusion from his comprehensive review, viz. future work on durables should proceed under the maintained hypothesis that commitment is achievable by durable goods producers. In our work, we employ the concept of a stationary equilibrium (Rust 1985), which renders the commitment problem irrelevant.

A second gap is revealed when we consider the central role of resale markets for durable goods. The co-existence of new and used goods make these products behave as substitutes, albeit imperfect substitutes, which then raises the specter of cannibalization. A forward-looking firm will internalize the cannibalization arising from current sales on sales in future periods,
and seek solutions to this problem. Similar to the commitment problem, the literature has uncovered a large number of solutions, including leasing contracts (Desai and Purohit 1998; Hendel and Lizzeri 1999a), buyback programs (Levinthal and Purohit 1989; Purohit and Staelin 1994), planned obsolescence (Fudenberg and Tirole 1998), control over resale markets (Shapiro 1995), and raising the costs of resale transactions (Anderson and Ginsburgh 1994).

Despite the central role of resale markets as evidenced from this literature, extant work on trade-ins does not include resale markets. Thus, it affords a very limited lens on the problem. In our work, the co-existence of new and used goods is an integral element of the model.

Third, although the psychology of resale transactions has been studied in the trade-in literature, the defining characteristic of used goods transactions is missing from that body of work. Starting with Akerlof (1970), the information asymmetry between buyers and sellers of used goods, and its impact on market outcomes, has been viewed as a central element of these markets. The incumbent owner cannot communicate the quality of her used good credibly to the buyer, thus only lemons ${ }^{5}$ are offered for sale, which then shuts down the used goods market. Recent modeling (e.g., Hendel and Lizzeri 1999b) has shown that used goods markets do not shut down completely in the face of the lemons problem, but that the volume of trade is reduced to the detriment of both consumers and producers. Given this centrality of the lemons problem, and given that trade-ins directly involve used goods, our work incorporates this issue into the model very directly.

To sum, there has been no prior work that has examined the practice of trade-ins, while accommodating the co-existence of new and used good markets, the presence of adverse selection in used good markets, and heterogeneity of consumer preferences. Further, there has been no empirical examination of this phenomenon. We turn now to our model, which attempts to accommodate all of the above features.

## 3. MODEL

Consumers: We assume a fixed number of infinitely lived, utility maximizing consumers who consume one unit of a durable good per period. We model these heterogeneous consumers with a

[^2]vertical differentiation model (e.g., Mussa and Rosen 1978; Shaked and Sutton 1982), such that if prices were identical, all consumers would have the same preference rankings of the products. For tractability, we assume a uniform distribution of the valuation of quality, $\theta$, over the set $[\underline{\theta}, \bar{\theta}]$, and normalize $\underline{\theta}=0$ and $\bar{\theta}=1$. The consumer's per period linear indirect utility function (ignoring income effects) is $u(\theta, \eta)=\theta \eta-p$, where $\eta$ is per period quality of the good, and $p$ is the price of the good.

Product: The product lasts two periods and is denoted 'new' in the first period and 'old' in the second ${ }^{6}$. A new product provides a quality of $v$. The quality represent the total utility from using the product, including functional, aesthetic, and/or hedonic utility. The new good deteriorates to a high-quality used good (a peach) with probability $\alpha$, or to a low-quality used good (a lemon) with probability $(1-\alpha)^{7}$. After period 2 the good becomes useless and is scrapped costlessly.

Without loss of generality, we assume that a peach provides a quality of $(1+s)$, while a lemon provides a quality of $(1-s)$. Further, we assume $\alpha$ equals $1 / 2$, i.e., a new good has an equal probability of becoming a peach or a lemon in the second period. The parameter $s$ thus indexes the extent of quality uncertainty about used goods. Throughout the paper we assume that $0<s<1$ (assumption A1), to rule out the implausible case of used goods with negative utility. We also assume that $s<(4 / 5)(v-1)$ (assumption A2), so that $s$ is not 'too large' ${ }^{8}$. This guarantees a) a positive flow of goods every period, b) the new good deteriorates after one period, c) the used good market is active, and d) positive prices.

A brief comment is in order about the exogeneity of the quality of the new good and the extent of quality uncertainty. Initial quality levels (and deterioration rates) for durable goods are relatively difficult to change in the short term because of the large fixed costs involved. Our background assumption, therefore, is that these decisions have been made in some previous quality game, and that price is the only current decision facing firms.

[^3]Producer: An infinitely lived profit-maximizing producer chooses the price of his new good and a trade-in program, if any. The marginal cost of production is normalized to zero without loss of generality.

Adverse Selection: The quality level of the used good is private information to the seller. Buyers form expectations about the average quality of these goods, but they are unaware of the quality of a particular item. This degree of quality uncertainty is captured by $s$. The higher the value of $s$, the more uncertain the buyers of a used good are about its quality ${ }^{9}$.

## 4. ANALYSIS

### 4.1 Characterizing Consumer Behavior and the Stationary Equilibrium

In a general set-up, in every period each consumer makes a consumption decision based upon the prices prevailing in the market, as well as her own consumption decision in the previous period. In effect, both consumers and the firm solve a dynamic maximization problem. Consumers take new and used prices as given and decide their consumption decision at the beginning of each period, while the firm sets the new good price on the basis of anticipated consumer behavior. Used good prices are determined competitively through market clearing. For expositional purposes, we refer to a consumer's decision in a particular period as an action, while her action in the previous period is referred to as her state in the current period.

In any period, the consumer can take one of three actions - she can i) buy a new good, ii) buy a used good, or iii) not buy a good. Action iii), in turn, could arise in two cases, distinguished by the consumer's state. Thus, she could have bought a new good in the last period, and decided to hold on to the good this period (the good could have turned out to be either a peach or a lemon). Or, she may not have bought a good at all in the last period. Formally, we can represent the action that a consumer can take in any particular period as the following five-dimensional binary vector ${ }^{10}$ :
$b^{t}(\theta)=\left[n^{t}(\theta), h_{p}^{t}(\theta), h_{l}^{t}(\theta), u^{t}(\theta), i^{t}(\theta)\right]$.
where,

[^4]$n^{t}(\theta)=1$ refers to a purchase of a new good by type $\theta$ at time $t$.
$h_{p}^{t}(\theta)=1$ refers to the holding of a (good that was revealed to be a) peach by type $\theta$ at time $t$.
$h_{l}^{t}(\theta)=1$ refers to holding a (good that was revealed to be a) lemon by type $\theta$ at time $t$.
$u^{t}(\theta)=1$ refers to purchase of a used good by type $\theta$ at time $t$.
$i^{t}(\theta)=1$ refers to type $\theta$ not using any good at time $t$.
Note that a non-zero value of $h_{p}^{t}(\theta)$ or $h_{l}^{t}(\theta)$ is possible only when the state of the consumer is $n^{t-1}(\theta)=1$, i.e., holding in the current period $(t)$ necessarily implies that a new good was purchased in the previous round ( $t-1$ ). Additionally, we impose the following constraint: $n^{t}(\theta)+h_{p}^{t}(\theta)+h_{l}^{t}(\theta)+u^{t}(\theta)+i^{t}(\theta)=1$, that ensures consumers have at most one good during any period.

Let $\mathrm{H}_{\theta}\left[b^{t-1}(\theta), b^{t}(\theta), p^{t}\right]$ be the pay-off for consumer $\theta$ given state $b^{t-1}(\theta)$, action $b^{t}(\theta)$, and price vector $p^{t}$ (new and used prices). The following Bellman equation outlines the action that a consumer would choose to maximize her utility:
$V^{t}(\theta)\left[b^{t-1}(\theta), p^{t}\right]=\max _{b^{t}(\theta)}\left\{\mathrm{H}_{\theta}\left[b^{t-1}(\theta), b^{t}(\theta), p^{t}\right]+\delta V^{t+1}(\theta)\left[b^{t}(\theta), p^{t+1}\right]\right\}$.
Note that in (1), the action $b^{t}(\theta)$ in period $t$ becomes a state variable in period $t+1$. Given the consumer behavior outlined above, the producer determines a new good price each period to maximize his profits. A stationary equilibrium in the above setting is one where prices as well as aggregate consumer behavior remain constant across time. The existence of such an equilibrium in this setting has been formally shown in Rust (1985) and Konishi and Sandfort (2002). The stationary equilibrium is essentially a fixed point in strategy space that players converge to. Hence, this concept is well-suited to understanding the long-run behavior of firms and consumers. Furthermore, recent work in durable goods has extensively employed stationary equilibrium to study a number of issues, such as the impact of adverse selection on prices (Hendel and Lizzeri 1999(b)), trading patterns across vintages (Stolyarov 2002), and the presence of simultaneous leasing and selling in durable markets (Huang et al. 2001).

The characterization of the stationary equilibrium proceeds as follows ${ }^{11}$. In the first step, we search for feasible patterns of consumer behavior. Since a good lasts for two periods, we only need to look at all the possible actions of a consumer at two consecutive periods of time. We narrow these down to feasible patterns of consumer behavior that are consistent, incentive compatible and individually rational. In the second step, we classify the consumer segments that follow the behaviors just outlined. Table 2 shows the pay-off matrix for a consumer for all possible states and actions. The following lemma summarizes the feasible patterns of consumer behavior and the ensuing consumer segments (proofs of all lemmas and propositions are provided in the Technical Appendix).

Lemma 1: In stationary equilibrium, a consumer's consumption pattern is one of the elements of the set $\Omega(\theta)=\left[n^{t-1}(\theta) n^{t}(\theta), n^{t-1}(\theta) h_{p}^{t}(\theta), h_{p}^{t-1}(\theta) n^{t}(\theta), u^{t}(\theta) u^{t-1}(\theta), i^{t-1}(\theta) i^{t}(\theta)\right]$. Consumers in the interval
$\left(\theta_{1 a}, 1\right)$ follow consumption pattern $n^{t-1}(\theta) n^{t}(\theta)$ (buy new each period),
$\left(\theta_{2 a}, \theta_{1 a}\right)$ follow consumption pattern $\left[n^{t-1}(\theta) h_{p}^{t}(\theta), h_{p}^{t-1}(\theta) n^{t}(\theta)\right]$ (buy new and hold if a peach is realized, sell if a lemon is realized), $\left(\theta_{3 a}, \theta_{2 a}\right)$ follow consumption pattern $u^{t}(\theta) u^{t-1}(\theta)$ (buy used each period), and $\left(0, \theta_{3 a}\right)$ follow consumption pattern $i^{t-1}(\theta) i^{t}(\theta)$ (do not buy), with $0 \leq \theta_{3 a} \leq \theta_{2 a} \leq \theta_{1 a} \leq 1$.

Intuitively, consumers sort themselves into different consumption patterns based upon their willingness to pay (similar to the canonical Mussa \& Rosen (1978) model). The highest types, whom we call Compulsive Buyers, consume (on average) the highest quality and buy new goods each period. Thus, these consumers sell their used good regardless of its quality realization. Consumers next in the quality ladder buy a new good, but hold onto their used good if it is a peach, and sell if it is a lemon. We refer to these consumers as Strategic Holders. Consumers in the third segment consume a used good each period; we refer to these consumers as Cheapskates. Since the used goods this segment buys can come from either the Compulsive Buyers or the Strategic Holders, the average quality of used goods consumed by the Cheapskates segment

[^5]depends upon the relative sizes of the first two segments. Finally, we assume incomplete market coverage, so the lowest types do not buy anything; we refer to this segment as Non-Buyers. Note that we rule out all other possible behaviors (e.g., buy used in the first period and new in the second) in the proof for Lemma 1 detailed in the Technical Appendix.

Having outlined the feasible patterns of consumer behavior, we turn to calculating segment sizes, prices, qualities, etc., under stationary equilibrium. Our analysis has two parts to it. We start by analyzing a durable goods market with adverse selection but no trade-ins. This model provides us benchmarks, as well as helps gain some intuition leading in to our final model, wherein we model trade-ins in markets with adverse selection. Before we deal with the adverse selection case, it is useful to point out that in a model with quality uncertainty but no adverse selection, each buyer would update to her optimal vintage every period ${ }^{12}$. In other words, no buyer would hold on to her good for more than one period ${ }^{13}$. Quite intuitively, the presence of adverse selection introduces friction into the market, and could cause consumers to not trade every period. We explore this intuition and its ramifications in greater detail in what follows.

### 4.2 Markets without Trade-Ins

We begin by characterizing markets with adverse selection issues, but without trade-ins. Recall that $s$ represents the spread of used good quality - as $s$ increases, buyers are more uncertain about quality. Potential used goods buyers form an expectation about the quality of the used good offered for sale. As outlined in the previous section, there are only four patterns of behavior to consider within this market. We now write down the value functions of each of these segments, as a prelude to characterizing the equilibrium.

[^6]Segment la (Compulsive Buyers): These consumers buy a new good every period and sell it after one period, which yields them a discounted utility of:

$$
V^{n a}(\theta)=v \theta-p_{n a}+\delta\left[p_{u a}+V^{n a}(\theta)\right]
$$

which can be expressed as:

$$
\begin{equation*}
V^{n a}(\theta)=\frac{v \theta-p_{n a}+\delta p_{u a}}{1-\delta} \tag{2}
\end{equation*}
$$

where $V$ represents the consumer's value function, $p_{n a}$ is the new good price, $p_{u a}$ is the used good price and $\delta$ is the discount rate.
Segment $2 a$ (Strategic Holders): These consumers exhibit state-dependent behavior, i.e., they buy a new good, and hold if the new good deteriorates into a peach, but sell if it deteriorates into a lemon. The discounted utility of these consumers is:

$$
V^{h a}(\theta)=v \theta-p_{\text {na }}+\underbrace{(1 / 2) \delta\left\{p_{\text {ua }}+V^{h a}(\theta)\right\}}_{\text {Lemon }}+\underbrace{(1 / 2) \delta\left\{(1+s) \theta+\delta V^{h a}(\theta)\right\}}_{\text {Peach }}
$$

Simplifying, we get:

$$
\begin{equation*}
V^{h a}(\theta)=\frac{v \theta-p_{n a}+(1 / 2) \delta p_{u a}+(1 / 2)(1+s) \delta \theta}{1-(1 / 2) \delta-(1 / 2) \delta^{2}} \tag{3}
\end{equation*}
$$

Segment $3 a$ (Cheapskates): These consumers buy used goods every period. Their discounted utility is:

$$
\begin{equation*}
V^{u a}(\theta)=\frac{w_{a} \theta-p_{u a}}{1-\delta} \tag{4}
\end{equation*}
$$

where $w_{a}$ is the consumer's expectation about the quality of used goods in the market.
Segment $4 a$ (Non-buyers): These consumers do not buy goods in any period, and get zero utility.

### 4.2.1 Solution Strategy

A producer sets the price of the new good recognizing the consumer behavior patterns delineated above ${ }^{14}$. The price determines the size of each of the segments, which in turn determine the

[^7]quantity of the new good demanded as well as the quality of the used good supplied. Our calculation of the equilibrium solution consists of the following steps:
Step 1: Taking new and used good prices as given, we calculate the marginal consumer for each of the segments described above.

Step 2: Using the market clearing condition and the fact that new good flow each period is constant in a stationary equilibrium, we calculate the new and used good prices in terms of expected used good quality and new good flow per period.

Step 3: We use segment sizes to determine the used good quality being supplied, which in equilibrium must equal the expected used good quality.

Step 4: Finally, we calculate the new good price that optimizes per-period profits for the producer.

### 4.2.2 Segment Boundaries

The marginal consumer ( $\theta_{1 a}$ ) at the boundary between the compulsive buyer and strategic holder segments is found by equating (2) and (3). This gives:

$$
\begin{equation*}
\theta_{1 a}=\frac{p_{n a}-(1+\delta) p_{u a}}{v-(1+s)} . \tag{5}
\end{equation*}
$$

The marginal consumer ( $\theta_{2 a}$ ) at the boundary between the strategic holder and cheapskate segments is found by equating (3) and (4):

$$
\begin{equation*}
\theta_{2 a}=\frac{2\left(p_{n a}-(1+\delta) p_{u a}\right)}{2 v+(1+s) \delta-(2+\delta) w_{a}} . \tag{6}
\end{equation*}
$$

Finally, the marginal consumer $\left(\theta_{3 a}\right)$ at the boundary between the cheapskate segment and the non-buyer segment is found by equating (4) to zero:

$$
\begin{equation*}
\theta_{3 a}=p_{\text {ua }} / w_{a} . \tag{7}
\end{equation*}
$$

Observe that our expressions for prices involve segment boundaries, which are themselves derived endogenously. In what follows, we derive prices and segment boundaries completely in terms of exogenous parameters, along with equilibrium profits and the optimal quantity of new goods produced.

### 4.2.3 Prices and Quantities

Denote $y_{a}$ as the producer's choice of new good output per period. In the Technical Appendix we show that in stationary equilibrium, two-thirds of the strategic holders segment buys new goods every period while one-third holds (Lemma TA2). Using this result, we can write:

$$
\begin{equation*}
\underbrace{\left(1-\theta_{1 a}\right)}_{\text {Compulsive Buyers }}+(2 / 3) \underbrace{\left(\theta_{1 a}-\theta_{2 a}\right)}_{\text {Strategic Holders }}=y_{a} \text {. } \tag{8}
\end{equation*}
$$

Market clearing requires that:

$$
\begin{equation*}
\underbrace{\left(1-\theta_{11}\right)}_{\text {Compulsive Buyers }}+(1 / 3) \underbrace{\left(\theta_{1 a}-\theta_{2 a}\right)}_{\text {Strategic Holders }}=\underbrace{\left(\theta_{2 a}-\theta_{3 a}\right)}_{\text {Cheapskates }} \text {. } \tag{9}
\end{equation*}
$$

Using equations (5), (6) and (7) and solving (8) and (9) simultaneously yields:

$$
\begin{align*}
& p_{n a}=3\left(1-y_{a}\right)(v-1-s)+\left(1-2 y_{a}\right)(1+\delta) w_{a}-\frac{12\left(1-y_{a}\right)(1+s-v)^{2}}{6 v-(1+s)(4-\delta)-(2+\delta) w_{a}},  \tag{10}\\
& p_{u a}=\left(1-2 y_{a}\right) w_{a} \tag{11}
\end{align*}
$$

Recall that compulsive buyers always sell their purchased good regardless of its quality realization, while strategic holders sell only if they realize a lemon. The average used good quality supplied by compulsive buyers is 1 while strategic holders supply an average quality of (1-s). Knowing this, we can derive the overall average used good quality supplied, and in turn, the optimal profit and per period new good output. The results are not reproduced here to save space - for future reference, we denote the optimal outputs and profits as $y^{*}{ }_{a}$ and $\pi^{*}{ }_{a s}$ respectively, and report the relevant expressions and derivations in the Technical Appendix.

### 4.3 Markets with Trade-ins

We now turn to an analysis of markets with adverse selection problems, but where the producer is able to offer trade-ins, i.e., consumers can bring in their used good as partial payment for a new good. Denote $p_{r}$ as the new good price for buyers who trade-in, and $p_{m r}$ as the new good price for buyers who do not trade-in ${ }^{15}$. The producer resells the used good at its resale market price, $p_{u r}$. We can view these prices in two ways. In one approach, producers offer two new good prices; $p_{r}$, the new good price for buyers who trade-in, and $p_{m r}$, the new good price for

[^8]buyers who do not trade-in, with the traded-in good being paid for at its resale market price of $p_{u r}$. Alternatively, producers offer a single new good price, $p_{r}$, but offer a payment ( $p_{m r}-p_{r}+p_{u r}$ ) for the traded-in good, that is higher than the price that prevails in the resale market.

In either case, trade-ins exist only if $p_{m r}-p_{r}+p_{u r} \geq p_{u r}$. Otherwise, all consumers would sell directly into the resale market. Put differently, a consumer who trades in needs to be charged a lower effective price (including the value of the traded-in good) than a buyer who does not trade-in ${ }^{16}$. As before, we delineate the four possible patterns of consumer behavior.

Segment lr (Compulsive Buyers): Since the trade-in price is lower than the non trade-in price, these consumers buy a new good every period through a trade-in, regardless of their realization of used good quality. Their discounted utility is:

$$
\begin{equation*}
V^{r}(\theta)=\frac{v \theta-p_{r}+\delta p_{u r}}{1-\delta} \tag{12}
\end{equation*}
$$

Segment $2 r$ (Strategic Holders): These consumers hold their peaches, but trade in their lemons for new goods. Their discounted utility is:

$$
V^{h r}(\theta)=v \theta-(1 / 2)\left(p_{r}+p_{m r}\right)+\underbrace{(1 / 2) \delta\left\{p_{u r}+V^{h r}(\theta)\right\}}_{\text {Lemon }}+\underbrace{(1 / 2) \delta\left\{(1+s) \theta+\delta V^{h r}(\theta)\right\}}_{\text {Peach }}
$$

Simplifying, we get:

$$
\begin{equation*}
V^{h r}(\theta)=\frac{v \theta-(1 / 2)\left(p_{r}+p_{u r}\right)+(1 / 2) \delta p_{u r}+(1 / 2)(1+s) \theta}{1-(1 / 2) \delta-(1 / 2) \delta^{2}} . \tag{13}
\end{equation*}
$$

The utility of these consumers depends on the new good quality, the used good price, and the size of $s$. Larger values of $s$ increase the utility from holding peaches. Intuitively, buying a new good that deteriorates stochastically includes the option of holding a peach. Thus, the higher the $s$, the higher the value of this option. The new good price is effectively (1/2) $\left(p_{r}+p_{m r}\right)$ because these consumers trade-in lemons (and pay a price $p_{r}$ for the new good), but hold peaches (subsequently paying $p_{m r}$ for a new good), and these two events have an equal likelihood of happening.
Segment $3 r$ (Cheapskates): These consumers buy a used good every period. Their discounted utility is:

[^9]\[

$$
\begin{equation*}
V^{u r}(\theta)=\frac{w_{r} \theta-p_{u r}}{1-\delta} \tag{14}
\end{equation*}
$$

\]

Segment $4 r$ (Non-buyers): These consumers do not buy in any period, and get zero utility.

### 4.3.1 Segment Boundaries

The marginal consumer ( $\theta_{1 r}$ ) located at the boundary of the compulsive buyer and strategic holder segments is indifferent between buying a new good every period versus buying a new good and holding on to it, if it is a peach. Equating (12) and (13), we have:

$$
\begin{equation*}
\theta_{1 r}=\frac{p_{m r}+(1+\delta)\left(-p_{r}+\delta p_{u r}\right)}{\delta(1+s-v)} \tag{15}
\end{equation*}
$$

Similarly, the marginal consumer $\left(\theta_{2 r}\right)$ located at the boundary between the strategic holder and cheapskate segment is found by equating (13) and (14). It is important to note that while one would observe strategic holders displaying a variety of behaviors, they all follow the same decision rule. We will observe a certain fraction holding on to their peaches, another fraction buying new goods by trading in lemons, and the remainder buying new goods after scrapping their previously held peaches ${ }^{17}$. Equating equations 13 and 14 , we get:

$$
\begin{equation*}
\theta_{2 r}=\frac{p_{r}+p_{m r}-2(1+\delta) p_{u r}}{(1+\delta) s+2 v-(2+\delta) w_{r}} \tag{16}
\end{equation*}
$$

Finally, the marginal consumer $\left(\theta_{3 r}\right)$ at the boundary between the cheapskate and nonbuyer segments is obtained by equating (14) to zero:

$$
\begin{equation*}
\theta_{3 r}=p_{u r} / w_{r} . \tag{17}
\end{equation*}
$$

### 4.3.2 Prices and Quantities

Let $y_{r}$ be the optimal flow of new goods every period (determined by the producer's optimization problem). Again using the result (Lemma TA2) that two-thirds of the strategic holders segment buys new goods every period while one-third holds, we have:

$$
\begin{equation*}
\underbrace{\left(1-\theta_{1 r}\right)}_{\text {Segment }-1 r}+(2 / 3) \underbrace{\left(\theta_{1 r}-\theta_{2 r} r\right.}_{\text {Segment }-2 r})=y_{r} . \tag{18}
\end{equation*}
$$

[^10]Market clearing requires that:

$$
\begin{equation*}
\left(1-\theta_{1 r}\right)+(1 / 3)\left(\theta_{1 r}-\theta_{2 r}\right)=\left(\theta_{2 r}-\theta_{3 r}\right) . \tag{19}
\end{equation*}
$$

Using equations (15), (16) and (17), and solving (18) and (19) simultaneously yields expressions for new and used good prices. As before, we solve for used good quality by equating buyers' expected used good quality with used good quality supplied. For reasons of space, we relegate these expressions to the Technical Appendix. Given these expressions for prices and used good quality, we solve the producer's per-period profits. Maximizing these profits with respect to $p_{r}$ and $p_{m r}$ leads to our equilibrium solutions in Table $3^{18}$. Our results can be stated in the form of the following propositions.

Proposition 1: In stationary equilibrium, when a producer accepts trade-ins, he will charge a new good price of $p_{r}$ to consumers who trade-in and a new good price of $p_{m r}>p_{r}$ to consumers who do not trade-in.

The thrust of this proposition is that the producer gives an incentive to consumers who buy a new good with a trade-in. We refer to this incentive as a 'trade-in discount'. Formally, this discount is the difference between the price paid by consumers who buy a new good without trading-in and those who buy with a trade-in, i.e., $p_{m r}-p_{r}{ }^{19}$.

We consider the intuition for this result by comparing worlds with and without trade-ins. In each case, consider the case of positive quality uncertainty (i.e., $s>0$ ). This uncertainty, coupled with the fact that quality is revealed only through use, and only to the user, gives rise to the adverse selection (lemons) problem. How exactly does adverse selection impact consumer behavior in our model, and how do trade-ins modify this behavior? Understanding this is the key to comprehending the role of trade-ins.

First, note that as quality uncertainty increases, the peach is a better peach and the lemon is a worse lemon. Buying the new good confers an option value on the buyer - the more alluring the peach, the greater the value of the option. This tempts consumers to hold - recall that in our model, the strategic holder segment comprises consumers who hold if the realization is a peach, and sell if it is a lemon. This causes the segment of strategic holders to expand. This expansion

[^11]comes at the expense of both the compulsive buyers (who buy new every period) and the cheapskates (who buy used every period). There are now fewer compulsive buyers, because the utility from a better peach is enough to tip some consumers over to the holders segment. There are also fewer cheapskates, because the quality of used goods being offered for sale is lower; the lemons are worse.

All of the above is true both with and without trade-ins. Trade-ins help ameliorate the problem caused by adverse selection, by providing an extra wedge to help shrink the size of the strategic holders segment. This is accomplished by charging a relatively higher price to consumers who buy new without trading in, compared to consumers who buy new with a tradein. This has the effect of discouraging consumers from holding on to their used good. Figure 1 illustrates the impact of trade-ins on the size of the strategic holders segment, for any given level of $s$. Observe that the trade-in regime always has a smaller strategic holders segment than the regime without trade-ins. Looking at Figures 2 and 3, note also that the compulsive buyer and cheapskate segments are larger with trade-ins than without. This is a counterpart to the fact that the strategic holders segment is smaller with trade-ins.

In summary, trade-ins work by squeezing the strategic holders segment from both sides, i.e., by expanding the size of both the compulsive buyers and the cheapskates segments. Figure 4 summarizes the above discussion by illustrating segment sizes under both trade-in and no tradein regimes. So far we have derived the producer's optimal prices and quantities and discussed consumer behavior in the presence and absence of trade-ins. We now turn to characterizing the effect of exogenous parameters on equilibrium outcomes.

### 4.3.3 The Effects of Quality Uncertainty (s)

Impact on Trade-In Discount: Mathematically, the trade-in discount is the difference between the price paid by consumers who buy a new good without trading-in and those who buy with a tradein, and is the basis of the producer's policy of price discrimination. As discussed earlier, a larger $s$ increases the option value of holding. Trade-ins help discourage this behavior, by using the trade-in discount as a wedge to separate consumers who trade-in from those who don't. Clearly, as quality uncertainty increases, the producer has to do more to price discriminate, i.e., he has to offer a larger discount. The proposition below states this formally.

Proposition 2: As the quality uncertainty of used goods increases, the trade-in discount increases.

Impact on Volume of Used Good Trade: Adverse selection is essentially a friction in the marketplace, leading to the lowering of used good transactions. In Akerlof's original model, the friction is enough to shut the market down entirely. In our case, the market still functions, and it is of interest to see what factors impact the number of transactions of used goods that take place, and how. Holding behavior would clearly reduce the volume of trade. As outlined earlier, a higher $s$ leads to a larger segment of potential holders. While all compulsive buyers sell back used goods irrespective of quality realization, potential holders keep the peaches. Hence a larger potential holder segment (a consequence of larger $s$ ) would imply more consumers holding on to their cars, thus decreasing the volume of trade in the used good market. Formally:
Proposition 3: As the quality uncertainty increases, the volume of trade in the used good market decreases.

Impact on Prices and Quality: When no trade-ins are offered, the new good price goes down with $s$ (intuitively, the new good price is partly determined by the used good price, and with higher quality uncertainty, the used good price falls). With trade-ins, we can no longer make an unambiguous claim of this kind. Figure 5 shows new good prices with and without trade-ins. The new good price goes down for some customers (those who trade-in), but it increases for other customers (those who do not trade-in).

As regards used good prices, clearly one would expect used good prices to go down as quality uncertainty increases, regardless of the regime. This is a result that was first shown by Akerlof, and follows directly from the fact that under conditions of adverse selection, increasing quality uncertainty leads to a worsening of the quality of used goods being traded, which is reflected in a lower price. Equivalently, one can think in terms of the quality of used goods supplied, as quality uncertainty increases. Whether in a regime of trade-ins or not, used goods come from two sources - all compulsive buyers, and strategic holders who realize a lemon. We have already discussed how, as quality uncertainty increases, the option value of holding on to the good increases. In other words, the compulsive buyer segment shrinks while the
strategic holder segment expands. Given the latter only sells lemons, the expected quality of used goods inevitably declines ((see Figures 6 and 7). Formally:

Proposition 4a: The (expected) quality of used goods decreases as quality uncertainty increases. Proposition 4b: The price of used goods decreases as quality uncertainty increases.

### 4.3.4 The Effects of Deterioration

Recall that a new good provides a first period quality of $v>1$, while a used good provides a second period quality of 1 , and a quality of 0 thereafter. Thus, a larger $v$ represents a steeper deterioration rate.

Impact on Trade-In Discount: A higher $v$ makes a used good a poorer substitute for a new good. This has a direct impact on the incentive to hold, because the option value of holding decreases. In terms of segment size, the strategic holder segment shrinks, because even the prospect of a peach is not alluring enough (see Figure 8). Consumers on the boundary adjoining the compulsive buyer segment 'defect' to becoming compulsive buyers, which expands that segment (see Figure 9). Interestingly, a steeper depreciation thus counteracts the effect of increased adverse selection; even a very good peach provides quality that is quite far removed from that provided by a new good. In practical terms, this means that the producer has to worry less about making consumers buy new instead of holding. We therefore expect the trade-in discount to go down with a steeper decline in new good quality. This is stated formally below.

Proposition 5: The steeper the deterioration rate, the smaller the trade-in discount.

Impact on Volume of Used Good Trade: As discussed above, with increasing deterioration the strategic holder segment shrinks, while the compulsive buyer segment expands. This effectively means that more cars are released into the used good market, implying a higher volume of trade. This leads to the next proposition, which applies to both trade-in and no trade-in regimes:

Proposition 6: The steeper the deterioration rate, the higher the volume of trade in the used good market.

Impact on Quality: With increasing deterioration, a used good is a poorer substitute for a new good. As before, a higher deterioration leads to a shrinking of the strategic holder
segment, and an expansion of the compulsive buyer segment. This increases the quality of used goods, because compulsive buyers sell a car regardless of whether it turns out to be a peach or a lemon, while strategic holders sell only lemons. Therefore, the proportion of peaches in the used good market increases as the compulsive buyer segment expands and the strategic holder segment shrinks.

Proposition 7: The steeper the deterioration rate, the higher the (expected) quality of used goods.

## 5. EMPIRICAL STUDY

### 5.1 Empirical Research Context and Hypotheses Tested

We use the automobile market to test our hypotheses, as it fits the assumptions of our model. Automobiles are durable products that deteriorate with age, and are characterized by steady improvements rather than abrupt changes in technology. There are active resale markets for used goods, and virtually all producers accept trade-ins. Table 1 describes the extent of tradeins for some common makes of vehicles.

There are an enormous variety of vehicles in the marketplace, so we need to define our unit of analysis carefully. Following past work (e.g., Goldberg 1996), we define our unit of analysis as a make-model combination (e.g., Ford Taurus, Toyota Camry, etc.). Given our need to observe new and used vintages of the same make-model, we require data over time. To this end, we selected a four-year window (1999-2002) for our observations. Notice that the transactions for used automobiles within this period include vintages prior to 1999, so we track all the vintages of all transacted vehicles. We also need to control for year-specific shocks that might affect all vehicle transactions.

Finally, our theoretical model yielded effects across regimes as well as within-regime. Since all automobile producers accept trade-ins, we restrict our attention to the within-regime comparisons. The specific hypotheses to be tested are stated below. In each instance, we note the model result that yielded the hypothesis. In what follows, and presaging the variable construction, we state our hypotheses in terms of reliability, which is the inverse of quality uncertainty.

Hypothesis 1: The net price paid by buyers who purchase with a trade-in is lower than the net price paid by buyers who purchase without a trade-in. (Proposition 1).
Hypothesis 2: The size of the trade-in discount decreases with the reliability of the vehicle.
(Proposition 2).
Hypothesis 3: The size of the trade-in discount decreases for vehicles with a steeper deterioration rate. (Proposition 5).

Hypothesis 4: The volume of trade in the used good market increases for vehicles with greater reliability. (Proposition 3)
Hypothesis 5: The volume of trade in the used good market increases for vehicles with a steeper deterioration rate. (Proposition 6).

### 5.2 Empirical Specification

We formulate econometric tests of the hypotheses by estimating a reduced form equation for each of the two dependent variables (price and volume of trade). We employ the simplest reduced form equations consistent with our refutable implications.
Price Specification: Our three hypotheses about the trade-in discount (H1, H2, H3) are tested with the following equation for household $i$ for new vehicle $j$ in year $t$ :

$$
\begin{align*}
P_{i j t}= & \beta_{0 j}+\beta_{1} \text { TradeIn }_{i j t}+\beta_{2} \text { Reliability }_{j t}+\beta_{3} \text { Deterioration }_{j t}+\beta_{4}\left(\text { TradeIn }_{i j t} * \text { Reliability }_{j t}\right) \\
& +\beta_{5}\left(\text { TradeIn }_{i j t} * \text { Deterioration }_{j t}\right)+\boldsymbol{\eta} \mathbf{H}_{i t}+\boldsymbol{\lambda} \mathbf{Z}_{j t}+\boldsymbol{\delta} \mathbf{X}_{t}+\varepsilon_{i j t}, \tag{20}
\end{align*}
$$

where the variables are defined as follows:
$P_{i j t}$ : Price paid by household $i$ for vehicle $j$ at year $t$
TradeIn $_{i j t}$ : Dummy variable indicating whether the new purchase by household $i$ involved a trade-in

Reliability $_{j t}$ : Reliability rating for vehicle $j$ in year $t$
Deterioration $_{j t}$ : Deterioration rate for vehicle $j$ in year $t$
$\mathbf{H}_{i t}$ : Vector of characteristics of household $i$
$\mathbf{Z}_{j t}:$ Vector of characteristics of vehicle $j$
$\mathbf{X}_{t}$ : Vector of year dummy variables
The relevance of the various independent variables is as follows. The trade-in dummy
variable follows directly from Hypothesis 1 - the hypothesis would be supported by a negative coefficient $\left(\beta_{1}<0\right)$. The reliability variable follows directly from Hypothesis 2 , and corresponds to a positive coefficient of the interaction of reliability with the trade-in dummy $\left(\beta_{4}>0\right){ }^{20}$.

The deterioration variable follows directly from Hypothesis 3, which held that the size of the trade-in discount diminishes with greater deterioration. This effect corresponds to a positive coefficient of the interaction of deterioration with the trade-in dummy $\left(\beta_{5}>0\right)$.

In addition to these hypothesized effects, the randomly varying coefficient $\beta_{0 j}$ captures unobserved effects of the make-model of the vehicle, and is assumed to be distributed as $\mathrm{N}(\beta$, $\sigma_{\beta j}^{2}$ ). The vector of household characteristics, $\mathbf{H}$, is included to control for price effects arising from bargaining differences across households and possible discriminatory effects facing minority and female heads of households that have been documented in previous studies (e.g., Goldberg 1996). The vector of vehicle characteristics, $\mathbf{Z}$, is included to control for price differences arising from the differences in trim levels within a make-model. Finally, the vector of year dummies, $\mathbf{X}$, is included to control for year-specific shocks that impact the automobile industry.

Volume of Used Good Trade Specification: The hypotheses about the volume of used good trade $(\mathrm{H} 4, \mathrm{H} 5)$ are tested with the following equation for used vehicle $j$ in year $t$ :

VOT $_{j t}=\gamma_{0 j}+\gamma_{1}$ Reliability $_{j t}+\gamma_{2}$ Deterioration $_{j t}+\boldsymbol{\varsigma} \mathbf{X}_{t}+\varepsilon_{i j t}$.
where the variables are defined as follows:
$V O T_{j t}$ : Volume of trade for used vehicle $j$ in year $t$
Reliability $_{j t}$ : Reliability rating for vehicle $j$ in year $t$
Deterioration $_{j t}$ : Deterioration rate for vehicle $j$ in year $t$
The relevance of the independent variables is as follows. The reliability variable follows directly from Hypothesis 4 , which would be supported by a positive coefficient ( $\gamma_{1}>0$ ). The deterioration variable follows directly from Hypothesis 5, which would be supported by a positive coefficient ( $\gamma_{2}>0$ ). In addition to these hypothesized effects, we control for unobserved effects of the make-model with the randomly varying coefficient $\gamma_{0 j}$, which is assumed to be
distributed as $\mathrm{N}\left(\gamma, \sigma^{2}{ }_{\gamma j}\right)$. We include the vector of year dummies, $\mathbf{X}$, to control for year-specific shocks that impact the auto industry. Notice, however, that we do not include the household characteristics vector, as this equation is aggregated across households.

### 5.3 Data and Measures

### 5.3.1 Data Sources

We assembled information from three different sources to construct our sample of observations. These are a) Consumer Expenditure Survey (CES) conducted by the Bureau of Labor Statistics, b) the Kelly Blue Book (KBB) complied by a private industry source, and c) Consumer Reports magazine. We describe each of these sources below.

The Bureau of Labor Statistics maintains the CES panel to construct the Consumer Price Index. As such, it is a very comprehensive survey that is implemented as follows. Each quarter, detailed interviews are conducted with 4500 randomly selected households to gather information about their expenditures covering a large number of areas. We confine our attention to the section on automobile purchases. Each quarter, $25 \%$ of households are dropped from the sample and replaced with new members. We use CES data from 1999-2002 for our analysis.

Each CES observation in the automobile ownership section of the survey includes information about the brand, the model year, the purchase year and month, and various household demographic variables. The make-model of any vehicle traded-in is also recorded, along with its odometer reading and other trim level details. As shown below, this source is used for most of the variables for our study.

Our second source of data is the annual issues of Kelly Blue Book, which is a syndicated data source that assembles price information for various models and vintages of automobiles derived from auctions and other dealer-dealer transactions. It is widely used in the auto industry to provide benchmark resale prices. We use this source to compute our deterioration rate measure.

Our third source of data is annual issues of Consumer Reports, which is a widely respected magazine that collects and publishes a wide variety of performance and reliability information on a variety of consumer products. We use this source to construct our vehicle reliability measure.

### 5.3.2 Measures

Equations 20 and 21 involve price paid (new, with and without trade-in), vehicle reliability, deterioration rate, and volume of used trade. We discuss below the construction of the measures of these constructs. Table 4 summarizes the descriptive statistics for our sample.

Price: This is the net price paid for the new automobile. For those transactions without a trade-in, the net price (net of all discounts) is taken directly from the CES data. However, constructing the corresponding measure for transactions with a trade-in is more complicated. In principle, we need to add the market value of the traded-in vehicle to the cash paid to the seller of the new automobile. The CES includes a "trade-in allowance", but this number is an accounting entity recorded during the transaction, and there are several reasons to suspect that it deviates from the arms length resale price for the traded-in vehicle. First, it is not a cash quantity, and thus can be manipulated by the dealer. Second, we conducted interviews with car dealers that confirmed our intuition that these accounting entries are influenced by a number of factors, including the dealer's desire to meet the owner's often inflated valuation of their asset ${ }^{21}$.

As such, we construct our net price measure for trade-in transactions by combining the CES net price and the "Private Party Value" shown in the KBB data for the make-model and vintage of the traded-in vehicle. KBB describes this number as the price a consumer can expect to get in an arms-length resale transaction. The net price paid (from CES) + private party value of the traded-in vehicle (from KBB) is our measure of the net price.

Trade-in: A dummy variable indicating whether the transaction involved a trade-in is recorded directly in the CES data.

## Reliability: We use reliability as a reverse-coded measure of $s$. Following Desai and Purohit

 (1999), we use the 1-5 rating reported by Consumer Reports for the make-model of vehicle for the purchase year. A higher number indicates a more reliable car. Consumer Reports constructs this measure from reader surveys and its own in-house tests.[^12]Deterioration: We operationalize the deterioration rate of a vehicle as the ratio of the per-period quality of a new good $(v)$ to the expected per-period quality of a used good (normalized to 1 ). The construct embodies deterioration along all relevant quality dimensions, including functional quality and aesthetic quality, so we seek a comprehensive measure. To accomplish this, we capitalize on the fact that the per-period quality of a durable good in equilibrium is given by its implicit rental price. In other words, if a durable good is purchased at price $p$, used for one period and sold at the end of that period at a price $p_{u}$, then $\left(p-p_{u}\right)$ is directly related to the per-period quality of the good during the period of consumption (ignoring discounting). Following Porter and Sattler (1999), we construct our measure of the deterioration rate for a make-model from the pattern of prices as $\left(p_{j 1 t}-p_{j 4 t}\right) /\left(p_{j 4 t}-p_{j 7 t}\right)$, where $p_{j k t}$ is the price of vehicle $j$, aged $k$ years at time $t$. The numerator is the quality of a "newer" vehicle (aged 1 to 4 years) while the denominator is the quality of an "older" vehicle (aged 4 to 7 years). The higher this number, the greater the rate of deterioration ${ }^{22}$. Each of the numbers required to compute this measure is obtained from KBB.

Volume of Used Good Trade (VOT): We construct our measure (VOT) with the following data from the CES survey:

$$
V O T_{j t}=\frac{\left(\text { Used Purchases }_{j t}+\left(\text { Used Sales }_{j t}+(\text { Used Trade }-i n s)_{j t}\right.\right.}{(\text { Total Stock })_{j t}}
$$

where $j$ is a particular make-model and $t$ is the year of observation. Each of the numbers required to compute the VOT measure is the sample aggregate of the individual household observations. The numerator represents the total number of transactions of a particular make-model $j$ in year $t$, including purchases, outright sales, and trade-in sales. The denominator represents the total available stock of the particular make-model in the sample, and serves to adjust for the huge differences in the stocks of different make-models. The measure lies between 0 and 1, with a higher number representing a greater volume of trade.
Vehicle Characteristics: We control for the effects of vehicle characteristics on prices by employing variables for the following data recorded in the CES: a) Make-Model, b) Airconditioning, c) Auto-transmission, d) Front-wheel drive, and e) Sunroof. Plainly, a much larger

[^13]set of possible characteristics might be used, but these are similar to those used in previous work (e.g, Goldberg, 1996). Of these, the make-model dummy variable is noteworthy, as it is used to control for unobserved effects with the random effects specification described earlier.
Customer Characteristics: Given prior empirical evidence of possible price discrimination in the automobile market based on observed customer demographics (Ayers and Siegelman 1995; Goldberg 1996; Scott Morton et al. 2003), we include variables for household income, female head of household, and minority head of household.
Year Dummies: We seek to control for industry-wide effects that might influence new as well as used prices. To this end, we use a set of calendar year dummies to control for the year of the transaction.

### 5.4 Results

Tables 5 a and 5 b report the results of the estimation of the price and volume of trade equations respectively. Note at the outset that unobserved make-model effects are significant in both regressions (random effect $=3568.43$ and 0.168 respectively, $\mathrm{p}<0.01$ ). We turn now to the hypotheses tests embedded in the price (H1, H2, H3) and VOT (H4, H5) equations respectively.

Hypothesis 1: The trade-in coefficient from the price equation supports our hypothesis ( $\beta_{1}=$ $-4155.5, \mathrm{p}<0.01$ ) of a positive trade-in discount. The net price paid by buyers who purchase with a trade-in (including the value of the traded-in car surrendered) is significantly lower than the net price paid by buyers who purchase the identical new car without a trade-in. This is the fundamental prediction of our model. We examine the magnitude of this discount as follows. The net price paid for a new automobile by a buyer is:

$$
\begin{align*}
& \text { Net Price }=\beta_{1}(\text { Trade-in Dummy })+\beta_{2}(\text { Reliability })+\beta_{3}(\text { Deterioration })+\beta_{4}(\text { Trade-in Dummy* } \\
& \quad \text { Reliability })+\beta_{5}(\text { Trade-in Dummy } \tag{22}
\end{align*}
$$

where $\Delta$ is an omnibus term representing the rest of the estimation equation. The prices in the two types of transactions and the difference are computed from the estimates as follows: Without Trade-in Net Price $=-695.0943 *($ Reliability $)-524.0247 *($ Deterioration $)+\Delta$

With Trade-in Net Price $=-4155.4685-695.0943 *($ Reliability $)-524.0247 *($ Deterioration $)+$

$$
\begin{align*}
& 73.5826 *(1 * \text { Reliability })+1191.3930 *(1 * \text { Deterioration })+\Delta  \tag{24}\\
& \text { Trade-In Discount } \equiv(\text { Without Trade-in })-(\text { With Trade-in })=4155.4685- \\
& 573.5826 *(1 * \text { Reliability })-1191.3930 *(1 * \text { Deterioration }) \tag{25}
\end{align*}
$$

At the sample average value of reliability (3.38) and deterioration (1.32), we get a tradein discount of $\$ 644.21$, which is approximately $3 \%$ of the average price paid for new vehicles in our data. This is a managerially significant quantity, and speaks to the importance of the trade-in program to the producer.

Hypothesis 2: The positive reliability coefficient from the price equation supports the hypothesis that an increase in reliability leads to a fall in the trade-in discount $\left(\beta_{4}=573.5826, \mathrm{p}<0.01\right)$. The managerial significance of the need to soften the adverse impact of low reliability in a lemonsprone resale market is illustrated by comparing the discounts for low versus high reliability make-models.

The trade-in discount size is computed as $[-4155.4685+573.5826 *(1 *$ Reliability $)+$ 1191.3930*(1*Deterioration)] from our estimated price equation. At the sample average value of deterioration, this reduces to $\left[-2582.83+573.5826^{*}\left(1^{*}\right.\right.$ Reliability $\left.)\right]$. For a vehicle with low reliability (one unit below the sample average) and average deterioration, the estimated discount is $\$ 1,217.70$, while for a vehicle with high reliability (one unit above the sample average) the equivalent discount is only $\$ 70.53^{23}$. From our results, we see that greater reliability confers two advantages to the producer of that make-model. First, consumers are obviously willing to pay more for the new vehicle. Also, such vehicles suffer less from the lemons problem in the used market, so a smaller trade-in discount suffices as well, which increases the producer's profit.

Hypothesis 3: This hypothesis is the counterpart of hypothesis 2 for the deterioration rate, i.e., an increase in the deterioration rate reduces the size of the trade-in discount. The positive coefficient of the deterioration variable in the price equation supports this hypothesis ( $\beta_{5}=$ 1191.3930, $\mathrm{p}<0.05$ ).

[^14]The managerial impact of deterioration is also quite large. For vehicles with a greater deterioration rate (a standard deviation above the mean), the discount shrinks to $\$ 155.65$, while this expands to $\$ 1,251.73$ for vehicles with a smaller deterioration rate (a standard deviation below the mean).

Hypothesis 4: The hypothesis that the volume of used good trade for a make-model increases with reliability is supported $\left(\gamma_{1}=0.0128, \mathrm{p}<0.01\right)$.

Hypothesis 5: The hypothesis that the volume of used good trade for a make-model increases with the deterioration rate is supported $\left(\gamma_{2}=0.0418, \mathrm{p}<0.01\right)$.

We note that the joint support for H 4 and H 5 speaks to the countervailing pressures on the producer to intervene in the marketplace for used cars. From H4, we see that the lemons problem hurts the efficiency of the resale market, which pushes producers to intervene, whereas H5 shows that reduced cannibalization (greater deterioration) from used goods pushes producers to leave the used market alone.

## 6. CONCLUSIONS

This paper sought to examine the familiar practice of accepting trade-ins in durable goods markets. In particular, we sought to understand this practice in markets where durables deteriorate over time, and where the owners of these goods know their quality levels better than prospective buyers in the used market (the lemons problem). Under these circumstances, customers hold on to their goods because of the inefficient prices induced in the used market.

Past explanations for trade-ins have turned primarily on cannibalization and commitment issues. Deliberately reducing the quantity of used goods for resale minimizes cannibalization and enables producers to commit to price skimming policies. Trade-in programs operate differently in our work. Offering a new good discount for the trade-in transaction induces some owners to turn in their goods rather than to hold them. In effect, this increases the average quality of used goods offered for resale, which softens the negative impact of the lemons problem. In fact, in the absence of adverse selection, trade-ins play no efficiency-enhancing role.

From a broader theory standpoint, our results speak to the adverse selection issue in durable goods markets. Warranties, brand names and reputations are the traditional signaling tools used to address the adverse selection problem. Unlike these forms of "burning money", our work shows that trade-in programs are uniquely useful in attacking this problem in durable goods markets. They increase resale market efficiencies as witnessed by the increase in the volume of used good trade.

We hasten to add that despite the enhanced efficiency of resale transactions, trade-ins are a mixed blessing, because the prices of new goods are increased for those consumers who do not trade-in. At its core, a trade-in program involves price discrimination with its usual ambiguous effects on overall welfare. Thus, public policy skepticism about a producer's interventions in resale markets is not excluded by our analysis.

Our analysis also speaks to managers regarding the introduction and proper design of trade-in programs. First of all, our analysis shows that producers in durable goods market should consider trade-in programs as a matter of routine. Despite cannibalization concerns arising from a more active resale market, a producer's profits will inevitably rise from introducing trade-ins because the lemons problem is so pervasive.

The proper design and size of the discount serves to strengthen the case for trade-ins. We gain some sense of the size and structure of a trade-in program by looking at our estimates from the car data. Recall that consumers got an average trade-in discount of $\$ 644$, or about $3 \%$ of the purchase price of a new good. These discounts were substantially larger $(\$ 1,217)$ for less reliable models, as well as for models that deteriorated more slowly ( $\$ 1,251$ ). The competitive advantages to be captured from these strategies are obvious.

We close with some thoughts on directions for future research. Incorporating trade-ins into a world where a durable asset lasts more than two periods (Stolyarov 2002) would provide for richer substitution patterns among vintages of various ages. Another avenue for future research is to model producer competition to examine the strategic role of trade-ins. For instance, would producers offer trade-ins to induce customers to switch brands? Third, our model structure was chosen with a view to abstracting away from commitment problems faced by the firm. It would be useful to consider a model where commitment problems are relevant, and examine the relative efficacy of trade-ins versus other market mechanisms, such as leasing, in
ameliorating this problem. Finally, consumers display endowment effects and related framing phenomena when they act as sellers. Embedding a richer model of consumers alongside our profit-maximizing producer could yield insights into the market level consequences of these behavior patterns.

Table 1: Trade-ins in the US Automobile Market

| Make | Percentage of Purchases with Trade-ins |
| :--- | :--- |
| Toyota | 12.90 |
| Honda | 18.70 |
| Ford | 19.56 |
| GMC | 28.85 |
| Pontiac | 26.32 |
| Hyundai | 26.53 |

Source: Consumer Expenditure Survey (1999-2002)

Table 2: Pay-off Matrix for a consumer of type $\theta$

|  | $n^{t-1}(\theta)$ | $h^{t-1}{ }_{p}(\theta)$ | $h^{t-1}(\theta)$ | $u^{t-1}(\theta)$ | $i^{t-1}(\theta)$ |
| :--- | :--- | :--- | :--- | :--- | :--- |
| $n^{t}(\theta)$ | $v \theta-p_{\text {na }}+p_{\text {ua }}$ | $v \theta-p_{\text {na }}$ | $v \theta-p_{\text {na }}$ | $v \theta-p_{\text {na }}$ | $v \theta-p_{\text {na }}$ |
| $h_{p}^{t}(\theta)$ | $(1+s) \theta$ | - | - | - | - |
| $h_{l}^{t}(\theta)$ | $(1-s) \theta$ | - | - | - | - |
| $u^{t}(\theta)$ | $w_{a} \theta$ | $w_{a} \theta-p_{\text {ua }}$ | $w_{a} \theta-p_{\text {ua }}$ | $w_{a} \theta-p_{\text {ua }}$ | $w_{a} \theta-p_{\text {ua }}$ |
| $i^{t}(\theta)$ | $p_{\text {ua }}$ | 0 | 0 | 0 | 0 |

Table 3: Analytical Results (Markets with Trade-ins)

| Variable | Result |
| :--- | :--- |
| New Good <br> Price $\left(p_{r}\right)$ | $\frac{s^{4}-36 s(v-1)(1+v)(3+v)+16(v-1)^{2}(1+v)+s^{3}(21+5 v)+16 s^{2}(5+v(4+v))}{(4+5 s-4 v)\left(s^{2}+8 s(3+v)-8(v-1)(3+v)\right.}$ |
| New Good <br> Price $\left(p_{m r}\right)$ | $\frac{s^{3}-4(v-1)(1+v)(3+v)+s^{2}(19+3 v)+2 s\left(15+v^{2}\right)}{s^{2}+8 s(3+v)-8(v-1)(3+v)}$ |
| Used Good <br> Price $\left(p_{u r}\right)$ | $\frac{\left(16+16 s+s^{2}-16 v\right)(4+s(5+s)-4 v)}{(4+5 s-4 v)\left(s^{2}+8 s(3+v)-8(v-1)(3+v)\right)}$ |
| Used Good <br> Quality <br> $\left(w_{r}\right)$ | $1-\frac{s^{2}}{4 v-4-4 s}$ |
| Output $\left(y_{r}\right)$ | $\frac{36(1+s-v)(1+v)}{9 s^{2}+4(44+4 v+2(5+7 v))(s+1-v)}$ |
| Compulsive | $\frac{2(2 v-2-3 s)(1+v)}{8(v-1)(3+v)-8 s(3+v)-s^{2}}$ |
| Buyers |  |
| Strategic |  |
| Holders | $\frac{3 s(1+v)}{8(v-1)(3+v)-8 s(3+v)-s^{2}}$ |
| Cheapskates | $\frac{(4 v-4-5 s)(1+v)}{8(v-1)(3+v)-8 s(3+v)-s^{2}}$ |
| Non-Buyers | $\frac{16 v-16-16 s-s^{2}}{8(v-1)(3+v)-8 s(3+v)-s^{2}}$ |
| Profits $\left(\pi_{r}\right)$ | $\frac{18(1+s-v)(1+v)^{2}}{9 s^{2}+4(44+4 v+2(5+7 v))(s+1-v)}$ |

Table 4: Data Description

| Variable | Description | Data Source | Mean | Standard Deviation |
| :---: | :---: | :---: | :---: | :---: |
| Price | Final new vehicle price paid in a transaction net of all discounts (\$) | CES and KBB | 22444.9 | 5240.6 |
| VOT | Volume of trade (Number of used goods traded as a fraction of total stock of a make-model in a year) | CES | 0.146 | 0.043 |
| Reliability | Expected used good reliability of a new vehicle | Consumer <br> Reports | 3.38 | 1.41 |
| Deterioration | Deterioration measure for a new vehicle constructed using used good price series | KBB | 1.32 | 0.41 |
| Trade-In | Dummy indicating if transaction involved a trade-in | CES | 0.15 | 0.36 |
| AutoTrans | Dummy indicating if vehicle has automatic transmission | CES | 0.89 | 0.32 |
| AirCondition | Dummy indicating if vehicle has airconditioning | CES | 0.97 | 0.15 |
| SunRoof | Dummy indicating if vehicle has a sunroof | CES | 0.19 | 0.39 |
| FrontWheel | Dummy indicating if vehicle has a front wheel drive | CES | 0.14 | 0.35 |
| Income | Income bracket in which household falls | CES | 6.00 | 3.71 |
| Female | Dummy indicating if household head is a female | CES | 0.37 | 0.48 |
| Minority | Dummy indicating if household head belongs to a minority group | CES | 0.13 | 0.34 |
| Yr1999 | Dummy indicating if purchase was made in 1999 | CES | 0.26 | 0.44 |
| Yr2000 | Dummy indicating if purchase was made in 2000 | CES | 0.27 | 0.44 |
| Yr2001 | Dummy indicating if purchase was made in 2001 | CES | 0.21 | 0.41 |
| Yr2002 | Dummy indicating if purchase was made in 2002 | CES | 0.20 | 0.40 |

Table 5a: Net Price Estimates (Equation 19)

| Variable | Estimate | Std. Error |
| :--- | :--- | :--- |
| Random Intercept | $\mathrm{E}\left(\beta_{0 j}\right)=23336.1694^{* *}$ | 1240.6003 |
| Trade-in Dummy $\left(\beta_{1}\right)$ | $-4155.4685^{* *}$ | 774.0595 |
| Reliability $\left(\beta_{2}\right)$ | $-695.0943^{* *}$ | 165.9453 |
| Deterioration $\left(\beta_{3}\right)$ | $-524.0247^{* *}$ | 171.9141 |
| Trade-in Dummy*Reliability $\left(\beta_{4}\right)$ | $573.5826^{* *}$ | 125.7830 |
| Trade-in Dummy*Deterioration $\left(\beta_{5}\right)$ | $1191.3930^{*}$ | 467.6876 |
| AutoTransmission | $969.7682^{* *}$ | 202.1307 |
| AirCondition | $-836.8827^{*}$ | 400.6056 |
| SunRoof | $1420.4021^{* *}$ | 169.5663 |
| FrontWheel | $3321.3789^{* *}$ | 206.5456 |
| Income | $41.9266^{*}$ | 17.0757 |
| Female | $-381.2715^{* *}$ | 131.2184 |
| Minority | 276.4398 | 184.7578 |
| Yr1999 | $1405.1186^{* *}$ | 168.5566 |
| Yr2000 | $717.0227^{* *}$ | 178.4980 |
| Yr2001 | $1418.952^{* *}$ | 189.2084 |
| Yr2002 | $2165.0335^{* *}$ | 315.6115 |
| Number of Observations | 490 |  |

## Note:

1. $* * \mathrm{p}<0.01 \quad * \mathrm{p}<0.05$
2. Random Effects regression with White heteroskedasticity consistent covariance matrix.
3. Adjusted $\mathrm{R}^{2}=0.598$

Table 5b: Volume of Trade Regression (Equation 20)

| Variable | Estimate | Std. Error |
| :--- | :--- | :--- |
| Random Intercept | $\mathrm{E}\left(\gamma_{0 \mathrm{j}}\right)=0.0614^{* *}$ | 0.0092 |
| Reliability $\left(\gamma_{1}\right)$ | $\mathrm{Std} \operatorname{dev}\left(\gamma_{\left.\gamma_{\mathrm{j}}\right)}\right)=0.168^{* *}$ | 0.0015 |
| Deterioration $\left(\gamma_{2}\right)$ | $0.0418^{* *}$ | 0.0075 |
| Yr1999 | $-0.0180^{*}$ | 0.0073 |
| Yr2000 | -0.0011 | 0.0076 |
| Yr2001 | -0.0051 | 0.0071 |
| Number of Observations | 80 |  |

Note:

1. ${ }^{* *} \mathrm{p}<0.01 \quad{ }^{*} \mathrm{p}<0.05$
2. Random Effects regression with White heteroskedasticity consistent covariance matrix.
3. Adjusted $\mathrm{R}^{2}=0.486$


Figure 1: Impact of Quality Uncertainty on Strategic Holders Segment


Figure 2: Impact of Quality Uncertainty on Compulsive Buyers Segment


Figure 3: Impact of Quality Uncertainty on Cheapskates Segment


Figure 4: Comparing Regimes: Trade-Ins versus No Trade-Ins


Figure 5: Impact of Quality Uncertainty on New Good Prices

## Note:

$\mathrm{P}(\mathrm{n})$ : New good price in no trade-in regime
$\mathrm{P}(\mathrm{r})$ : New good price in a trade-in regime for buyers who trade-in
$\mathrm{P}(\mathrm{mr})$ : New good price in a trade-in regime for buyers who purchase without a trade-in


Figure 6: Impact of Quality Uncertainty on Used Good Quality


Figure 7: Impact of Quality Uncertainty on Used Good Prices


Figure 8: Impact of Deterioration on Strategic Holders Segment


Figure 9: Impact of Deterioration on Compulsive Buyers Segment

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[^1]:    ${ }^{1}$ We define a trade-in transaction as one where an item of merchandise is taken as partial payment for a purchase of a new good.
    ${ }^{2}$ This contrasts with the work on markets for goods that are long lived, but which are subject to rapid improvements. Here, the emphasis shifts to explaining upgrades (e.g., Fudenberg and Tirole 1998), and leapfrogging behavior across successive generations (e.g., Grenadier and Weiss 1997).
    ${ }^{3}$ We use the terms "lemons problem", "adverse selection", and "asymmetric information" interchangeably to describe transactions where sellers are better informed than are buyers about the quality of the transacted item. ${ }^{4}$ The "discount" can take the form of a lower price for the new good and/or a higher price for the used good.

[^2]:    ${ }^{5}$ Formally, a lemon has a quality level lower than the level expected by the buyer.

[^3]:    ${ }^{6}$ We could let products last more than two periods before they die (e.g., Stolyarov 2002), but this complicates the bookkeeping of the vintages that must be tracked in the analysis.
    ${ }^{7}$ The origins of these terms are obscure, but they are commonly used in the US and other English-speaking countries. For instance, www.peacheorlemon.co.uk, provides automobile reviews of UK cars, with five peaches and five lemons representing the best and worst used cars, respectively.
    ${ }^{8}$ For most of our results to go through, we only need a much weaker assumption than A2, namely $v>(1+s)$, which implies that a new good deteriorates for sure after one period.

[^4]:    ${ }^{9}$ We consider transactions, both of new and used goods, as taking place between anonymous agents. This helps abstract away from issues such as signaling, reputation building, etc., as solutions to the adverse selection problem.
    ${ }^{10}$ Most of the notation in this section closely follows Huang et al. (2001).

[^5]:    ${ }^{11}$ In stationary equilibrium, the time dependency in the value functions outlined in equation (1) drops out. After the completion of each optimal pattern of behavior, the consumer returns to the start of the same cycle again. This greatly simplifies the calculation of the closed-form solutions of the equilibrium outcomes.

[^6]:    ${ }^{12}$ Note the difference between the terms quality uncertainty and adverse selection. One could have a market with the former and not the latter. Thus, one could have quality uncertainty revealed at the end of the first period to every consumer. At the other extreme, and less realistically for our context, one could have the quality realization revealed to no consumer. In either case there is clearly no adverse selection, because there is no asymmetry of information. In what follows, we speak only to the case where adverse selection is present, i.e., quality uncertainty coupled with asymmetric information.
    ${ }^{13}$ We prove this result formally in the Technical Appendix, as well as other results relating to a model with quality uncertainty but no adverse selection.

[^7]:    ${ }^{14}$ Note that setting the new good price is equivalent to determining optimal new good flow per period, since the two are directly related in a market of fixed size.

[^8]:    ${ }^{15}$ We use the subscript ' $r$ ' to denote the regime with trade-ins throughout.

[^9]:    ${ }^{16}$ We do not impose this condition - it emerges naturally in equilibrium, as will be shown in proposition 1.

[^10]:    ${ }^{17}$ Note that no particular individual can uniquely be identified ex-ante as always holding or always trading in. In equilibrium, however, the segment's behavior in aggregate is constant over time.

[^11]:    ${ }^{18}$ Although the results in Table 1 are for the case where $\delta \rightarrow 1$, there is no loss of generality.
    ${ }^{19}$ As an aside, note that the existence of trade-ins in equilibrium implies that the producer's profits are higher when offering trade-ins than otherwise. We show this formally in Proposition T1A in the Technical Appendix.

[^12]:    ${ }^{21}$ Nevertheless, for robustness, we re-ran our models using the 'trade-in allowance' reported in the CES data. Our results remained qualitatively unchanged.

[^13]:    ${ }^{22}$ We chose vintages 1,4 , and 7 , because cars newer than 1 year or older than 7 years are rarely traded in.

[^14]:    ${ }^{23}$ This calculation is illustrative, and should not literally be applied to specific make-models because of the unobserved random effects of a make-model. A posterior Bayesian estimate for each make-model would need to be included in our calculation to apply this to a specific make-model.

