Manufacturer Certification in Second-Hand Markets

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Abstract

We analyse an overlapping generations model of manufacturer certification in durable goods markets with asymmetric information about the quality of used goods. The functioning of second-hand markets has two effects on markets for new goods, a substitution and a resale value effect. Through certification, manufacturers reduce adverse selection in second-hand markets and extract resulting rents through the markets for new goods. Certification may increase profits at the expense of social welfare, by increasing average quality while decreasing trading volume. Manufacturers may be willing to subsidise certification to increase profits on new goods and thus have an advantage over third-party certifiers.

Keywords: Durable goods, second-hand markets, adverse selection, certification.

JEL Classification: L11, L15, L62, L68.

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1 Introduction

There is a growing trend of the practice of 'used stock management', whereby original equipment manufacturers influence the market for used goods and its interaction with the market for new goods. The most notable example of this practice is the market for used cars. Increasingly, automobile manufacturers offer 'approved used' schemes under which second-hand vehicles are certified to a given minimum quality standard. The market for cars has a number of special features that together make quality certification a potentially profitable practice. First, cars are durable goods that often change ownership several times over their life cycle. Second, the market for cars is characterised by potentially significant quality deterioration and informational asymmetries, with buyers at a disadvantage relative to sellers. The durability of goods means that sellers must contend with the intertemporal effects of current production decisions and weigh off increased present output with a higher future stock of used goods. Quality deterioration itself gives rise to competing intertemporal effects. On the one hand, high quality used cars exert competitive pressure on the market for new cars, the so-called substitution effect. On the other hand, high quality used cars may be sold on the used car market for a premium, thereby increasing the value of new cars and thus creating a resale value effect. Manufacturer certification of used cars therefore does not merely serve to decrease informational asymmetries, but also influences manufacturers' profits via its impact on the substitution and resale value effects.

The used car market plays an increasingly important role on the bottom line of original equipment manufacturers (OEMs). The global value of the used car market was valued at USD 1.2 trillion in 2020, and is expected to increase to USD 1.5 trillion by 2027 (Statista, 2022). Certified pre-owned (CPO) cars have been steadily gaining importance in this market. CNW Marketing Research shows that in the U.S., the number of certified used cars sold has increased from 452,829 in 1997 to 2.75 million in 2021 (Murry & Schneider, 2016; Lutz, 2022). Customers are willing to pay 5 percent more for CPO products than used goods sold privately (Chen & Hsu, 2017), and CPO cars are on average 3-7 percent more expensive than other used cars (Murry & Schneider, 2016). In 2005, CPO cars were sold at an average premium of USD 1680 in the U.S. (Navarre et al., 2007).

According to a study by Capgemini (2007), "the most important success strategy in the used car business may be the development of trust-inducing initiatives such as certified used vehicle programs" which reduce asymmetric information, improve residual (resale) values and strengthen new car sales (Navarre et al., 2007). Most prominent car manufacturers such as Honda, BMW, Toyota and Mercedes offer these 'approved used' programs, whereby they certify the quality of used cars. Approved used cars go through, on average, a hundred-point inspection by the original manufacturers, are mostly low mileage (less than 100,000 miles) and less than five years old (Dredge, 2020). Most manufacturers such as Ford and Volkswagen also offer a thirty days/ 1000 miles' exchange policy, at least one year of roadside assistance and two years of warranty (Dow, 2022). Manufacturers of other durable goods, such as Rolex for watches and Kodak and Xerox for printing systems, also offer certification programs for pre-owned goods.

Thus, the used car market has become more reliant on CPO options in recent years. With varying types of certification, the used car market is more segmented and there is less information asymmetry than without such certification. Despite this trend, there is little to no theoretical work on quality certification of used goods in durable goods markets. In this paper, we present a theoretical model that explores certification of the quality of used goods by original manufacturers in a

durable goods market with adverse selection and vertical product differentiation. It incorporates the major features of durable goods markets, including quality variance and uncertainty among used goods, competition between new and used goods and heterogeneity in consumer valuation of product quality. Our results confirm that certified used goods cannibalise the sales of new goods, but the introduction of certification allows the manufacturer to charge higher prices for the new goods. Furthermore, the manufacturer benefits from providing certification when goods are more durable and there is a high degree of quality uncertainty in the used goods market. In recent years, cars have become more durable than before (Hendel & Lizzeri, 2002). This research suggests that the decision of manufacturers to provide certification for used goods can be explained by the recent increase in durability. Moreover, our results show that the manufacturers may also subsidise certification and recoup profits through an increase in the prices of new goods. This allows manufacturers to provide certification at a lower fee, giving them an advantage over third party certifiers.

This research also has important implications for policy planners, which cannot be inferred from the existing studies on certification of single-use consumer goods. Though certification reduces the problem of adverse selection, our results indicate that certification helps the manufacturers increase the prices of new goods and reduce the supply of new goods to the extent that it is mostly detrimental for social welfare and consumer surplus. In contrast, previous studies show that the practice of leasing durable goods can be welfare improving for the society (Hendel & Lizzeri, 2002).

In the next section, we provide an overview of the literature on adverse selection in durable goods market and on certification. In Section 3, we lay out the model and its analysis. In sections 4 and 5, we provide the results and concluding remarks, respectively.

2 Literature Review

This paper draws on and contributes to several different strands of literature, namely those on durable goods markets, on adverse selection and on certification, respectively.

Durable goods markets and adverse selection

Different aspects of markets for durable goods have been considered by Akerlof (1970) and Coase (1972) and more recently by Anderson & Ginsburgh (1994) and Waldman (1996). The paper most relevant to our research is by Hendel & Lizzeri (1999a), who study the problem of adverse selection in durable goods markets. They allow for information asymmetry in the used goods markets, examining the problem of adverse selection in the used goods market and the competition between new and used goods.

Subsequent work has analysed ways in which manufacturers can interfere directly or indirectly in second-hand markets. One prominent such practice in the market for cars is leasing. Hendel & Lizzeri (2002) and Waldman & Johnson (2009) contend that leasing allows monopolists to partly solve information asymmetry as ex-leased cars are of a higher quality than other used cars, leading to a better segmentation of the market. To reduce the *substitution effect*, manufacturers also keep the quality of used goods lower than new goods by reducing the outside maintenance options for users. Manufacturers often end warranty coverage when users opt for outside maintenance

options, thereby discouraging the practice (Hendel & Lizzeri, 1999b). In this paper, we explore how manufacturers use certification as a tool to interfere in the second-hand markets. Similar to leasing, manufacturer certification of used car quality alleviates information asymmetry and allows manufacturers to charge higher new good prices. While the option of leasing segments the new goods market into leasing and selling options, certification impacts the new goods market through its effects on the second-hand markets.

Rao et al. (2009) and Chen and Hsu (2017) explore topics in durable goods markets that are closer to our research questions and use a similar underlying model. Rao et al. (2009) explore the incentive of manufacturers to offer trade-in options, whereby consumers can return their used goods for a rebate on the new goods. On the other hand, Chen & Hsu (2017) study whether the manufacturer should only trade-in high quality used goods and if it is beneficial to sell these as CPO products. They conclude that the CPO option does not cannibalise the sales of new goods and provides limited profits in addition to those generated by trade-ins. Their results differ from this paper's conclusions due to their underlying assumptions. They assume that manufacturers do not incur any costs in certifying the quality of used goods. They also assume that the consumer's willingness to hold on to a high quality used good is exogenous. Thus, they do not account for the impact of certification on the incentive of consumers to hold on to their high quality used goods.

A closely related issue to adverse selection is that of moral hazard. Used goods' quality, assumed as exogenous in most studies examining adverse selection, is dependent on how owners use and maintain their goods (Rust, 1986; Waldman & Johnson, 2009). With the exception of Waldman & Johnson (2009), most researchers study the problems of adverse selection and moral hazard in isolation. Correspondingly, we do not consider moral hazard in our analysis, as including both adverse selection and moral hazard would add too much complexity and render the model intractable.

Certification and adverse selection

Research on certification with adverse selection explores the ability and incentives of intermediaries to disclose valuable information to agents, and its impact on the quality of products provided by sellers. Peyrache & Quesada (2004) argue that in environments where sellers opt for voluntary certification, intermediaries may not fully solve information asymmetries even when they have the ability to identify true quality. Similarly, Lizzeri (1999) shows that a monopoly intermediary would choose to communicate that a good meets a minimum standard, rather than to fully disclose its quality. This information disclosure has a significant impact on sellers' incentives to invest in quality. Albano & Lizzeri (2001) contend that since intermediaries make buyers more informed about quality, they increase low cost sellers' incentive to provide a higher quality. Contrarily, Biglaiser & Li (2018) and Bouvard & Levy (2018) show that the presence of multiple middlemen can worsen the sellers' moral hazard problem. If sellers can shop for certification among various middlemen, they will be less incentivised to invest in quality.

In contrast to previous work, our research sheds light on the role of manufacturers themselves as certifiers. It examines the extent to which manufacturers are motivated to alleviate adverse selection in the markets for durable goods. The certification of used goods in a durable goods market affects not only the market for used goods but also the market for new goods. These effects are not fully captured by earlier studies on certification of single-use consumer goods. Furthermore, the analysis of certification by manufacturers in durable goods markets has important policy and

welfare consequences, which are not captured in the existing studies.

3 Model

In this section, we present a model for analysing consumer behaviour in durable goods markets with information asymmetry and adverse selection in the used goods market. The model allows the manufacturer to provide quality certification in the used goods market. This certification provides a signal to the used good buyers that the product is of good quality. This model is an extension of the framework developed by Rao et al. (2009). A comparison of results for the benchmark model without certification (provided in Appendix A) and the model with certification shows how manufacturer certification of used goods affects the durable goods market, in terms of profits, sales of new goods and social welfare.

3.1 Setup

Consumers

In this market, there are infinitely-lived expected utility maximising consumers, who demand at most one unit of the product in any period t. Consumers discount future utility by the factor $\delta \in (0, 1)$. Consumers form rational expectations about the quality of new and used goods. They are heterogeneous in their valuation of product quality, parametrised by $\theta \sim \mathcal{U}[0, 1]$. The heterogeneity of consumers is modelled using the vertical differentiation model by Mussa & Rosen (1978). Consumers agree that a higher quality product is superior, but they differ in their willingness to pay for quality. Given this formulation, the net utility of a consumer with quality valuation θ, consuming a product with quality q_t and price p_t in a period t is:

$$U_t = \theta q_t - p_t \tag{1}$$

Product

A durable good lasts two periods, after which it has zero value in the scrap market and the durable goods market. The quality of goods deteriorates over time. In the first period, the product is referred to as 'new' and in the second as 'used'. A new good is of quality q^n, where $q^n = 2$. On the other hand, a used good can either be of good quality q^g or bad quality q^b, where $q^g = 2 - v$ and $q^b = 2 - v - s$. The parameter s represents the quality variation and uncertainty in the used goods market while v characterises the quality deterioration from new goods to used goods. A new good is always of a higher quality than a used good. Thus, we have that $q^n > q^g > q^b$, implying that $s > 0$, $v > 0$ and $v + s < 2$. This can be attributed to the value attached to newness of a good, a lesser probability of a breakdown of a new good, and other problems that appear as products age (Desai & Purohit, 1998). This assumption rules out that consumers would prefer a used good over a new good, if offered at the same price. Any new good deteriorates to a good quality used good (a *peach*) with probability β and to a bad quality used good (a *lemon*) with probability $1 - \beta$. Figure 1 summarises the quality deterioration of new goods to used goods.

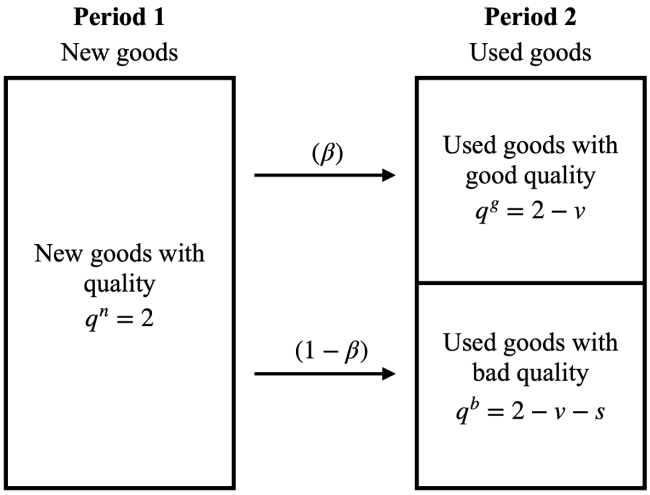


Figure 1: Product quality of new and used goods

Manufacturer

There is one infinitely-lived profit-maximising manufacturer that discounts the future by the factor δ. The manufacturer decides the supply of new goods y and whether to certify the quality of used goods. If the manufacturer certifies used goods as high quality, it also decides the certification fee f. The certification fee is charged to the sellers of used goods rather than the buyers, for maximum profits, as observed in most real-world markets and shown in the literature (Stahl & Strausz, 2011).

There are no fixed costs of production or certification. There is a constant and positive marginal cost of production c_1. The manufacturer incurs a constant and positive cost c_2 to test and certify each used good. After conducting the test, the manufacturer has perfect knowledge about its quality. In each period, the manufacturer maximises profits:

$$max_{y,f}\Pi = max_{y,f}\{(p^n - c_1)y + (f - c_2)n_c\} \tag{2}$$

where p^n is the price of new goods and n_c is the number of certified used goods. We elaborate more on n_c in the subsequent sections.

Market

In the market for new goods, both the consumers and the monopolist have perfect knowledge about the quality of the new good. On the other hand, the market for used goods is characterised by information asymmetry. Used goods sold in any period t were purchased and used by new good buyers in period $t-1$. Thus, only the sellers of used goods have perfect knowledge about its quality. The manufacturer gains perfect knowledge about the quality of any used good only after conducting a costly test. The manufacturer only provides certification if the used good is of high quality. Buyers of used goods observe whether the good has certification. They know that a certified used good is of quality q^g while a non-certified used good is of quality q^b.

The monopolist sets the supply for new goods y and the fee for certification f while market clearing determines the price for new goods p^n. The prices for certified used goods p^c and non-certified used

goods p^u are determined competitively by market clearing. The sequence of events is as follows. In any period, in the first stage, the firm sets y and f, based on predicted behaviour of rational consumers. Then, the consumers make consumption decisions taking the tuple (v, s, β, p, f, y) as given, where $p = (p^n, p^c, p^u)$. Consumers have unit demand and never own more than one good in a period. Thus, if they want to buy a good, they must sell or discard the good they already own.

All the symbols and definitions for variables and parameters for the model are summarised in Table 1.

Symbol	Definition	Assumptions
δ	Discount factor	$\delta \in (0,1)$
θ	Consumer valuation of product quality	$\theta \sim \mathcal{U}[0,1]$
q^n	Quality of a new good	$q^n = 2$
q^g	Quality of a good quality used good	$q^g = 2 - v$
q^b	Quality of a bad quality used good	$q^b = 2 - v - s$
s	Variation in used good quality	$s > 0$; $v + s < 2$
v	Quality deterioration from new to used goods	$v > 0$; $v + s < 2$
β	Probability of realising a peach	$0 < \beta < 1$
y	Supply of new goods	
f	Certification fee	
p^n	Price of new goods	
p^c	Price of certified used goods	
p^u	Price of non-certified used goods	
c_1	Marginal cost of production	$c_1 > 0$
c_2	Marginal cost of certification	$c_2 > 0$

Table 1: Summary of symbols for the model with certification

Role of the fee of certification

The manufacturer incurs a cost in testing each used good and charges a fee to the seller before conducting the test. A seller of any used good, regardless of its quality, can approach the manufacturer for testing their used good. However, the manufacturer only provides certification if the test shows that the used good is of a high quality. A positive fee of certification discourages sellers of low quality used goods from seeking certification. Moreover, the certification is only effective if $p^c - f > p^u$. Otherwise, sellers with high quality used goods will sell directly in the used goods market. The following Lemma describes this screening role of the fee of certification:

Lemma 1: Let $f > 0$ and $p^c - f > p^u$. Then, in equilibrium,

1. A rational seller with a low quality used good never seeks certification.
2. A rational seller with a high quality used good always seeks certification.

After solving the model, we verify that the manufacturer sets the certification fee such that $f > 0$ and $p^c - f > p^u$. Lemma 1 provides the strict conditions under which (1) and (2) hold. It is easy to see that for $f \geq 0$, it is a weakly dominant action for a rational seller with a low quality used good to not seek certification. Similarly, for $p^c - f \geq p^u$, it is a weakly dominant action for a rational seller with a high quality used good to seek certification.

Furthermore, certification alleviates information asymmetry in the used goods market. It allows sellers of used goods to obtain a higher price for good quality used products (all else equal), increasing the resale value of durable goods. This *resale value effect* leads to an increase in prices of new goods and hence profits. However, certified used goods are closer substitutes for new goods than used goods in the market without certification. Therefore, certified used goods cannibalise the sale of new goods more, leading to reduced demand for new goods. This is the adverse *substitution effect*, decreasing the profits earned. While a higher fee of certification reduces the resale value for a seller, it also discourages some owners of high quality used goods from seeking certification and selling their high quality used goods, reducing the substitution effect. The monopolist chooses the fee of certification to balance the positive resale value effect and the negative substitution effect, and cover the costs of certification.

4 Steady State Equilibrium

This section presents the analysis and solution of the model. Using backward induction to find equilibrium, we first characterise consumer behaviour to sort consumers into new and used good buyers based on their quality valuations, θ. Then, we find the identity of indifferent consumers between consumer types to find segment sizes for each type of consumers. The segment sizes determine the demand for new and used goods and the supply of used goods. Using these, we find the market clearing prices and maximise the monopolist's objective function to characterise equilibrium supply and prices.

4.1 Characterising consumer behaviour

In each period t, a consumer takes one of the following consumption decisions: buy a new good, keep a used good, buy a certified used good, buy a non-certified used good or not use the good. When a consumer buys a new good, they not only consider the utility derived from the product in period t but also in period $t+1$, either through resale or continued use. They decide whether to sell or keep in period $t+1$ after observing the quality of their used good, that they bought as new in period t. Thus, two types of consumers choose not to buy a good in period t: (1) consumers who buy a new good in period $t-1$ and keep it in period t, and (2) consumers who have a low valuation for quality and choose not to own the good in any period.

Thus, given (v, s, β, p, f, y), a consumer decides their action in any period based on the discounted expected utility of actions in consecutive periods. Every two periods, consumers are at the start of the same cycle of decisions, with the same parameters and prices as before. Thus, for each consumer, the problem is stationary every two periods. We characterise a stationary equilibrium and calculate steady state values for all endogenous variables, assuming that the consumers' taste for quality θ and the firm's profit maximising problem is constant over time. Most previous researchers also analyse the durable goods market in a steady state (Hendel & Lizzeri, 1999a; Rao et al., 2009; Chen & Hsu, 2017).

The possible actions of rational consumers in consecutive periods lead to five types of consumers in the steady state:

1. Compulsive buyers: acquire a new good in each period.
2. Strategic holders: acquire a new good in some period t, keep the good if they observe quality q^g in period $t+1$ and sell otherwise.
3. Certified used good buyers: acquire a certified used good in each period.
4. Non-certified used good buyers: acquire a non-certified used good in each period.
5. Non-buyers: never buy a good.

The above classification of types of consumers comprehensively defines all possible patterns of rational consumer behaviour in this model in a steady state (see proof in Appendix B). In equilibrium, the consumers self-select into segments based on their quality valuation θ, each segment representing each type of consumers. The higher the θ, the more they are willing to pay for a given quality. Thus, as shown in Figure 2 below, the highest valuation segment [θ_1,1] represents compulsive buyers, [θ_2,θ_1] represents strategic holders, [θ_3,θ_2] comprises certified used good buyers, [θ_4,θ_3] represents the non-certified used good buyers and [0,θ_4] the non-buyers.

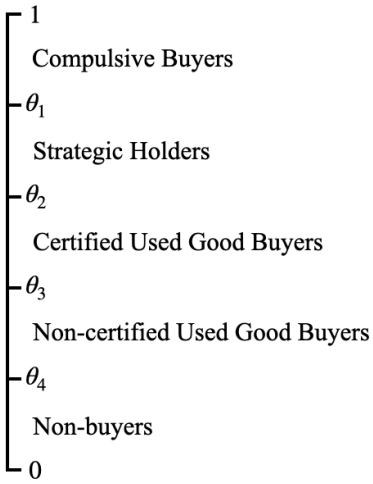


Figure 2: Consumer segments in the model with certification

4.2 Discounted expected utility for each type of consumer

We proceed to characterise the value functions for different types of consumers.

Compulsive Buyers: $\theta \in [\theta_1, 1]$

These consumers buy a new good in period t, sell it in period $t+1$ and then again acquire a new good. The expected discounted utility of a consumer with valuation θ is:

$$V^n(\theta) = (\theta q^n - p^n) + \delta(\beta(p^c - f) + (1-\beta)p^u + V^n(\theta)) \tag{3}$$

The first term represents the expected utility in period t from using a new good, net of its price. The second term shows the discounted utility from resale of the used good and buying a new good

again in period $t+1$. If the quality q^g is realised with probability β, the resale value obtained is $p^c - f$. However, if q^b is realised, the used good has a resale price p^u. Rearranging the equation yields the following value function:

$$V^n(\theta) = \frac{\theta q^n - p^n + \delta(\beta(p^c - f) + (1-\beta)p^u)}{1-\delta} \tag{4}$$

Strategic Holders: $\theta \in [\theta_2, \theta_1]$

These consumers buy a new good in period t and keep it in period $t+1$ if they observe quality q^g. Otherwise, they sell it in period $t+1$ to buy a new good in the same period. A consumer with valuation θ gets expected discounted utility:

$$V^s(\theta) = (\theta q^n - p^n) + \delta(\beta(\theta q^g + \delta V^s(\theta)) + (1-\beta)(p^u + V^s(\theta))) \tag{5}$$

As before, the first term represents the expected utility in period t from using a new good, net of its price. The second term shows the discounted expected utility depending on the behaviour in period $t+1$. With probability β, quality q^g is realised and the consumer uses the good in period $t+1$. At the end of period $t+1$, the good is useless with no value in the scrap market, so the consumer discards it and buys a new good in period $t+2$. With probability $1-\beta$, quality q^b is realised, the consumer sells the good at price p^u, and buys a new good in period $t+1$. Rearranging and simplifying the equation gives the value function:

$$V^s(\theta) = \frac{\theta q^n - p^n + \delta(\beta\theta q^g + (1-\beta)p^u)}{(1-\delta)(1+\delta\beta)} \tag{6}$$

Certified Used Good Buyers: $\theta \in [\theta_3, \theta_2]$

These consumers buy a certified used good in period t, discard it at the end of period t and buy a certified used good in period $t+1$. Their discounted expected utility includes expected utility from using a certified used good in period t net of p^c and discounted utility from repurchase of a certified used good in period $t+1$. For a consumer with valuation θ, the following equations represent the discounted expected utility and the value function respectively:

$$V^c(\theta) = (\theta q^g - p^c) + \delta V^c(\theta) \tag{7}$$

$$V^c(\theta) = \frac{\theta q^g - p^c}{1-\delta} \tag{8}$$

Non-certified Used Good Buyers: $\theta \in [\theta_3, \theta_4]$

These consumers buy a non-certified used good in every period, which has quality q^b. By the same logic as above, the following equations show the discounted expected utility and the value function for a consumer with valuation θ:

$$V^u(\theta) = (\theta q^b - p^u) + \delta V^u(\theta) \tag{9}$$

$$V^u(\theta) = \frac{\theta q^b - p^u}{1 - \delta} \tag{10}$$

Non-buyers, for which $\theta \in [0, \theta_4]$, get zero utility.

4.3 Segment sizes

To calculate the segment sizes for each type of consumer, we find the quality valuations (θ) of indifferent consumers between segments. A consumer with valuation θ_1 is indifferent between being a compulsive buyer and a strategic holder. θ_1 is found by equating equations (4) and (6), and substituting $q^n = 2$, $q^g = 2 - v$ and $q^b = 2 - v - s$:

$$\theta_1 = \frac{p^n - (p^c - f) - \delta(\beta(p^c - f) + (1 - \beta)p^u)}{v} \tag{11}$$

Similarly, the marginal consumer between the strategic holders' segment and certified used good buyers' segment has valuation θ_2, found by equating equations (6) and (8):

$$\theta_2 = \frac{p^n - p^c - \delta(\beta p^c + (1 - \beta)p^u)}{v} \tag{12}$$

Correspondingly, we find θ_3 and θ_4 by equating equations (8) and (10) and equation (10) to zero (utility of a non-buyer), respectively.

$$\theta_3 = \frac{p^c - p^u}{s} \tag{13}$$

$$\theta_4 = \frac{p^u}{2 - v - s} \tag{14}$$

Equations (11) and (12) show that if the manufacturer charges $f = 0$, then $\theta_1 = \theta_2$ and there are no strategic holders in the market. This resembles a model with perfect information and no frictions in the second-hand market.

4.4 Market clearing

Segment sizes for each type of consumer determine the demand for new, certified used and non-certified used goods, and the supply for certified used and non-certified used goods. The supply of new goods y is determined by the manufacturer and taken as given by the consumers.

The equilibrium in the new goods market in any period is characterised by:

$$(1-\theta_1)+\frac{1}{1+\beta}(\theta_1-\theta_2)=y \tag{15}$$

The right-hand side (RHS) of equation (15) is the supply of new goods, while the left-hand side (LHS) is the demand for new goods. In any period, compulsive buyers always demand new goods. Strategic holders demand new goods in period t either when (1) they chose to keep a high quality used good in period $t-1$ or (2) they bought a new good in period $t-1$ and it deteriorates to quality q^b in period t. The strategic holders that buy a new good in period $t-1$, which deteriorates to quality q^g in period t, do not appear in the market in period t. Thus, only a fraction of the strategic holders' segment buys new goods in any given period. The derivation of the proportion of segment $[\theta_2, \theta_1]$ that buys new goods in any given period is provided in Appendix B.

The equilibrium in the certified used goods market in any period is characterised by:

$$(\theta_2-\theta_3)=\beta(1-\theta_1) \tag{16}$$

The LHS is the demand for certified used goods, which only comprises of the segment $[\theta_3,\theta_2]$, the certified used good buyers. The RHS represents the supply of certified used goods. Since only compulsive buyers sell high quality used goods, the supply of certified goods depends on the probability β of compulsive buyers realising a peach.

The equilibrium in the non-certified used goods market in any period is characterised by:

$$(\theta_3-\theta_4)=(1-\beta)\left((1-\theta_1)+\frac{1}{1+\beta}(\theta_1-\theta_2)\right) \tag{17}$$

The LHS is the demand for non-certified used goods, which only includes the segment for non-certified used good buyers. The RHS is the supply for non-certified used goods, which includes all used goods in the market with quality q^b, sold by compulsive buyers and strategic holders.

4.5 Market clearing prices

Using equations (11)-(14) to define market segments and equilibrium conditions given in equations (15)-(17), we solve for market clearing prices.

Proposition 1: Given y and f, the following prices clear the markets for new goods, certified used goods and non-certified used goods, respectively:

$$p^n=\frac{2+\delta(2-v-s)+\beta(2-f-\delta(v-2+\beta(f-s)))}{1+\beta}-y(4-v+2\delta(2-v)-s(1-\beta)(1+\delta(2+\beta))) \tag{18}$$

$$p^c = 2 - v + y(s(1-\beta) - 2(2-v)) \tag{19}$$

$$p^u = (2 - v - s)(1 - 2y) \tag{20}$$

Using market clearing prices given by equations (18)-(20), we solve the firm's profit maximization problem:

$$max_{y,f}\Pi = max_{y,f}\{(p^n - c_1)y + (f - c_2)n_c\} \tag{21}$$

The solution to the above maximisation problem provides profit maximising choices of the monopolist for the supply of new goods y and the fees for certification f. Substituting these into equations (18)-(20) yields the equilibrium prices. We provide the equilibrium values for the main variables of this model in Appendix C, solved using $c_1 = 0.2$ and $c_2 = 0.1$. Due to the complexity of the model, it cannot be solved without assuming specific marginal costs.

5 Results

In this section, we discuss how certification of used goods by the manufacturer affects the durable goods market. In particular, we analyse the effects of certification on the supply of new goods, prices of new and used goods, the monopolist's profits, the relative sizes of consumer segments (compulsive buyers, strategic holders etc.) and social welfare. Further, we examine the impact of quality uncertainty in the used goods market and of quality deterioration from new to used goods on the new and used goods markets.

To analyse the effects of certification, we compare equilibrium values for the model with certification and the model without certification (provided in Appendix A). The key difference in the models is the assumption regarding information asymmetry. Without certification, the sellers of used goods have perfect knowledge about its quality, while the buyers form rational expectations about the quality of used goods, q^u, as they cannot discern the quality of used goods before purchase and use. Thus, there is only one market for used goods. Correspondingly, there are four types of consumers in the market: compulsive buyers, strategic holders, used good buyers and non-buyers. To compare the results, we refer to any variable x from the model without certification as $\widehat{x}$. For instance, the equilibrium prices for new and used goods in the market without certification are $\widehat{p^n}$ and $\widehat{p^u}$, respectively. Similarly, the equilibrium supply of new goods is $\widehat{y}$ without certification.

Throughout this section, we assume the marginal costs to be constant at $c_1 = 0.2$ and $c_2 = 0.1$, unless stated otherwise. All figures are constructed using $\delta = 0.9$. For the model without certification, it is difficult to obtain closed-form solutions without making additional assumptions about parameter values. Thus, to illustrate the results, we conduct a numerical analysis at specific parameter values, provided at the beginning of each subsection. For each parameter s, v and β, we restrict the range of values to obtain non-negative segment sizes in equilibrium. These results are robust to a wide range of parameter values. We run multiple simulations to obtain numerical

solutions using different values of underlying parameters and compare the results with those outlined here to verify our findings.

5.1 Certification fee in equilibrium

The results confirm the role of the certification fee as a screening mechanism, encouraging only sellers of high quality used goods to seek certification in equilibrium.

Result 1: Let $0.6 < \delta < 1$, $0 < \beta < 1$, $0 < v < 1$ and $0.2 < s < 1$. Then, we have that $f > 0$ and $p^c - f > p^u$ in equilibrium.

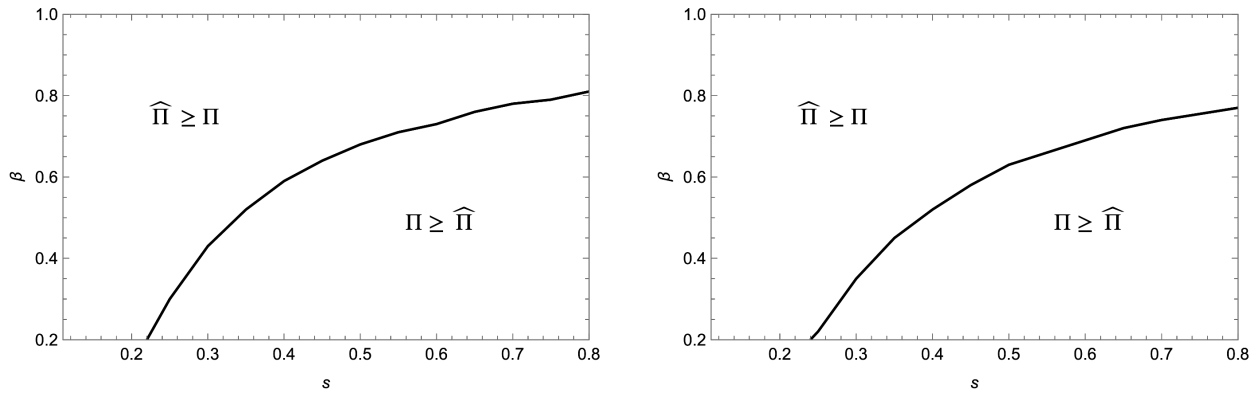
Result 1 follows from the equilibrium values provided in Appendix C for the model with certification. It shows that as long as all agents are patient enough and the difference between the quality of high and low quality used goods s is sufficiently large, the manufacturer charges a fee such that it separates the markets for high and low quality used goods.

A positive fee for certification gives an incentive to owners of high quality used goods to hold on to them. Keeping all else equal, an increase in the certification fee reduces the resale value of high quality used goods $p^c - f$ further below p^c. This discourages the owners of high quality used goods from selling them, increasing the segment of strategic holders in the market. Increasing the fee for certification thus has three main effects: (1) it reduces the resale value of high quality used goods for sellers, and hence weakens the positive resale value effect on the price of new goods; (2) it increases the revenue earned from certification of each used good; and (3) it reduces the substitution effect from certified used goods by increasing the segment of strategic holders and thus reducing the amount of certified used goods (relative to new goods) in the market. The manufacturer sets the fee to balance these opposing effects.

5.2 Monopolist's choice between certification and no certification

Certification has an ambiguous effect on the profits of the monopolist, which depends on the exogenous parameter values $(s, v, \beta, \delta, c_1, c_2)$. The monopolist only chooses to provide certification when it leads to an increase in profits. Figures 3a and 3b below show the values of s and β for which the monopolist earns greater profits by providing certification, at $v = 1$ and $v = 1.2$ respectively. To construct these figures, we solve the monopolist's maximisation problems for values of s from 0.1 to 0.8 (step size of 0.05) and for values of β from 0.2 to 1 (step size of 0.01).

As the figures show, certification is more profitable for high values of s, low values of v and/or low values of β. At these values of underlying parameters, there is more adverse selection in market without certification. Certification increases profits by reducing the incentive to hold on to high quality used goods, and hence reducing adverse selection. Section 5.5 explains the relative impact of changing s, v and β on the markets with and without certification in detail.



(a) $v = 1$ **(b)** $v = 1.2$

Figure 3: Monopolist's choice between certification and no certification

5.3 Effects of certification

The practice of certifying used goods solves the information asymmetry in the used goods market. When purchasing used goods, consumers correctly infer that the non-certified used goods have bad quality, q^b, while the certified used goods have quality q^g. Thus, there are two sub-markets for used goods and different types of consumers appear in each of these markets. In contrast, in the model without certification, consumers cannot make any distinction between types of used goods and form rational expectations about the quality of used goods, $\widehat{q^u}$.

Certification in second-hand markets has a significant impact on the prices of new and used goods. The price of certified used goods p^c is higher than the price of used goods $\widehat{p^u}$ in the model without certification. Consumers of used goods are willing to pay a higher price for certified used goods as they have a higher expected quality than used goods in the model without certification ($q^g \geq q^u$). Moreover, for high values of v and/or β and low values of s, the price of non-certified used goods in the model with certification p^u is lower than the price of used goods in the model without certification $\widehat{p^u}$, as non-certified used goods only have goods of low quality q^b. Overall, the average resale price of used goods is generally higher in the model with certification, except at low values of s and high values of β.[2] Consequently, the price for new goods is generally higher in the market with certification than without. This reflects the resale value effect of certification.

Result 2: Given δ, let $s \geq \underline{s}$, $\beta \leq \bar{\beta}$ and $v \leq \bar{v}$ such that $\Pi \geq \widehat{\Pi}$. Then, the market with certification has a higher new good price p^n than the market without certification $\widehat{p^n}$. The difference between p^n and $\widehat{p^n}$ reflects the *resale value effect* of certification.[3]

Figure 4 shows the effect of certification on market segments for $s = 0.5$, $v = 0.75$ and $\beta = 0.5$. All high quality used goods are certified by the manufacturer. The opportunity to obtain a higher resale price, $p^c - f$, for high quality used goods reduces the consumers' incentive to hold on to them. Thus, some consumers with valuation θ who are strategic holders in the market without

[2]The average resale price in the model without certification is $\widehat{p^u}$. The average resale price in the model with certification is $\frac{n_c(p^c-f)+n_u p^u}{n_c+n_u}$, where n_u is the supply of non-certified used goods.

[3]The price of new goods in the market with certification may be higher even outside these intervals, but is always higher within these intervals.

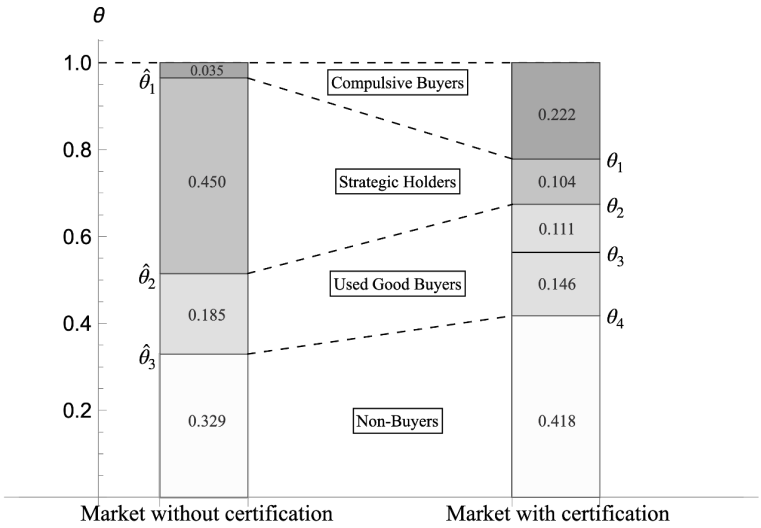


Figure 4: Effect of certification on consumer segments

certification are compulsive buyers in the market with certification. As Figure 4 shows, the quality valuation θ_1 of the indifferent consumer between being a compulsive buyer and a strategic holder is lower in the market with certification. Furthermore, certified used goods have a higher expected quality than the average quality of used goods in markets without certification ($q^g \geq q^u$). Therefore, consumers with a lower valuation of quality that choose to be strategic holders in the market without certification, prefer buying a certified used good every period in the market with certification. This is the substitution effect of certification. It leads to a higher θ_2 in the market with certification. Both these effects lead to a smaller segment of strategic holders in the market with certification than without. Furthermore, due to the substitution effect of certification, the market with certification has a lower new good supply ($y \leq \widehat{y}$). The following results summarise these effects.

Result 3: The introduction of certification reduces the incentive of consumers to hold on to high quality used goods. Given δ, let $s \geq \underline{s}$, $\beta \leq \bar{\beta}$ and $v \leq \bar{v}$ such that $\Pi \geq \widehat{\Pi}$. Then, the segment of strategic holders is smaller in the market with certification than without.

Result 4: Given δ, let $s \geq \underline{s}$, $\beta \leq \bar{\beta}$ and $v \leq \bar{v}$ such that $\Pi \geq \widehat{\Pi}$. Then, the market with certification has a lower new goods supply y than the market without certification $\widehat{y}$. The difference between y and $\widehat{y}$ reflects the *substitution effect* of certification.

The impact on other consumer segments, however, depends on the parameter values for s, v and β. This is due to two opposing effects of certification: (1) the market with certification has a lower new good supply and (2) certification in the used goods market reduces the segment of strategic holders. The former effect decreases the goods available for purchase in the new goods market and hence the used goods available for resale, reducing both the compulsive buyers and the used good buyers. The latter effect translates to more compulsive buyers in the market and hence a greater percentage of used goods appear in the market for resale. At high values of s, low values of v and/or low values of β, the segment of compulsive buyers is bigger and there are more used good buyers in the market with certification than without.

5.4 Welfare impact of certification

Though certification reduces the problem of adverse selection, it leads to an increase in the price of new goods and a decrease in the supply of new goods. Certification also impacts the prices of used goods, but since these prices are transfers between used goods sellers and buyers, this does not affect the overall consumer surplus. The following formulae define consumer surplus and welfare in markets with and without certification:

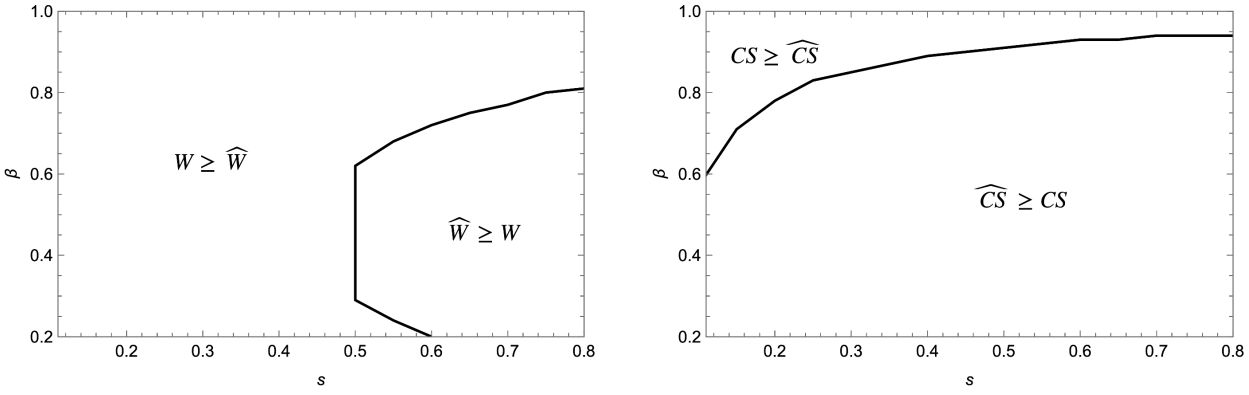
$$W = \int_{\theta_1}^{1} V^n(\theta)d\theta + \int_{\theta_2}^{\theta_1} V^s(\theta)d\theta + \int_{\theta_3}^{\theta_2} V^c(\theta)d\theta + \int_{\theta_4}^{\theta_3} V^u(\theta)d\theta + \frac{\Pi}{1-\delta} \tag{22}$$

$$CS = \int_{\theta_1}^{1} V^n(\theta)d\theta + \int_{\theta_2}^{\theta_1} V^s(\theta)d\theta + \int_{\theta_3}^{\theta_2} V^c(\theta)d\theta + \int_{\theta_4}^{\theta_3} V^u(\theta)d\theta - \frac{c_1 y + c_2 n_c}{1-\delta} \tag{23}$$

$$\widehat{W} = \int_{\theta_1}^{1} V^n(\theta)d\theta + \int_{\theta_2}^{\theta_1} V^s(\theta)d\theta + \int_{\theta_3}^{\theta_2} V^u(\theta)d\theta + \frac{\widehat{\Pi}}{1-\delta} \tag{24}$$

$$\widehat{CS} = \int_{\theta_1}^{1} V^n(\theta)d\theta + \int_{\theta_2}^{\theta_1} V^s(\theta)d\theta + \int_{\theta_3}^{\theta_2} V^u(\theta)d\theta - \frac{c_1 \widehat{y}}{1-\delta} \tag{25}$$

The consumer surplus takes into account the value functions for consumers for quality valuations $\theta \sim \mathcal{U}[0,1]$ and the discounted stream of costs incurred in production and certification. On the other hand, the welfare formula includes the value functions for consumers and the discounted stream of profits for the monopolist. Figures 5a and 5b show the values of s and β for which the welfare and consumer surplus are higher in a market with certification than without, respectively. To construct these figures, we first solve the monopolist's maximisation problems at $v = 1$, $c_1 = 0.2$ and $c_2 = 0$, for values of s from 0.1 to 0.8 (step size of 0.05) and for values of β from 0.2 to 1 (step size of 0.01). Then, we calculate the welfare and consumer surplus in these markets.



(a) Welfare **(b) Consumer surplus**

Figure 5: Welfare and consumer surplus in markets with and without certification

As Figure 5 shows, a planner who only cares about the consumer surplus and total costs would prefer the monopolist to provide certification when the probability of realising a peach β is high or uncertainty in quality s is low. The range of values of s and β for which the planner prefers the market without certification increases when either v decreases or c_2 increases. Conversely, as shown in Section 5.2, the monopolist prefers the market with certification for high values of s and low values of v and β. Certification leads to significantly higher prices for new goods and lesser supply for new goods at lower values of v and β, and higher values of s. The overall market size $1-\theta_4$, i.e. the consumers that utilise new or used goods in any period, is also smaller in the market with certification for these ranges of s, v and β. A combination of these effects leads to a lower consumer surplus in the market with certification. Certification may increase social welfare but the manufacturer extracts most of the excess surplus.

5.5 Comparative statics

5.5.1 Effects of quality uncertainty in used goods on the durable goods market

All else equal, an increase in s leads to an increase in the difference between the qualities of good and bad quality used goods. It increases the deterioration from new to bad quality used goods $(v+s)$ but keeps the deterioration from new to good quality used goods (v) constant. Using $v=1$ and $\beta=0.5$, we solve the maximization problems for the models with and without certification for $0.1 \leq s < 1$, to obtain non-negative segment sizes. Figures 6 and 7 show the impact of s on y and f, respectively.

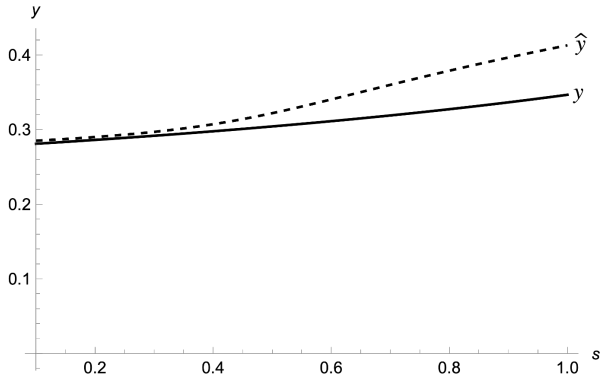


Figure 6: Effect of s on y and $\widehat{y}$

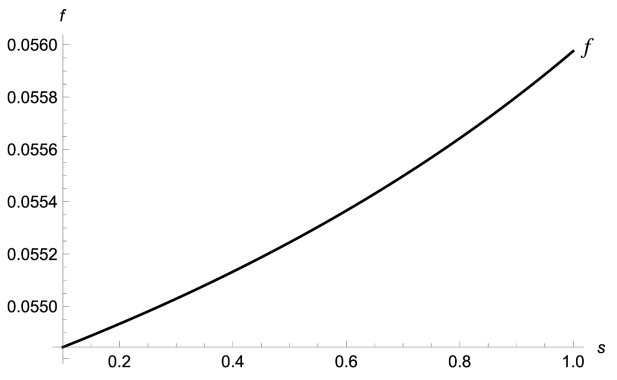
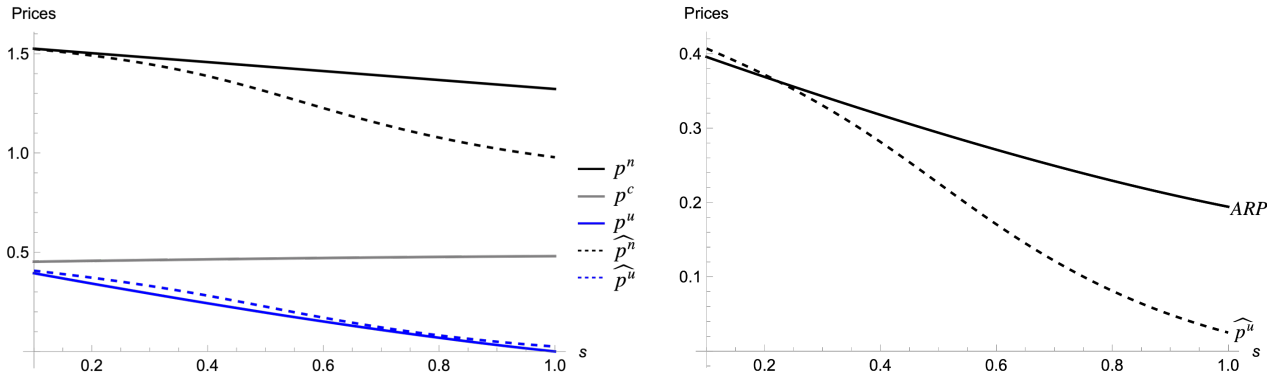


Figure 7: Effect of s on f

As the figures show, the supply of new goods is increasing in s in both the markets. This effect, however, is stronger in markets without certification. Used goods are an imperfect substitute for new goods. As s increases, bad quality used goods become a worse substitute for new goods, while there is no effect on the substitutability of high quality used goods. Without certification, buyers cannot distinguish between the types of used goods. Therefore, an increase in s reduces the competition from used to new goods and $\widehat{y}$ increases. With certification, the new goods market faces competition from both certified and non-certified used goods. An increase in s reduces the quality of non-certified used goods but not of certified used goods. Therefore, though an increase in s reduces the competition to new goods from non-certified used goods, the certified used goods are still good substitutes for new goods. Therefore, though y still increases in s, the impact is

smaller with certification. As s increases, the substitution effect of certification also increases as shown by the increasing difference between the supply of new goods in both markets. Moreover, as s increases, the difference in quality between certified and non-certified used goods increases. The sellers of high quality used goods are willing to pay a higher fee to signal their quality to the buyers, allowing the manufacturer to charge a higher certification fee.

Figure 8 shows the impact of changing s on the prices in the markets, while Figure 9 illustrates the effect on the size of the segment for strategic holders in markets with and without certification.



(a) All prices **(b) Average resale prices**

Figure 8: Effect of s on prices

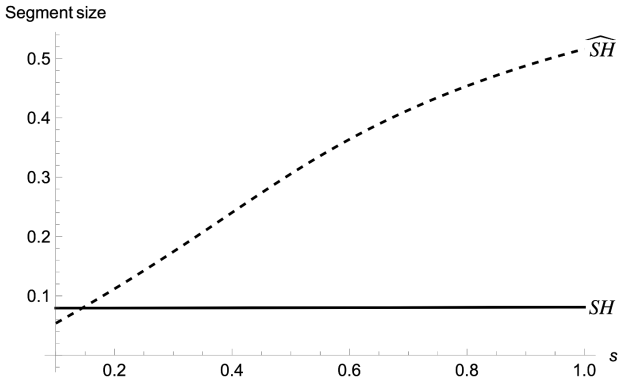


Figure 9: Effect of s on strategic holders

The resale price in the market without certification is $\widehat{p^u}$. The average resale price with certification is defined as:

$$ARP = \frac{n_c(p^c - f) + n_u p^u}{n_c + n_u} \tag{26}$$

where $n_u = (\theta_3 - \theta_4)$ is the supply of non-certified used goods and $n_c = (\theta_2 - \theta_3)$ is the supply of certified used goods.

New good prices decrease in s for both the markets, as buyers expect the resale value to be lower when deterioration from new to low quality used goods is higher. In markets without certification,

as s increases, it reduces the average quality supplied of used goods as (1) the quality of low quality used goods decreases and (2) more consumers hold on to their high quality used goods as they expect a lower resale price for higher s. This leads to a reduction in $\widehat{p^u}$ and consequently $\widehat{p^n}$. With certification, p^u falls as the quality of non-certified used goods, $q^b = 2 - v - s$, decreases. However, an increase in s has a lesser impact on p^c, as certified used goods comprise of only high quality used goods. As the competition from non-certified used goods decreases with an increase in s, p^c slightly increases. Though f also increases with s, the change in $p^c - f$ is negligible. Thus, since changing s does not significantly impact the resale value of high quality used goods, it also does not encourage consumers to hold on to them. The separation of certified and non-certified used goods reduces the fall in the average resale price, dampening the impact of s on the price of new goods. The increasing difference between the prices of new goods in both the markets reflects the increasing resale value effect of certification as s increases. Figure 10 displays the impact of s on profits in both the markets.

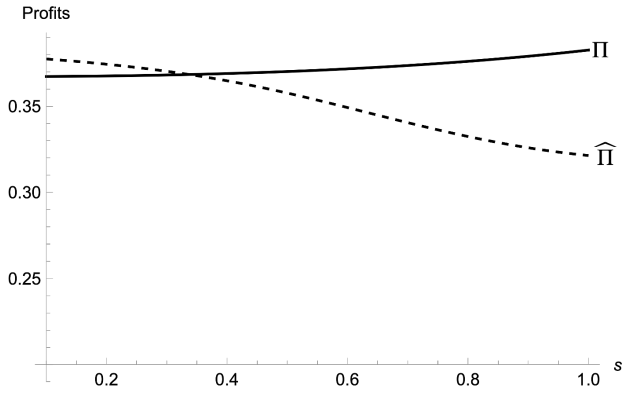


Figure 10: Effect of s on profits

In the market without certification, profits fall as s increases. Comparatively, s does not have a significant impact on profits in the market where the monopolist provides certification. As Figures 8 and 9 show, the impact of certification on resale prices and the incentive to hold on to high quality used goods is less significant at lower values of s, showing that certification plays a minimal role in the market at these values. For $s \leq 0.34$, the adverse substitution effect from certified used goods and the costs of certification outweigh the positive resale value effect and fees from certification. Intuitively, at low values of s, there is little uncertainty and information asymmetry in the market for used goods. Therefore, the market without certification exhibits a very low level of adverse selection (small segment of strategic holders). This reduces the role that certification can play in the market, making it a costly venture with little benefits. Thus, the monopolist chooses not to provide certification for $s \leq 0.34$. The following result summarises the difference in the impact of quality uncertainty in used goods on markets with and without certification.

Result 5: Certification allows the monopolist to insulate its profits from changes in uncertainty in the quality of used goods, by separating the markets for high and low quality used goods.

5.5.2 Effects of quality deterioration from new to used goods on the durable goods market

All else equal, an increase in v leads to an increase in deterioration from new to used goods, v and $v+s$ for high quality used goods and low quality used goods, respectively. Unlike s, an increase in v makes all used goods worse substitutes for new goods. Thus, it reduces the durability of products. However, the higher values of v can also be interpreted as a higher quality premium for new goods, as it increases the relative quality of new goods $q^n = 2$ to the quality of used goods, $q^g = 2 - v$ and $q^b = 2 - v - s$. Figures 11, 12 and 13 show the impact of v on the supply of new goods, the certification fee and the size of the segment for strategic holders in both the markets, respectively, for $\beta = 0.5$ and $s = 0.5$. The parameter values $v \geq 0.6$ ensure non-negative segment sizes in both the markets.

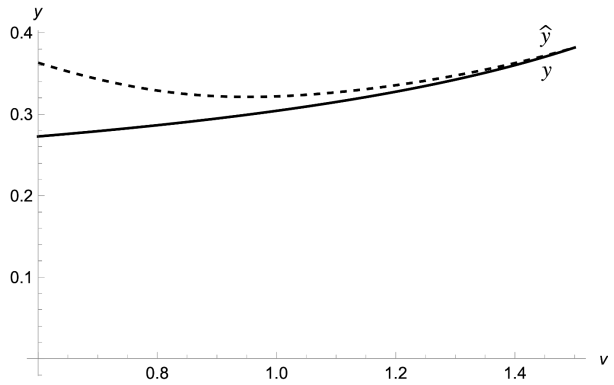


Figure 11: Effect of v on y and $\widehat{y}$

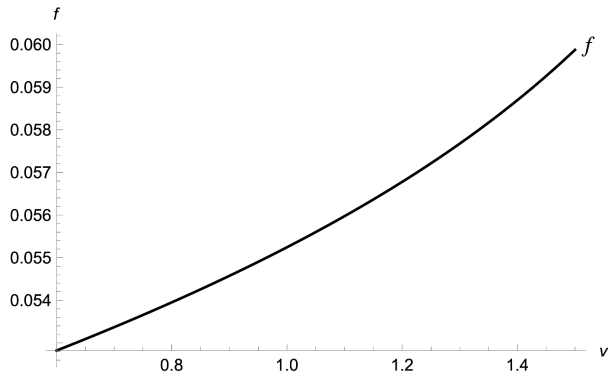


Figure 12: Effect of v on f

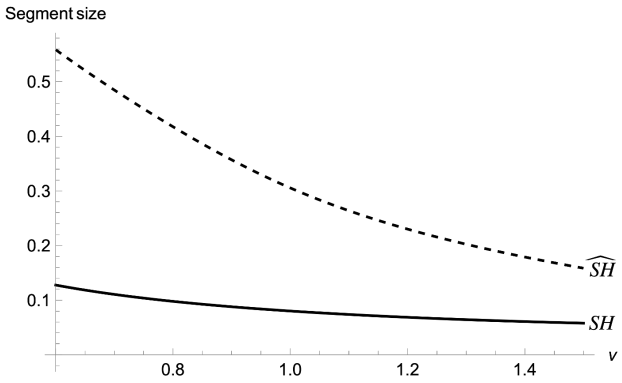


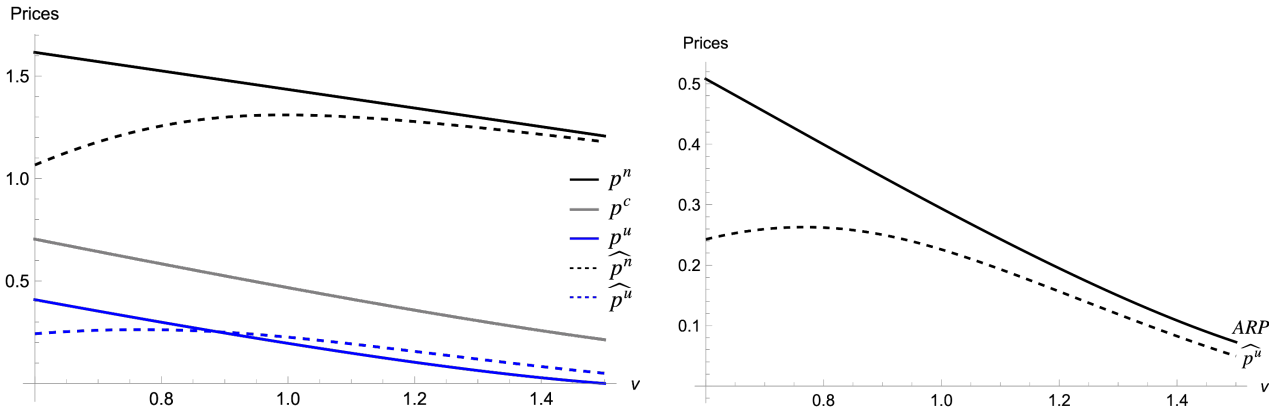
Figure 13: Effect of v on strategic holders

Without certification, $\widehat{y}$ is decreasing in v for $v \leq 0.95$ and increasing otherwise. As v increases, the quality premium from upgrading to new goods from high quality used goods increases. This reduces the incentive to hold on to good quality used goods in the second period, decreasing the segment of strategic holders and increasing the compulsive buyers. Furthermore, as the proportion of high quality used goods for sale in the market increases, the difference between q^g and $\widehat{q^u}$ decreases. This prompts some strategic holders to become used good buyers instead. For $v \leq 0.95$, more strategic holders become used good buyers than compulsive buyers as v increases, leading to a decrease in $\widehat{y}$. Increase in demand for used goods also increases the price for used goods $\widehat{p^u}$. As the resale value

increases, $\widehat{p^n}$ also increases. As v keeps on increasing above 0.95, the substitutability between new and used goods reduces. More strategic holders become compulsive buyers than used good buyers as v increases for $v \geq 0.95$. Therefore, $\widehat{y}$ increases. Though the competition from used goods to new goods decreases, the price of new goods $\widehat{p^n}$ falls slightly as the resale value of used goods $\widehat{p^u}$ decreases due to the fall in $\widehat{q^u}$.

However, in the market with certification, we only observe an increase in y as v increases. As v increases, the quality of certified and non-certified used goods, $q^g = 2 - v$ and $q^b = 2 - v - s$, decreases, while the quality of new goods $q^n = 2$ is constant. Thus, as v increases, the competition from both certified and non-certified used goods decreases, leading to an increase in y. Furthermore, as shown in Figure 14b, the average resale value in the market with certification decreases as v increases. This leads to a decrease in p^n. The difference between the prices of new goods in the markets with and without certification illustrates the resale value effect, which decreases as v increases. On the other hand, the new good supply is higher without certification, reflecting the substitution effect of certification; as v increases, this effect also becomes weaker.

Furthermore, as v increases, the segment of strategic holders also decreases in the market with certification. As the quality premium for new goods over certified used goods (v) increases, the incentive to hold on to them decreases. This increases the sellers of high quality used goods in the market, hence the demand for certification increases. This leads to an increase in the fee charged for certification. Figures 14 and 15 show the impact of changing v on the prices and profits in both the models.



(a) All prices **(b) Average resale prices**

Figure 14: Effect of v on prices

As shown in Figure 15, profits generally increase in v in both the markets. The additional gains from certification diminish as v increases, as both the resale value and substitution effects weaken gradually. The following result recaps the impact of v on both the markets.

Result 6: The manufacturer benefits more from certification when quality deterioration is low. As v increases, the role of certification in durable goods markets diminishes as both the resale value and substitution effects of certification disappear.

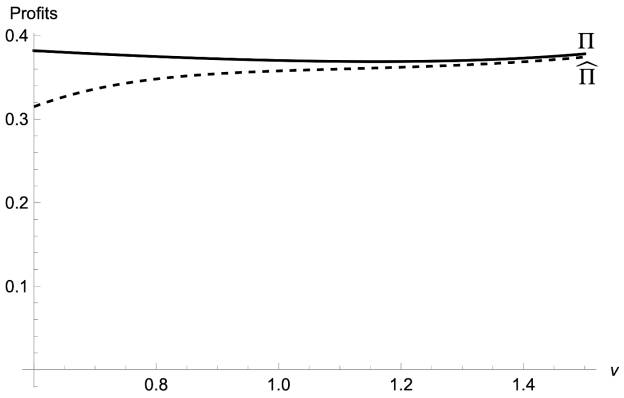


Figure 15: Effect of v on profits

5.5.3 Effects of probability of realising a peach on the durable goods market

All else equal, for buyers of new goods, an increase in β leads to an increase in expected quality of the good realised in the next period. On the other hand, for the manufacturer, it increases the proportion of high quality used goods available in the next period, comprising those in use by the previous owners and those sold in the used goods market. Figures 16, 17 and 18 show the impact of β on the optimal supply of new goods, the certification fee and the prices in both the markets, respectively, for $s = 0.5$ and $v = 1$.

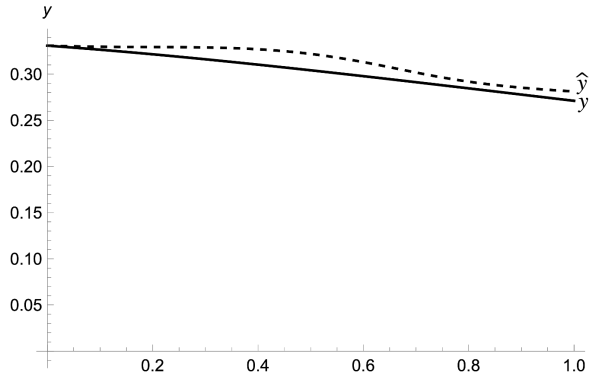


Figure 16: Effect of β on y and $\widehat{y}$

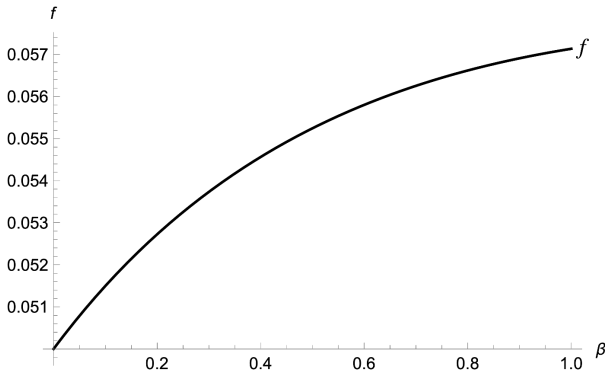
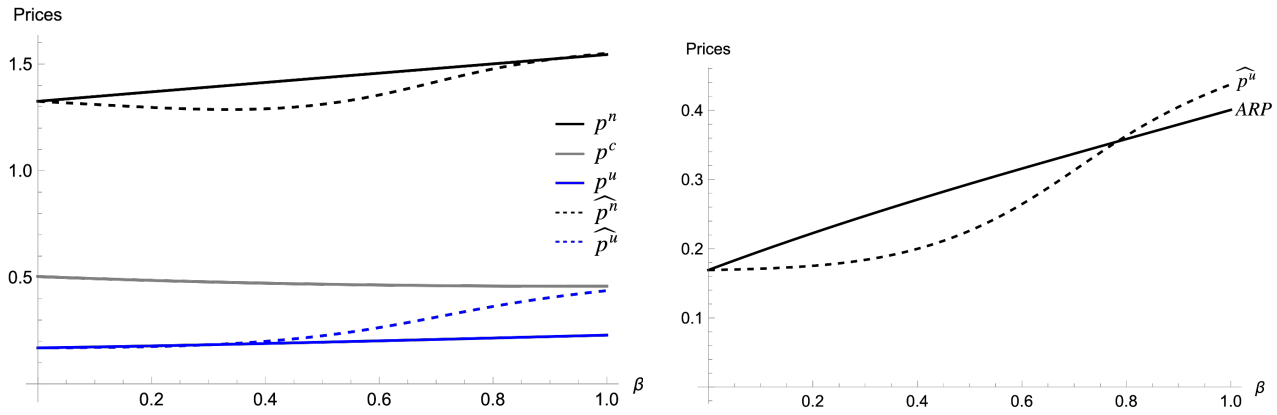


Figure 17: Effect of β on f

In both the markets with and without certification, new goods supply decreases in β. As β increases, the proportion of high quality used goods in the market increases. This increases the competition from used goods to new goods, leading to a decrease in y and $\widehat{y}$. Without certification, $\widehat{q^u}$ increases as β increases, leading to an increase in $\widehat{p^u}$ and hence $\widehat{p^n}$. With certification, though p^c and p^u do not change significantly, ARP increases with β as the number of certified used goods relative to non-certified used goods increases. As the resale value increases, p^n also increases.

As shown in Figures 16 and 18, both the difference between $\widehat{y}$ and y and that between $\widehat{p^n}$ and p^n increase initially and then decrease. These correspond to the changing substitution and resale value effects of certification, respectively. At very low levels of β, almost all used goods are of low quality so there is low information asymmetry. Similarly, at very high values of β, almost all



(a) All prices **(b) Average resale prices**

Figure 18: Effect of β on prices

used goods are of high quality and consumers do not need certification to differentiate between qualities. Thus, the information asymmetry is more significant at intermediate values of β, leading to a greater impact of certification on the market. Figure 19 shows the impact of β on profits. The monopolist's excess profits from certification also initially increase with β and then decrease. The monopolist chooses not to provide certification for $\beta \geq 0.68$.

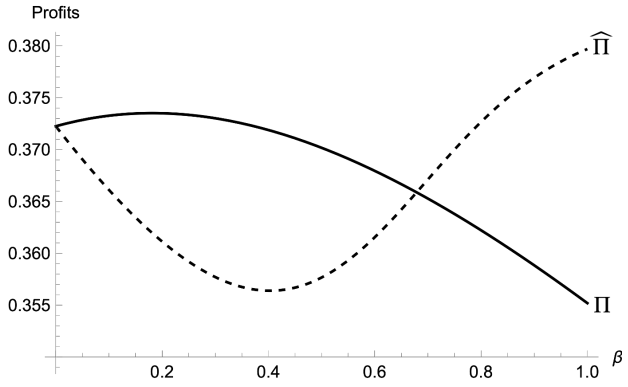


Figure 19: Effect of β on profits

Result 7: The manufacturer benefits most from certification at intermediate values of β, where quality uncertainty is high. For $\beta \geq 0.68$, the monopolist chooses not to provide certification.

5.6 Third-party certification

In real world durable goods markets, there are multiple types of certification programs available. In the car market, dealers and third-party certifiers (for instance, The AA in the United Kingdom) provide their own certification programs for used goods as well. The results for this model also shed light on why manufacturers prefer to offer their own certification programs. As Figures 7, 12 and 17 show, the manufacturer charges a very low fee for certification. Figure 20 illustrates the relative profits earned by the manufacturer in markets with certification from the fee of certification and

the resale value effect of certification, at $v = 1$ and $\beta = 0.5$.

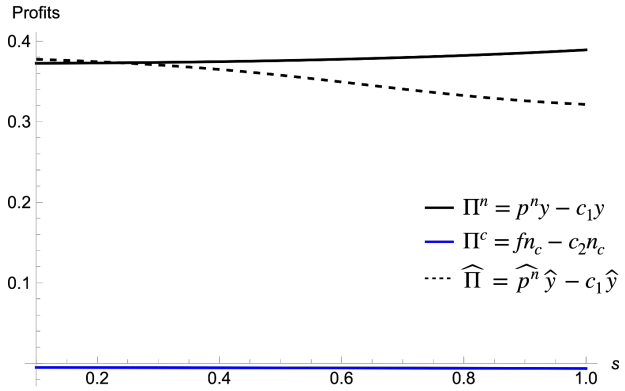


Figure 20: Relative profits earned from the new goods market and certification

As Figure 20 shows, the manufacturer does not cover the costs of certification with the fee, and the increase in profits results from the resale value effect only. For lower values of δ, the manufacturer can earn $f n_c - c_2 n_c > 0$, but this gain is generally minimal. The main increase in profits still results from the resale value effect. On the other hand, the dealer only gains from the fees of certification. To analyse the fee charged by a third-party dealer, suppose that the timing of the game is as follows:

1. The manufacturer sets y to maximise profits:

$$max_y \Pi^m = max_y (p^n y - c_1 y) \tag{27}$$

2. Then, the dealer sets f to maximise profits:

$$max_f \Pi^d = max_f (f n_c - c_2 n_c) \tag{28}$$

3. Then, the consumers make consumption decisions taking the tuple (v, s, β, P, f, y) as given, where $P = (p^n, p^c, p^u)$. Market clearing determines the prices.

For $\delta \to 1$ and $c_1 = 0.2$, the equilibrium results are:[4]

$$\tilde{f} = \frac{1}{2}(c_2 + v\tilde{y}) \tag{29}$$

where

$$\tilde{y} = \frac{2(19 - 5v - 5s(1-\beta)) - 5\beta c_2}{10(2(8 - 3v - s(1-\beta)(3+\beta)) + \beta v)} \tag{30}$$

Comparatively, with manufacturer certification, the equilibrium values are:

[4]The expressions in terms of δ are provided in Appendix C.

$$f = \frac{c_2}{2} \tag{31}$$

$$y = \frac{19 - 5v - 5s(1-\beta) - 5\beta c_2}{10(8 - 3v - s(1-\beta)(3+\beta))} \tag{32}$$

The results show that the dealer charges a higher certification fee than the original manufacturer. Therefore, the model with dealer certification has a larger consumer segment of strategic holders and exhibits more adverse selection than manufacturer certification. This reduces the resale value effect of certification on the new goods market. The manufacturer earns greater profits when it offers certification itself, despite the costs of testing, as it can increase the resale value effect by *subsidising* the certification process. Thus, the manufacturer prefers to provide certification for the used goods itself even when there are third-party intermediaries available to provide certification.

6 Discussion and Concluding Remarks

The monopolist designs its certification program to balance the gains from the resale value effect and the fees charged for certification and the losses from the substitution effect and the costs of certification. It adjusts f, the fees charged for certification, to maximise profits. The monopolist charges a positive fee for certification to separate the markets for high and low quality used goods. Certification completely solves the information asymmetry but the fee creates frictions in the market, leading to some consumers choosing to be strategic holders and thus resulting in adverse selection. These results are in line with real world durable goods markets, particularly the car market. Despite the prevalence of certification programs, some consumers still prefer holding on to their own cars rather than frequently exchanging them.

The introduction of certified used goods affects not only the sales in the used goods market but also the new goods market. Chen & Hsu (2017) arrive to a different conclusion when they study the CPO programs. They state that "*The CPO option attracts the used goods buyers and non-buyers; it does not cannibalize the sales of new goods*" (Chen & Hsu, 2017). Their results rely on two critical assumptions: (1) the monopolist provides certification without incurring any costs and (2) the CPO option does not affect the proportion of owners that hold on to high quality used goods (they assume the proportion of strategic holders in new good buyers to be exogenous). As the results show, the main impact of certification of used goods on the new goods market is through changes in the incentive to hold on to peaches. Furthermore, the monopolist adjusts the fee of certification to balance the resale value and substitution effects, and partly cover the costs of certification. These effects are not captured in Chen & Hsu (2017)'s analysis.

Furthermore, the monopolist only provides certification when products are more durable (low v) and/or when there is a higher degree of information asymmetry in the used goods market (low values of β and/or high values of s). Though certification reduces the problem of adverse selection, it does not necessarily increase the consumer surplus and social welfare in these markets. Through an increase in the prices of new goods and a reduction in the supply of new goods, the monopolist extracts all the excess surplus generated by solving the information asymmetry problem. The welfare impact of certification on the durable goods market is comparable to the impact of other

manufacturer interventions in the second-hand markets and certification of single-use consumer goods. Rao et al. (2009) show that trade-ins also have an ambiguous impact on social welfare. Similarly, Lizzeri (1999) shows that certifiers extract all the informational surplus from certification in single-use consumer goods. Contrarily, Hendel & Lizzeri (2002) show that leasing is welfare improving for the durable goods markets.

The existing studies on certification are based on third-party certifiers and single-use consumer goods. As this paper shows, the incentives of the original manufacturer for certifying used goods are different from those of third-party certifiers. Furthermore, the certification of used goods in the durable goods market simultaneously impacts the markets for new goods and used goods. These effects cannot be determined from studies on single-use consumer goods. Thus, this study helps planners make more informed decisions about whether to allow original manufacturers to provide certification in the used goods market.

Appendix

Appendix A: Model without certification

In this section, we provide a benchmark model for analysing consumer behaviour in the durable goods market with information asymmetry and adverse selection in the used goods market. This model is developed by Rao et al. (2009).

Setup

The model setup for consumers and products is unchanged from the model with certification. In the market for new goods, both the consumers and the monopolist have perfect knowledge about the quality of the new good. On the other hand, the market for used goods is characterised by information asymmetry. Used goods sold in any period t were purchased and used by new good buyers in period $t-1$. Thus, the sellers of used goods have perfect knowledge about its quality. However, the buyers of used goods cannot determine the quality of a used good before purchase and use. The buyers form rational expectations about the quality of used goods $\widehat{q^u}$.

The manufacturer decides the supply of new goods y in each period to maximise profits:

$$max_y \Pi = max_y(p^n y - c_1 y) \tag{1}$$

where p^n is the price of new goods and c_1 is the marginal cost of production.

Market clearing determines the price for new goods p^n and used goods p^u. In any period, in the first stage, the firm sets y, based on predicted behaviour of rational consumers. Then, the consumers make consumption decisions taking the tuple (v, s, β, p, y, q^u) as given, where $p = (p^n, p^u)$.

Steady state equilibrium

The model analysis and solution follow the same steps as the model with certification, and are described below.

Characterising consumer behaviour

In any period t, consumers can choose one of the following actions: buy a new good, keep a used good, buy a used good, or not use the good. As before, given the tuple (v, s, β, p, y, q^u), a consumer decides her action in any period based on the discounted expected utility of actions in consecutive periods. The possible actions of rational consumers in consecutive periods lead to four types of consumers:

1. Compulsive buyers: acquire a new good in each period

2. Strategic holders: acquire a new good in some period t, keep the good if they observe quality q^g in period $t+1$ and sell otherwise
3. Used good buyers: acquire a used good in each period
4. Non-buyers: never buy a good

The above classification of types of consumers comprehensively defines all possible patterns of rational consumer behaviour in this model in a steady state (see proof in Appendix B). There are now four segments of consumers based on their quality valuations θ, shown in Figure A1.

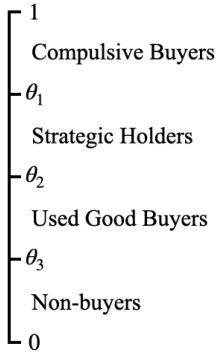


Figure A1: Consumer segments in the model without certification

Discounted expected utility for each type of consumer

The derivation of the value functions for each consumer segment follows the same procedure as before. Due to information asymmetry in the used goods market, both good and bad quality used goods are sold at the price p^u.

Compulsive Buyers: $\theta \in [\theta_1, 1]$

$$V^n(\theta) = \frac{(\theta q^n - p^n) + \delta p^u}{1-\delta} \tag{2}$$

Strategic Holders: $\theta \in [\theta_2, \theta_1]$

$$V^s(\theta) = \frac{(\theta q^n - p^n) + \delta(\beta\theta q^g + (1-\beta)p^u)}{(1-\delta)(1+\delta\beta)} \tag{3}$$

Used Good Buyers: $\theta \in [\theta_3, \theta_2]$

$$V^u(\theta) = \frac{\theta q^u - p^u}{1-\delta} \tag{4}$$

Non-buyers, for which $\theta \in [0, \theta_3]$, get zero utility.

Segment sizes

As before, we calculate the segment sizes by finding the quality valuations (θ) for marginal consumers between types:

$$V^n(\theta_1) = V^s(\theta_1),\ V^s(\theta_2) = V^u(\theta_2),\ V^u(\theta_3) = 0 \tag{5}$$

This gives the following expressions for the valuations of indifferent consumers between segments:

$$\theta_1 = \frac{p^n - p^u(1+\delta)}{v} \tag{6}$$

$$\theta_2 = \frac{p^n - p^u(1+\delta)}{(2-q^u)(1+\beta\delta) - v\beta\delta} \tag{7}$$

$$\theta_3 = \frac{p^u}{q^u} \tag{8}$$

Market clearing

The equilibrium in the new goods market in any period is characterised by:

$$(1-\theta_1) + \frac{1}{1+\beta}(\theta_1 - \theta_2) = y \tag{9}$$

The derivation of this equilibrium condition is similar to the derivation for the model with certification. The equilibrium in the used goods market in any period is characterised by:

$$(\theta_2 - \theta_3) = (1-\theta_1) + \frac{1-\beta}{1+\beta}(\theta_1 - \theta_2) \tag{10}$$

The LHS is the demand for used goods, which only comprises of the segment [θ_3,θ_2], the used good buyers. The RHS represents the supply of used goods. The first term is the supply of used goods from compulsive buyers, who never hold on to their used goods. The second term represents the used goods sold by strategic holders, who sell their used goods only if they deteriorate to a bad quality q^b with probability $1-\beta$.

Quality of used goods

Since consumers are rational, the expected quality of used goods q^u in the market equals the quality supplied of used goods. Using equation (10) to define the supply of used goods:

$$q^u = \frac{(1-\theta_1)(\beta q^g + (1-\beta)q^b) + \frac{1-\beta}{1+\beta}(\theta_1 - \theta_2)q^b}{(1-\theta_1) + \frac{1-\beta}{1+\beta}(\theta_1 - \theta_2)} \tag{11}$$

Market clearing prices

Using equations (6)-(8) to define market segments and equation (11) to define q^u, we solve for the market clearing prices using equilibrium conditions given in equations (9) and (10).

Proposition A.1: Given y, the following prices clear the markets for new goods and used goods, respectively:

$$p^n = q^u(1+\delta)(1-2y) - \frac{v(1-y)(1+\beta)((2-q^u)(1+\beta\delta) - v\beta\delta)}{\beta(q^u-2)(\beta\delta+1) + v\,(\beta^2\delta - 1)} \tag{12}$$

$$p^u = q^u(1-2y) \tag{13}$$

where

$$q^u = 2 - v + \frac{s(\beta-1)}{1+\beta(\lambda-1)} \tag{14}$$

and

$$\lambda = 1 - \frac{1}{2\beta} - \frac{s(1-\beta)(1+\beta\delta)}{2v(1+\beta)} + \frac{\sqrt{y\left((\beta-1)^2\beta^2 s^2 y(\beta\delta+1)^2 - 2\beta\left(\beta^2-1\right)sv(3y-2)(\beta\delta+1) + (\beta+1)^2v^2y\right)}}{2vy\beta(1+\beta)} \tag{15}$$

Using the market clearing prices given by equations (12) and (13), we solve the firm's profit maximization problem:

$$max_y \Pi = max_y(p^n y - c_1 y) \tag{16}$$

The solution to the maximisation problem in equation (16) gives the equilibrium supply of new goods. Substituting this into equations (12) and (13) yields the equilibrium prices of new and used goods.

Appendix B

This section provides the proofs skipped in the main text.

Lemma B.1: The equilibrium in the new goods market in any period is characterised by:

$$(1-\theta_1)+\frac{1}{1+\beta}(\theta_1-\theta_2)=y \tag{17}$$

Thus, the proportion of strategic holders, segment $[\theta_2,\theta_1]$, that demands new goods in any period is

$$\frac{1}{1+\beta} \tag{18}$$

Proof: While the model cannot predict each consumer's behaviour in the segment for strategic holders, the steady state analysis allows for a characterisation of the segment behaviour as a whole. Let x_t be the proportion of segment $[\theta_2,\theta_1]$ consumers that demand new goods in period t. Then, $1-x_t$ comprises the proportion that keep their used goods in period t. In period $t+1$, a proportion β of x_t will have high quality used goods and will hold on to their used goods. In a steady state, the proportion of the segment that holds their used goods must be the same in every period. Thus,

$$1-x_t=\beta x_t \tag{19}$$

$$x_t=\frac{1}{1+\beta} \tag{20}$$

Accordingly, the proportion of the strategic holders that hold their used goods is

$$1-x_t=\frac{\beta}{1+\beta} \tag{21}$$

■

Lemma B.2: The possible actions of rational consumers in consecutive periods lead to five types of consumers in the steady state in the model with certification.

Proof: There are 36 possible patterns of actions that a consumer can take in any two consecutive periods, given by the 6×6 matrix in Table B1. Given (v, s, β, p, f, y), a rational consumer only chooses the patterns of actions in the cells marked by a tick-mark. The proof proceeds by showing that actions in all the other cells (marked by a cross) are not consistent with rationality.

Given (v, s, β, p, f, y), suppose a rational consumer chooses to buy a new good instead of a certified or a non-certified used good in period t. In period $j \neq t$, given (v, s, β, p, f, y) is unchanged, a rational consumer will not choose to buy a certified or a non-certified used good instead of a new good. Similarly, a buyer of a certified or a non-certified used good in period t would not choose otherwise in period $j \neq t$. Similarly, if a consumer chooses not to use a product in any period t, it is not rational for her to buy either a new or a used good in any period $j \neq t$.

Suppose a consumer with valuation θ buys a new good in period t, it deteriorates to quality q^b in period $t+1$ and she decides to keep it instead of selling it for p^u and buying a new good. Then, it must be that:

$$\begin{aligned} & \theta q^b > p^u + \text{net utility from buying a new good in period } t+1 \\ \iff \quad & \theta q^b - p^u > \text{net utility from buying a new good in period } t+1 \end{aligned}$$

Then, it must be that she also prefers buying a used good over buying a new good in period t. Thus, a rational consumer never holds on to a used good with quality q^b.

Lastly, suppose that a consumer keeps a used good with quality q^g in period t. It must be that she bought a new good in period $t-1$. Then, as shown above, it is not rational for her to buy a certified or a non-certified used good in period $t+1$. She can also not keep the good in period $t+1$ as it lasts only two periods. Similarly, if a consumer buys a used good (either certified or non-certified) in period t, she cannot keep it in period $t+1$ as the product lasts only two periods.

		Period $t+1$					
		Buy new	Keep q^g	Keep q^b	Buy cert. used	Buy non-cert. used	Not use
Period t	Buy New	✓	✓	X	X	X	X
	Keep q^g	✓	X	X	X	X	X
	Keep q^b	X	X	X	X	X	X
	Buy cert. used	X	X	X	✓	X	X
	Buy non-cert. used	X	X	X	X	✓	X
	Not use	X	X	X	X	X	✓

Table B1: Consumer behaviour in consecutive periods in the model with certification

■

Lemma B.3: The possible actions of rational consumers in consecutive periods lead to four types of consumers in the steady state in the model without certification.

Proof: There are 25 possible patterns of actions that a consumer can take in any two consecutive periods, shown in the 5×5 matrix in Table B2. Given (v, s, β, p, y, q^u), a rational consumer only chooses the patterns of actions in the cells marked by a tick-mark. The proof proceeds by showing that actions in all the other cells (marked by a cross) are not consistent with rationality.

Given (v, s, β, p, y, q^u), suppose a rational consumer chooses to buy a new good in period t instead of a used good. In period $j \neq t$, given (v, s, β, p, y, q^u) is unchanged, she must find it rational to buy a new good instead of a used good. Thus, any consumer that buys a new good in any period t, does not choose to buy a used good in any period $j \neq t$. By similar logic, any rational consumer that buys a used good in period t does not buy a new good in period $j \neq t$. Similarly, if a consumer chooses not to use a product in any period t, it is not rational for her to buy either a new or a used good in any period $j \neq t$.

Suppose a consumer buys a new good in period t and it deteriorates to quality q^b. She can sell it for p^u and buy a used good with quality $q^u \geq q^b$ at the same price, as used goods contain both good and bad quality products. Thus, it is not rational to keep a used good with quality q^b in any period t.

Lastly, suppose that a consumer keeps a used good with quality q^g in period t. It must be that she bought a new good in period $t-1$. Thus, as shown above, it is not rational for her to buy a used good in period $t+1$. She can also not keep the good in period $t+1$ as it lasts only two periods. Similarly, if a consumer buys a used good in period t, she cannot keep it in period $t+1$ as the product lasts only two periods.

		Period $t+1$				
		Buy new	Keep q^g	Keep q^b	Buy used	Not use
Period t	Buy New	✓	✓	X	X	X
	Keep q^g	✓	X	X	X	X
	Keep q^b	X	X	X	X	X
	Buy used	X	X	X	✓	X
	Not use	X	X	X	X	✓

Table B2: Consumer behaviour in consecutive periods in the model without certification

■

Appendix C

This section contains the full expressions of variables that are skipped in the main text.

Equilibrium values in the model with dealer certification

For $c_1 = 0.2$ and $c_2 = 0.1$, we have that in equilibrium:

$$\tilde{f} = \frac{1}{20} + \frac{v\tilde{y}(1+\beta)}{2(1+\beta\delta)}$$

$$\tilde{y} = \frac{15\beta + \delta\left(20 - \beta(\beta-20) + 20s\left(\beta^2-1\right)\right) + 20v(\beta+1) + 16}{20(\beta+1)(4(\delta+1) + 2s\delta(\beta-1)((\beta+2)+1) + v(\beta+2))}$$

Equilibrium values in the model with certification

For $c_1 = 0.2$ and $c_2 = 0.1$, we have that in equilibrium:

$$y = \frac{(\beta\delta+1)(\beta(\beta(\delta(20s-1)-1) - 20\delta(v-2)+34) - 20\delta(s+v-2)+36)}{\omega}$$

$$f = \frac{2s(\beta^2-1)(1+\delta(2+\beta(5v+2+\delta(\beta-5v+2))))}{\omega} + \frac{(1+\beta)\left(8(\delta+1)(\beta\delta+1) - 10\beta\delta v^2(1-\delta) + v\left(\beta\left(18-\beta(1-\delta)-24\delta^2\right) - 4\delta - 2\right)\right)}{\omega}$$

where

$$\omega = 160(1+\beta)(1+\delta)(1+\beta\delta) + 40s\left(\beta^2-1\right)(1+\delta(2+\beta))(1+\beta\delta) + 10v\left(2\delta(\beta(\beta(\beta-2)-6)-4) - \beta\delta^2(\beta^2+8(1+\beta)) - 4(1+\beta) - \beta^3\right)$$

Table C1 shows the equilibrium values for the main variables of the model with certification, simplified using the parameter values $\beta = 0.5$ and $\delta = 0.9$.

Variable	Equilibrium Value
y	$\frac{29(540s+1080v-4261)}{1740(65s-304)+194890v}$
f	$\frac{54v(5s+141+10v)+87(65s-304)}{1740(65s-304)+194890v}$
p^n	$\frac{108v(232941-35140s-32580v)-29(65s-304)(540s-4801)}{400(11310s+19489v-52896)}$
p^c	$\frac{15660s^2+29s(7019-4560v)-4(v-2)(66125v-140911)}{3480(65s-304)+389780v}$
p^u	$\frac{(2-s-v)(40890s+66125v-140911)}{56550s+97445v-264480}$
Π	$\frac{29\big(88816+48600s^2v-5s(377-36v(1080v-4261))+4v(755693+90v(540v-4261))\big)}{4000v(52896-11310s-19489v)}$
θ_1	$\frac{145s(6738v+377)+4v(410230v-995077)-255664}{100v(11310s+19489v-52896)}$
θ_2	$\frac{145s(13422v-377)+3266180v^2-8181422v+255664}{200v(11310s+19489v-52896)}$
θ_3	$\frac{179220s+295820v-687213}{3480(65s-304)+389780v}$
θ_4	$\frac{40890s+66125v-140911}{870(65s-304)+97445v}$

Table C1: Equilibrium in the model with certification

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