Tractor Troubles: Right to Repair in Durable Goods Duopolies*

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Abstract

Does strategic competition in an oligopolistic market for a durable good deter manufacturers from restricting repairs provided by third-parties or durable goods owners themselves? Manufacturers argue yes, while the right-to-repair movement argues no. To address this policy-based question, I develop a theoretical framework in which differentiated Bertrand durable good duopolists choose strategically whether or not to limit competition from durable good owners in the aftermarket for repairs. I present numerical and analytical evidence that there exist reasonable market conditions in which manufacturers have a profit-maximizing incentive to restrict repairs. Further, I explicitly derive such conditions and discuss their implication for right-to-repair policy. (JEL L20, L40, Q14, Q16)

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1 Introduction

Durable goods like phones, cars, tractors, and ventilators are increasingly harder to repair. Is this just a consequence of technological growth or are manufacturers deliberately restricting repairs to seek out rents and deter competition with their own repair services? Apple has often been criticized for designing iPhones to be difficult to repair by anyone other than Apple itself (Chugh, 2021). Mercedes prohibits owners of electric EQS sedans from opening the hood (Golson, 2021). Farmers complain that tractor manufacturers like John Deere, Case IH, and AGCO are locking tractor owners out of software, restricting access to diagnostics, and adding clauses to end-user license agreements requiring them to obtain repairs from only authorized dealerships (VICE 2020). If a tractor experiences a mechanical breakdown or software error, only a technician from a manufacturer-authorized dealership may be allowed to perform the needed repairs.

These restrictions on repairs can be prohibitively costly to durable goods owners, particularly during time-sensitive operations. Farmers sometimes purchase extra tractors just to have a backup if one breaks down during planting or harvest (Bode, 2021). Doctors rationed ventilators while waiting on the manufacturer to fulfill a recall towards the end of the COVID-19 pandemic (U.S. FDA, 2022). Repair restrictions may also incentivize consumers to replace their equipment earlier than necessary. Apple was criticized for engaging in "programmed obsolescence" by slowing down older iPhones to prevent unexpected shutdowns without informing owners (Allyn, 2020). On the other hand, manufacturers argue that repair restrictions can improve repair quality, prohibit tampering, protect their intellectual property, and provide other benefits to durable good users and the communities they live and work in by. For example, one social and environmental benefit of repair restrictions and obsolescence is the compulsory adoption of equipment with cleaner combustion engines.

On May 6th 2021, the U.S Federal Trade Commission submitted a report to Congress on anti-competitive practices in repair markets that details the practices manufacturers employ to limit competition. It describes repair restrictions as a form of product tying, which is illegal under the Sherman and Clayton Antitrust Acts (FTC 2021). On July 9th, 2021, President Biden signed the Executive Order on Promoting Competition in the American Economy. Among other actions, the Order encourages the FTC to "limit powerful equipment manufacturers from restricting people's ability to use independent repair shops or do DIY (Do It Yourself) repairs—such as when tractor companies block farmers from repairing their own tractors." The Order's explicit mention of tractor repairs underscores the importance of the issue for farmers and other stakeholders in the agricultural industry. The Order also follows the introduction of right-to-repair legislation in major agricultural states like Nebraska and California. Colorado passed the Consumer Right To Repair Agricultural Equipment bill in April 2023. In 2022, Farmers filed class action lawsuits in federal court alleging John Deere violated the Sherman Act (Claburn, 2022). In September 2022, the House of Representatives Subcommittee on Underserved, Agricultural, and Rural Business Development held a hearing wherein Ken Taylor, 2022 Chairman of the Associated Equipment Distributors, explicitly argued that manufacturers and dealers have a disincentive to restrict repairs because the primary equipment market is highly competitive and nothing prevents buyers from switching to a competitor's product at the time of purchase (Taylor 2022).

When we take a cursory look at markets and industries which have faced criticism over repair restrictions, it is clear that most manufacturers are not monopolists, although industry structure suggests the potential to exercise market power. For example, John Deere, the farm equipment firm that is most often associated with repair restrictions in the media, accounted for over 40% of total market share for farm equipment in 2023 (Nasdaq 2023). The smartphone industry is less consolidated, with Samsung leading the industry at approximately 19% market share in Q2 2024 (Counterpoint Research 2024). Thus, given that at least some of the relevant industries for right-to-repair legislation have multiple manufacturers with significant market shares competing for sales, it's unrealistic to treat manufacturers as monopolists in equipment markets. Manufacturers don't just compete with consumers for repairs, they compete with one or more other manufacturers over supplying bundles of new equipment and repairs. In this article I treat manufacturers as differentiated Bertand duopolists to evaluate the right-to-repair issue.

A key policy question is whether strategic competition between manufacturers disincentivizes restricting third-party or DIY repairs. Suppose equipment and repairs are homogeneous, equipment buyers are forward looking, and they obtain economically significant benefits from repairs. Then, because repair-conscious buyers would prefer to purchase equipment with the weakest restrictions on repairs and lowest repair price, we might expect competition for new equipment sales to disincentivize profit-maximizing manufacturers from restricting third-party repairs or charging repair prices above marginal cost. Yet, there is substantial anecdotal evidence that manufacturers are charging markups and restricting repairs, particularly in the market for agricultural equipment like tractors (FTC 2021).

This argument regarding strategic competition between manufacturers was rejected by the Supreme Court of the United States in *Eastman Kodak Co. v. Image Technical Servs.*, Inc., 504 U.S. 451 (1992). Copier and printer manufacturer Kodak argued that its refusal to sell proprietary parts to independent repair providers was not a case of product tying because it didn't have a monopoly over equipment that they could tie to equipment service. The crux of Kodak's argument was that it could not possibly charge a monopoly price for parts and/or service and still maintain a profitable level of market share in the equipment market as buyers would simply switch to its competitors. The Court found that Kodak's argument held no "basic economic reality". The majority opinion cited amicus curiae by the US Department of Justice Antitrust Division and Borenstein et al. (2000). The latter found that substantial costs of gathering information and switching brands would limit buyers' ability to respond to markups in the aftermarket, permitting Kodak to charge an aftermarket price between the competitive and monopoly levels.

Yet, Kodak's argument still appears 32 years later in discussions concerning the right to repair. To understand its persistence, we need to consider how anticompetitive restrictions on repair differs from Kodak's original supracompetitive pricing argument. I argue that the anecdotal evidence of repair restrictions suggests that the right-to-repair movement isn't only concerned about the resulting market price of repairs, but also the mechanisms which drive the partial or full foreclosure of competition from DIY, third-party, or other alternative repair options. Whereas the Kodak case focuses on the incentives to charge markups, the right-to-repair movement focuses more on manufacturers' incentives to restrict repairs from others or foreclose the independent/DIY repair market entirely. This illuminates an additional dimension of competition between manufacturers. Not only do manufacturers compete in setting equipment and repair prices, they compete over equipment repairability.

We could assume that equipment buyers would strictly prefer equipment with greater repairability, but would this guarantee that competition between manufacturers will preclude restrictions on repairs? What if a manufacturer finds that by restricting DIY or third-party repairs they can charge a repair price above marginal cost and increase their profits? Could such an incentive exist for multiple competing manufacturers? What market setting or conditions are necessary for such equilibria to exist? How might such existence conditions inform right-to-repair policy? Addressing these questions is the primary objective of this article.

Beyond the economic literature on aftermarket competition associated with Eastman Kodak Co. v. Image Technical Servs. (Klein, 1993; Chen and Ross, 1993; Shapiro and Teece, 1994; Shapiro, 1995; Borenstein et al., 2000; Cabral, 2014; Zēgners and Kretschmer, 2017; Martens and Mueller-Langer, 2020), literature directly addressing the right to repair is scarce. Kahane (2021) is the only article that studies the empirical impact of a right-to-repair policy. They apply synthetic control and difference-in-differences methods to estimate how Massachusetts's 2012 Right to Repair Act (H.4362) affected the number and market share of independent auto repair providers in the state. H.4362 required manufacturers of automobiles sold in the state to provide independent auto repair shops in the state with diagnostic and service information equivalent to what is made available to authorized dealerships. Kahane

(2021) finds that the legislation increased the market share of small independent repair shops by approximately 3 percentage points. Jin et al. (2022) is the only theoretical study that directly addresses the right to repair and the potential welfare and environmental impacts of right-to-repair legislation. Their model focuses on a monopolist equipment provider competing with heterogeneous consumers over repairs in an infinite horizon sequential game. They find evidence of a non monotone U-shaped price response in the product market which suggests that the impacts of right-to-repair legislation are ambiguous and depend on various market and product characteristics. They conclude by noting that "an interesting direction for future research is to study competing manufacturers".

To address whether a competitive market for equipment deters restrictions and markups in the aftermarket for repairs, I present a theoretical model wherein manufacturers compete over equipment and repair prices, as well as the extent they will each restrict repairs provided by equipment buyers. Thus, the model treats repair restrictions as endogenous choice variables subject to strategic interaction with competitors. The model focuses solely on identifying the rent-seeking or profit-maximizing incentives to restrict and/or markup repairs, ignoring any other incentives for manufacturers (protecting IP, controlling repair quality, etc.). In contrast to the theoretical literature developed in the context of the Kodak case, I make simplifying assumptions which omit switching and information costs for equipment buyers. Hence, because buyers are not as "locked-in" as in previous analyses, the model I present is closer to a best-case scenario for the Kodak competition argument to be economic reality.

Even in this scenario, I find there exist economically reasonable conditions where a monopolist equipment manufacturer has a clear profit maximizing incentive to restrict repairs, as do differentiated-product Bertrand duopolists. Using these derived conditions, I argue that market characteristics like the degree of differentiation between manufacturers, the consumer cost of new equipment, and consumer characteristics like the discount rate, DIY costs, and preferences for equipment quality, drive the existence and magnitude of the incentive to restrict repairs. These conditions can also be applied to derive testable hypotheses regarding how equipment repair prices may respond to changes in repair restrictions. I find that it is optimal for manufacturers to increase repair restrictions and prices in tandem. It is through this lens of the interaction between repair restrictions and the capacity to charge markups for manufacturer repairs in which Kodak's original competition argument could potentially be reversed to argue that policies abating repair restrictions should reduce the price of repairs given strategic competition between equipment manufacturers. I conclude with a discussion of how the conditions I derive inform right-to-repair policy, providing a possible explanation for why legislation targeting specific markets has succeeded where broader legislation has failed to engender sufficient political support.

2 Theoretical Framework

In this section, I present a theoretical framework that addresses whether manufacturers have an incentive to restrict consumer repairs. The framework is most similar to Borenstein et al. (2000). I add repair restrictions modeled as a continuous choice variable for manufacturers rather than as an exogenous characteristic of equipment. Another key difference is that I model consumers choosing from a discrete set of repair options, whereas Borenstein et al. (2000) used a continuous service quantity variable. These adjustments allow competition to determine the equilibrium level of repair restrictions, and express this equilibrium in terms of market shares across a distinct set of consumer repair choices.

I consider different industry structures with increasing degrees of competition and heterogeneity in the primary/new equipment market to address whether strategic competition in the equipment market disincentivizes restricting repairs or if there exists an incentive to restrict repairs under competition. I make restrictive assumptions about market conditions and equipment/repair characteristics detailed below to focus on the repair restriction mechanism and reduce solution complexity.

Consider a risk-neutral consumer who has already decided to purchase a single unit of new equipment from a manufacturer, which they use over the course of two periods to generate utility. The consumer must purchase repairs in the second period. I assume that equipment and repair purchases are compulsory and the consumer does not have an outside option in either period. Such an assumption is reasonable in the context of endemic essential equipment like tractors or phones. In the first period, consumers purchase equipment at price θ and obtain a fixed amount of utility. In the second period, their equipment will always break down or depreciate, reducing their utility in period two by a fixed amount. The consumer then chooses whether to repair the equipment themselves or purchase repairs from the manufacturer. As in Borenstein et al. (2000), the consumer can only purchase repairs from the original manufacturer of their equipment and not from a competing manufacturer if they choose not to perform repairs themselves. An equipment manufacturer chooses their prices for new equipment and repairs, as well as the degree to which they want to increase the "costliness" of consumer repairs. The latter takes the form of a markup on the consumer's cost of self-repair. Denote manufacturer repairs with M and consumer DIY repairs with C.

The consumer's total utility if they purchase repairs from a manufacturer is then

$$U_M = \Omega - \theta + \delta\left[\Omega - h - P\right] \tag{1}$$

where Ω is the single-period utility from using the equipment, δ is the consumer's discount rate, h is the utility loss due to equipment breakdown or depreciation, and P is the price of manufacturer repairs. Their total utility if they choose to perform their own repairs is

$$U_C = \Omega - \theta + \delta\left[\Omega - h - c - \gamma\right] \tag{2}$$

where c is the consumer's cost of of DIY or third-party repairs and γ is the markup on consumer repairs chosen by the manufacturer, also referred to as the repair restriction. A real-world example of this sort of mechanism is smartphone manufacturers requiring consumers to purchased specialized tools or subscriptions to access and repair their devices.

To introduce consumer heterogeneity with an eye towards deriving positive market shares for consumer and manufacturer repairs, assume that the consumer self-repair cost c is uniformly distributed on the closed interval 0 and 1, i.e. $c \sim U[0, 1]$.

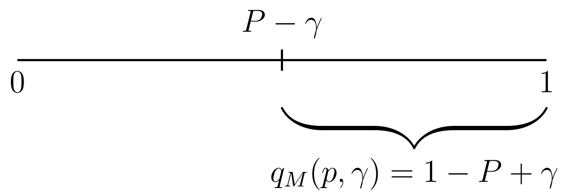
For simplicity, I omit the possibility of obtaining repairs through third-party independent repair providers. Thus, the complete set of equipment and repair options available to consumers in this framework depends solely on the number of equipment manufacturers. In the following subsections I derive equilibrium market shares, prices, and levels of repair restriction under a monopoly and a duopoly in the primary equipment market. In both cases, manufacturers face competition from consumers in the aftermarket for repairs.

2.1 Equipment Monopoly

I first consider a monopolist manufacturer as a benchmark case with which to compare against the duopoly case. The monopolist chooses θ, P and γ to maximize profits. I assume that the monopolist sets the new equipment price so that the net benefit of owning and repairing equipment across the two periods exceeds each consumer's utility from choosing not to buy equipment. Because there is a single supplier of equipment and mandatory purchases, their market share for equipment is 1 (100%). By imposing this restriction, I can ignore the monopolist's choice of θ because it is independent of the primary outcomes of interest in the repair market: its market share and price of repairs

Additionally, I assume that restricting consumer repairs is costly to the manufacturer and that these costs are quadratic in γ with marginal cost $\frac{k}{2}$, which is sufficient for an interior solution to the monopolist's profit-maximization problem to exist. The monopolist has perfect information about the distribution of consumer costs so they know how their choices affect consumer demand for manufacturer repairs. To derive consumer demand and market shares for each repair option, I find the c that identifies the consumer who is indifferent between manufacturer and consumer repair by equating the utility of the two options (Equations 1 and 2). Figure 1 shows the location of the indifferent consumer on the repair cost line and indicates the section of the line that defines the market share for manufacturer repairs.

Figure 1: Repair Cost Line and Indifferent Consumer Under Equipment Monopoly



Given the consumer demand function for manufacturer repairs $q_M(p, \gamma)$, the monopolist's profit-maximization problem is

$$\max_{P,\gamma} \quad \Pi = P\,(1 - P + \gamma) - k\frac{\gamma^2}{2}.$$

Solving the first order conditions, the monopolist's optimal repair price is $P^* = \frac{k}{2k-1}$ with repair restriction $\gamma^* = \frac{1}{2k-1}$ and profit $\Pi^* = \frac{k^2 - \frac{1}{2}k}{(2k-1)^2}$. As a first attempt at exploring how the right to repair would affect the monopolist's optimal price and profits, I examine when consumers have the full right to repair, e.g. $\gamma = 0$. In this case the monopolist repair price is $P^{RtR} = \frac{1}{2}$ with profit $\Pi^{RtR} = \frac{1}{4}$, regardless of k. Now suppose $k = 2$, so then without the right to repair the monopolist restricts the cost of consumer repairs by $\gamma^* = \frac{1}{3}$ and increases their profits to $\Pi^* = \frac{1}{3}$.[1] Therefore, in this highly simplified framework, we've shown that a monopolist has a profit maximizing incentive to restrict consumer repairs, so consumers wouldn't have the complete right to repair.

2.2 Equipment Duopoly

In this section I develop a differentiated products Bertrand duopoly of equipment manufacturers, A and B, who simultaneously set prices and repair restrictions to maximize profits. I assume that equipment is vertically differentiated according to quality and that consumers are heterogeneous in their preference for quality. This permits positive market shares for both

[1]Note that γ^* will decrease with k, but only reaches 0 in the limit to infinity.

manufacturers in equilibrium. The consumer has four choices:

Purchase equipment and repairs from A:

$$U_{MA} = \Omega - \theta_A + \alpha\Lambda + \delta\left[\Omega - h - P_A\right]$$

Purchase equipment from A and self-repair:

$$U_{CA} = \Omega - \theta_A + \alpha\Lambda + \delta\left[\Omega - h - c - \gamma_A\right]$$

Purchase equipment and repairs from B:

$$U_{MB} = \Omega - \theta_B + \delta\left[\Omega - h - P_B\right]$$

Purchase equipment from B and self-repair:

$$U_{CB} = \Omega - \theta_B + \delta\left[\Omega - h - c - \gamma_B\right]$$

where A and B denote firms. The subscripts M and C refer to manufacturer repairs and self-repairs, respectively. Λ denotes the utility from quality of equipment manufactured by A. I normalize the corresponding quality value for equipment manufactured by B to be zero. α denotes a consumer's intensity of preference for equipment quality. As with consumer repair costs, I assume $\alpha \sim U[0,1]$. Thus, each consumer in our market for equipment is identified by a coordinate on a unit square in the (c, α) plane. Without lost of generality, I assume manufacturer A has a quality advantage over B, e.g $\Lambda > 0$. I derive market shares for the four options by identifying the indifferent consumers for all pairs of choices and plotting them on the unit square to obtain the following six distinct indifference conditions for the differentiated products Bertrand duopoly:

$$U_{MA} = U_{CA} \implies c = P_A - \gamma_A \tag{3}$$

$$U_{MB} = U_{CB} \implies c = P_B - \gamma_B \tag{4}$$

$$U_{MA} = U_{MB} \implies \alpha = \frac{\theta_A - \theta_B + \delta\left(P_A - P_B\right)}{\Lambda} \tag{5}$$

$$U_{CA} = U_{CB} \implies \alpha = \frac{\theta_A - \theta_B + \delta\left(\gamma_A - \gamma_B\right)}{\Lambda} \tag{6}$$

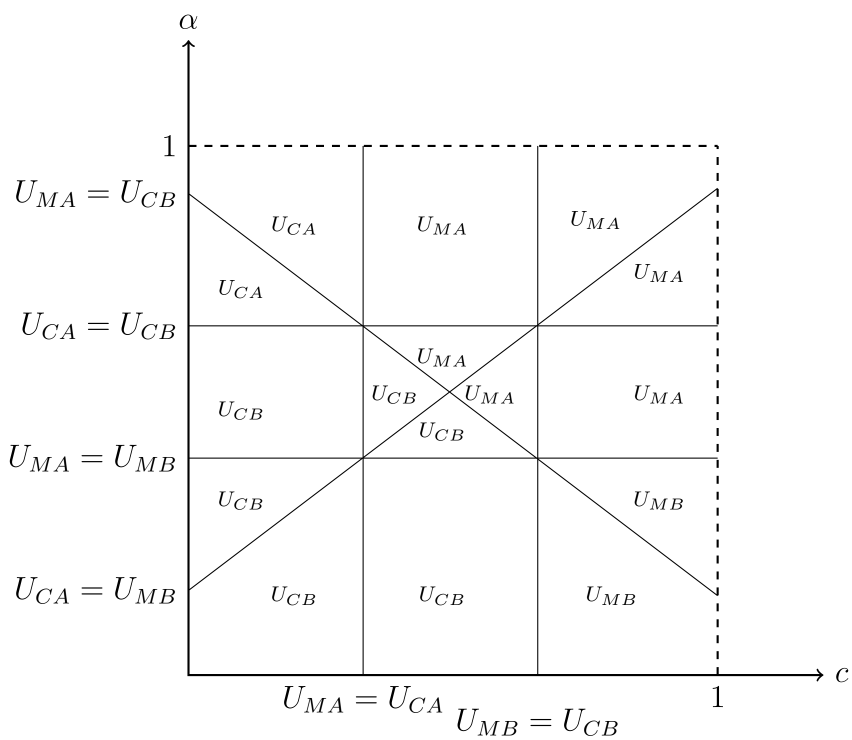
$$U_{MA} = U_{CB} \implies \alpha = \frac{\theta_A - \theta_B + \delta\left(P_A - \gamma_B\right)}{\Lambda} - \frac{\delta}{\Lambda}c \tag{7}$$

$$U_{MB} = U_{CA} \implies \alpha = \frac{\theta_A - \theta_B + \delta\left(\gamma_A - P_B\right)}{\Lambda} + \frac{\delta}{\Lambda}c. \tag{8}$$

Equations (3) and (4) identify the consumers indifferent between manufacturer and self-provided repairs for each firm. Increasing the price of manufacturer repairs increases the share of consumers that provide their own repairs, whereas increasing the repair restriction reduces this share. Equation (5) tells us that if the consumer is restricted to only purchase repairs from a manufacturer, then they choose to purchase from the manufacturer offering the equipment-repair bundle that maximizes their utility given their taste for equipment quality. Equation (6) shows that the choice between manufacturers for consumers who self-repair depends primarily on the initial prices and repair restrictions for equipment. Equations (7) and (8) define the consumers indifferent between providing their own repairs for equipment purchased from A (B) and buying and repairing equipment from B (A).

The conditions described in Equations (3) through (8) are linear functions of c and α, which I can plot in the (c, α) coordinate plane. These indifference lines then divide the (c, α) unit square into various regions with consumers on either side of an indifference line preferring one choice over the other. By plotting all of these lines on the unit square I can identify market shares for each choice as a function of the manufacturers' choice variables. For each region I check which of the choices maximizes the utility of every consumer in the region. Market shares are then obtained by summing the areas of the regions where each choice dominates. Figure 2 provides an example of how these indifference lines divide the consumer unit square.[2]

Figure 2: Indifference Lines and Dominant Consumer Choices When $P_A - \gamma_A < P_B - \gamma_B$



These market shares defined demand and the choice that dominates some of these regions depends on variables endogenous to the manufacturers. Specifically, the difference between repair price and restriction for each manufacturer (Equations (3) and (4)) determines whether Equation (7) or (8) is binding for identifying market shares. If manufacturer A provides cheaper, yet more restrictive repairs, than manufacturer B, i.e. $P_A - \gamma_A < P_B - \gamma_B$, then Equation (7) binds and consumers with $c \in [P_A - \gamma_A, P_B - \gamma_B]$ choose between purchasing both equipment and repairs from A or purchasing only equipment from B and providing their own repairs. The indifference line $U_{CA} = U_{MB}$ is no longer relevant because the

[2]It is possible to plot all of these lines neatly within the unit square only under strict assumptions regarding their intercepts and slopes, which I don't explicitly outline here. For example, one such condition is $0 \leq 1 - \frac{\theta_A - \theta_B}{\Lambda} \leq 1 \implies \theta_A \geq \theta_B$. If at a given equilibrium an indifference line does not lie within the unit square than it will not be relevant in the division of market shares. For example, if $\gamma_A = \infty$ at equilibrium then equations (3),(6),(8) will not intersect the unit square. This will result in the complete foreclosure of the market share for consumer self-repairs of A's equipment, which is consistent with a complete restriction on repairs.

other consumer options with utility U_{MA} and U_{CB} dominate across all consumers with $c \in [P_A - \gamma_A, P_B - \gamma_B]$. Alternatively, if $P_A - \gamma_A > P_B - \gamma_B$ then Equation (8) binds and consumers purchase repairs from B rather than repairing equipment from A themselves. Finally, if $P_A - \gamma_A = P_B - \gamma_B$, neither of these equations bind and consumers independently consider the choice between purchasing from A or B and the choice to provide their own repairs or purchase repairs from the manufacturer.

Because I define market shares by the sum of the geometric area of each distinct region where a choice dominates, and these dominant regions differ across the three cases described above, our market share functions are quite complex. Figures 3 through 5 plot the areas of the unit square that identify market shares for each consumer choice across each of the three cases: (i) $P_A - \gamma_A < P_B - \gamma_B$, (ii) $P_A - \gamma_A > P_B - \gamma_B$, (iii) $P_A - \gamma_A = P_B - \gamma_B$. The areas of the figures are marked as follows: CA (cyan) is the share of consumers who purchase new equipment from manufacturer A and provide their own repairs, MA (orange) is the share who purchase both new equipment and repairs from A, CB (lime) is the share who purchase new equipment from manufacturer B and provide their own repairs, and MB (pink) is the share which purchase both new equipment and repairs from B.

Figure 3: Market Shares Case (i): $P_A - \gamma_A < P_B - \gamma_B$, Equation (7) binds

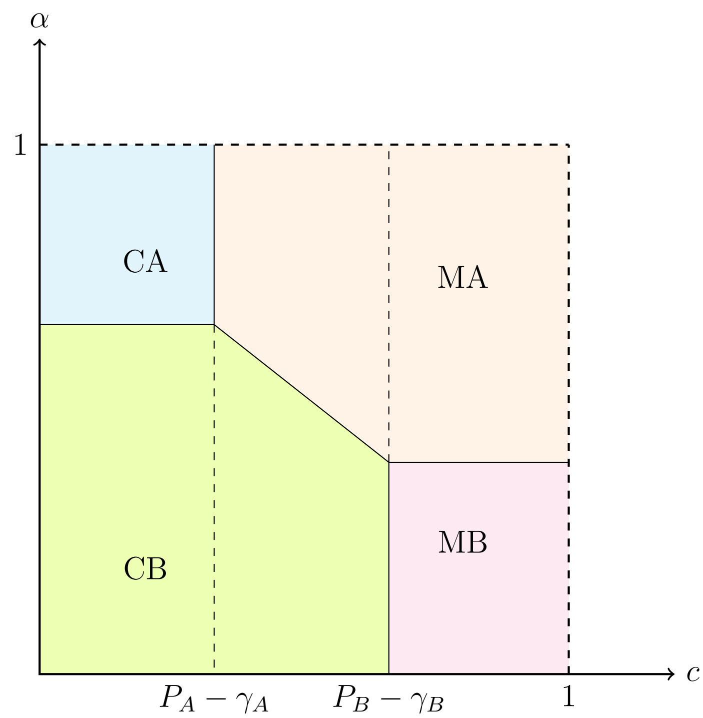


Figure 4: Market Shares Case (ii): $P_A - \gamma_A > P_B - \gamma_B$, Equation (8) binds

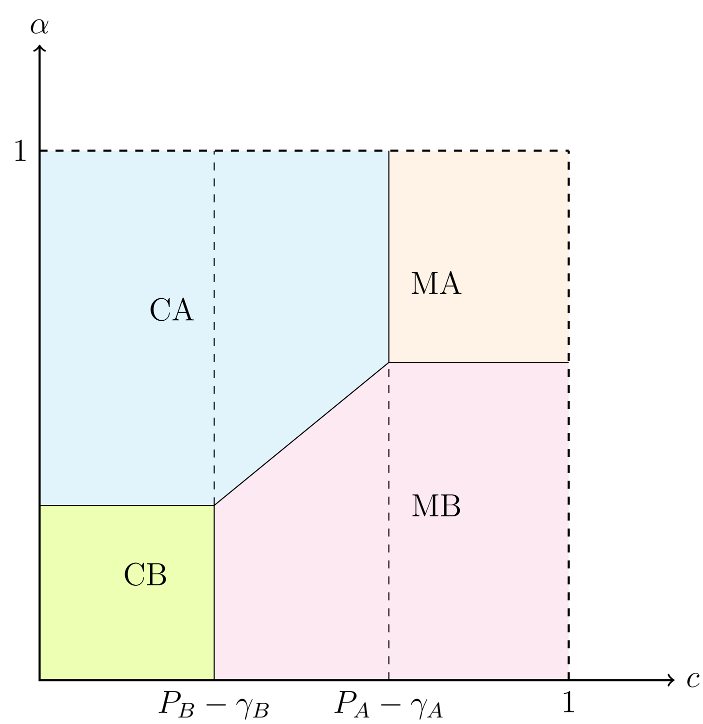
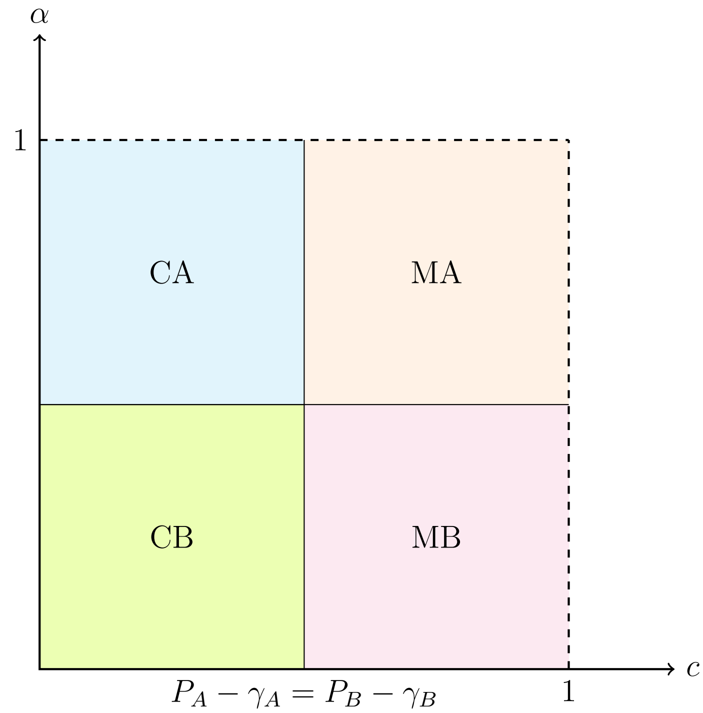


Figure 5: Market Shares Case (iii): $P_A - \gamma_A = P_B - \gamma_B$, neither (7) or (8) bind



Though we have three discrete cases with distinct expressions for each market share, it is possible to write each market share functions as a single expression by using max and min functions. Let S_{ij} denote a market share with $i \in \{M, C\},\ j \in \{A, B\}$. The market share functions which represent buyer demand for each of the repair choices are

$$\begin{aligned} S_{MA} = &\left(1 - \max\left\{P_A - \gamma_A, P_B - \gamma_B\right\}\right)\left(1 - \frac{\theta_A - \theta_B + \delta(P_A - P_B)}{\Lambda}\right) \\ &+ \max\left\{(P_B - \gamma_B) - (P_A - \gamma_A), 0\right\}\left(1 - \frac{\theta_A - \theta_B + \delta(\gamma_A - \gamma_B)}{\Lambda} + \frac{\delta}{2\Lambda}\left((P_B - \gamma_B) - (P_A - \gamma_A)\right)\right) \end{aligned}$$

$$\begin{aligned} S_{CA} = &\min\left\{P_A - \gamma_A, P_B - \gamma_B\right\}\left(1 - \frac{\theta_A - \theta_B + \delta(\gamma_A - \gamma_B)}{\Lambda}\right) \\ &+ \max\left\{(P_A - \gamma_A) - (P_B - \gamma_B), 0\right\}\left(1 - \frac{\theta_A - \theta_B + \delta(P_A - P_B)}{\Lambda} + \frac{\delta}{2\Lambda}\left((P_A - \gamma_A) - (P_B - \gamma_B)\right)\right) \end{aligned}$$

$$\begin{aligned} S_{MB} = &\left(1 - \max\left\{P_A - \gamma_A, P_B - \gamma_B\right\}\right)\left(\frac{\theta_A - \theta_B + \delta(P_A - P_B)}{\Lambda}\right) \\ &+ \max\left\{(P_A - \gamma_A) - (P_B - \gamma_B), 0\right\}\left(\frac{\theta_A - \theta_B + \delta(\gamma_A - \gamma_B)}{\Lambda} + \frac{\delta}{2\Lambda}\left((P_A - \gamma_A) - (P_B - \gamma_B)\right)\right) \end{aligned}$$

$$S_{CB} = \min\left\{P_A - \gamma_A, P_B - \gamma_B\right\}\left(\frac{\theta_A - \theta_B + \delta(\gamma_A - \gamma_B)}{\Lambda}\right)$$
$$+ \max\left\{(P_B - \gamma_B) - (P_A - \gamma_A), 0\right\}\left(\frac{\theta_A - \theta_B + \delta(P_A - P_B)}{\Lambda} + \frac{\delta}{2\Lambda}\left((P_B - \gamma_B) - (P_A - \gamma_A)\right)\right).$$

Given that these functions are derived from simple geometric formulas on the unit square, (e.g. area of a square or triangle) they exhibit noticeable symmetry. We see this same kind of symmetry in the expressions for market shares as with the monopolist manufacturer. Because the corners of each area are determined by the intersections of the indifference lines (Equations (3) through (8)), there are many equivalent representations of these functions. Here I've chosen what I consider to be the simplest representation which uses Equations (3) through (6) to express the intersection points.

2.3 Duopolist Choice Problem and Strategies

Given their respective market share functions, manufacturers' profit-maximization problems are

$$\max_{\theta_A, P_A, \gamma_A} \quad \Pi_A = (\theta_A + P_A)(S_{MA}) + (\theta_A)(S_{CA}) - k\frac{\gamma_A^2}{2} \tag{9}$$

$$\max_{\theta_B, P_B, \gamma_B} \quad \Pi_B = (\theta_B + P_B)(S_{MB}) + (\theta_B)(S_{CB}) - k\frac{\gamma_B^2}{2} \tag{10}$$

where k is identical for the manufacturers.[3] Unlike the monopoly case, the duopolists' new equipment prices are relevant for all consumer equipment/repair options even with the compulsory equipment purchase assumption. Following Borenstein et al. (2000), I assume that manufacturer costs of production for both equipment and aftermarket repairs are zero to make these specifications of the objective functions more tractable. I also assume that the manufacturers make their pricing and restriction choices simultaneously and that these choices are public knowledge. Both manufacturers have perfect information about how their choices affect consumer market shares and all possible choices of their competitor.

Solving the manufacturers' profit maximization problems gives us their best response

[3] Constraints which restrict choices to the unit square are omitted, so the solutions to (9) or (10) are the ones for the general problem.

functions which result in a Nash equilibrium at their intersection. In order to answer my first research question, I prove that a Nash equilibrium exists where at least one manufacturer restricts consumer repairs, e.g $\gamma_A^* > 0$ or $\gamma_B^* > 0$.

3 Restricting Repairs May Be Profitable

Let $\nu_i = (\theta_i, P_i, \gamma_i)$ for $i \in \{A, B\}$ denote a vector of manufacturer i's choices. Define a Nash equilibrium as a pair (ν_A^*, ν_B^*) such that

$$\Pi_i(\nu_A^*, \nu_B^*) \geq \Pi_i(\nu_A, \nu_B) \quad \forall\ (\nu_A, \nu_B) \neq (\nu_A^*, \nu_B^*),\ i \in \{A, B\}\,.$$

Solving for the Nash equilibria of this model is challenging given that the market share functions are discontinuous at $P_A - \gamma_A = P_B - \gamma_B$.[4] Consequently, I identify conditions where $\nu_i^0 = (\theta_i, P_i, 0)$ is not a Nash equilibrium using a proof by contradiction. To do so, I assume that not restricting repairs is an equilibrium. Then I show that it is profitable for at least one manufacturer to deviate and restrict repairs. If the profit functions were continuous everywhere on the unit square, I could accomplish this by deriving conditions where, given manufacturer B's choices, manufacturer A's first order condition for restricting repairs is non-zero. Instead, I rely on a more discrete approach in which I slightly increase manufacturer A's level of repair restriction and show that this lead to higher profits. First, I describe the economic intuition behind this approach. Second, I present computational evidence that suggests a Nash equilibrium may exist where $\gamma_A > 0$ and $\gamma_B > 0$. Finally, I prove this result analytically.

3.1 Economic Intuition

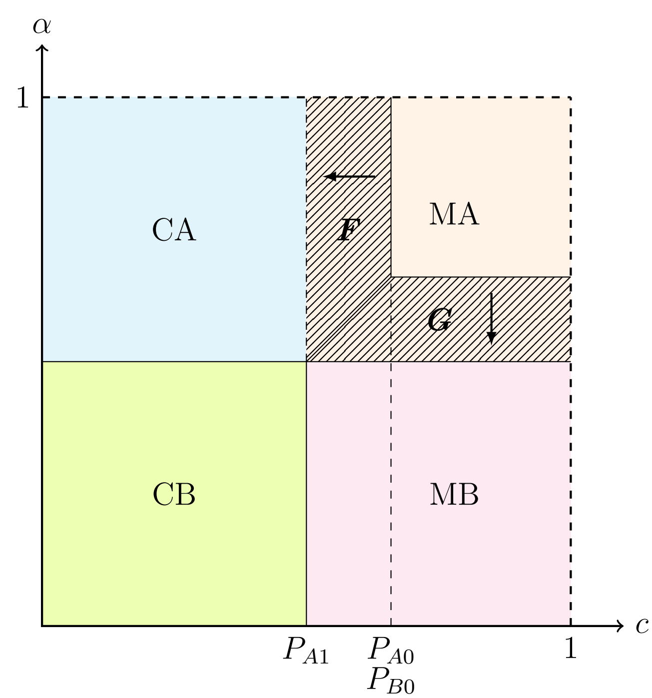
Suppose we fix each manufacturers' level of repair restriction at zero: $\gamma_A = \gamma_B = 0$. Then manufacturers only compete in their choices of equipment price θ_i and repair price P_i.

[4] The left and right hand limits differ at $P_A - \gamma_A = P_B - \gamma_B$.

Equipment repairs are assumed to be homogeneous across manufacturers because they are only differentiated in new equipment quality. Therefore, consumers should be indifferent between either manufacturers' repair services when neither restricts repair. The equilibrium repair price then follows from standard undifferentiated Bertrand price competition.

For example, if we start at some $P_{A0} = P_{B0} > 0$ which is not an equilibrium, either manufacturer can increase their repair market share by reducing their price of repairs. Figure 6 shows how market shares would shift if manufacturer A lowers their repair price to $P_{A1} < P_{B0}$. In this case, consumers of A's equipment in region F switch from DIY repairs to manufacturer repairs. This will increase A's profits since $\theta_A + P_A > \theta_A$, i.e. selling a bundle of equipment and repairs is worth more than selling just the equipment. Consumers of B's equipment and repairs in region G will switch to manufacturer A's equipment and repairs. Hence, A has an incentive to set a repair price lower than their competitors (manufacturer B and DIY consumers). By the same argument, manufacturer B has an incentive to lower their repair price.

Figure 6: Undifferentiated Bertrand price competition for repairs when $\gamma_A = \gamma_B = 0$



Given the manufacturers' competitive incentives to lower their repair prices, when neither firm can restrict repairs ($\gamma_A = \gamma_B = 0$), they will reach equilibrium at some point $P_A^* = P_B^*$ in the market for repairs. If manufacturer A were to slightly increases their repair price away from this equilibrium level by some small $\epsilon > 0$, they would lose market share for both equipment (CA + MA) and repairs (MA) as consumers switch to manufacturer B. This is Kodak's argument in practice. A does not have a profit incentive to deviate from a competitive repair price when $\gamma_A = 0$.

Now suppose that manufacturer A's repair restriction is not fixed at zero. I show that it is possible for A to recoup their losses from raising their repair price above the competitive level by restricting repairs in tandem with raising the price. Because $P_A - \gamma_A \geq 0$ on the unit square, A cannot restrict repairs unless they set $P_A > 0$, e.g. by increasing their repair price by ϵ. Now suppose that A increases their repair restriction γ_A by the same ϵ so that $(P_A + \epsilon) - (\gamma_A + \epsilon) > 0$. This markup on the cost of DIY repairs compels some consumers of A's equipment to switch from DIY to manufacturer repairs.

By restricting repairs, A is able to recover the market share they lost to competition with DIY repairs, thus selling more repair services at a higher price. However, A does not recoup all foregone market share at their higher repair price. Some consumers will instead find it optimal to switch to manufacturer B in response to A's restrictions. Therefore, manufacturer A faces a trade-off as restricting repairs increases their marginal revenue at the cost of losing some equipment market share to manufacturer B. Whether or not A has a profit incentive to restrict repairs depends on whether the gain in revenue on their post-restriction market share exceeds the revenue from market share lost to their competitor B. In the next subsection, I present computational evidence showing how this economic intuition leads to an approximate Nash equilibrium using a discrete grid of manufacturer choices.

3.2 Numerical Evidence

Though it is challenging to solve this model directly using traditional analytical methods, it is possible to identify an approximate solution using computational methods for a given set of parameters. I accomplish this by using a simple grid search over a discrete sample of potential manufacturer choices within the unit square.[5] An alternative approach would be to linearize the manufacturers' profit-maximization problems with explicit unit square constraints.

I start with a set of exogenous parameters (δ, Λ, and k) and a discrete sample of endogenous variables (θ_A, θ_B, P_A, P_B, γ_A, and γ_B). I use $\delta = 0.9$, $\Lambda = 1$, and $k = 0$ as a baseline set of parameters. I use the sequence $[0, 1.1]$ with steps of 0.1 to generate the sample of endogenous variables. This is a substantial limitation of the coarse grid search approach as we have to limit manufacturers to a small set of discrete choices for prices and repair restrictions, but this is sufficient for this computational example. I include 1.1 for both the P_i and γ_i choices because only $P_i - \gamma_i > 0$ needs to be satisfied for the choices to be within the unit square.

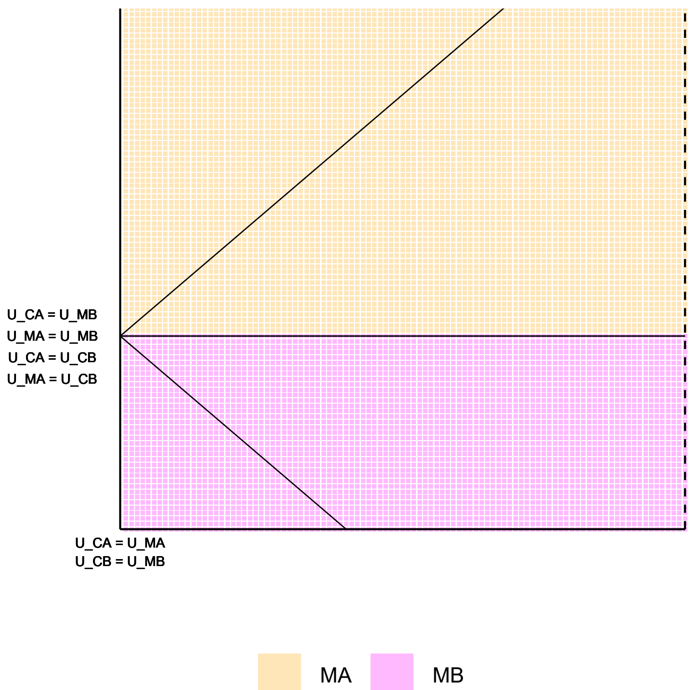
Given these sets of exogenous and endogenous variables, I generate a data set which covers all possible combinations of the latter. For each combination I compute market shares for each consumer choice and the corresponding profits for each manufacturer according to Equations (15) and (16). I generate a best-response function for each manufacturer $i \in \{A, B\}$ by taking the set(s) of (θ_i, P_i, and γ_i) that maximize profits for every combination of their competitor's choices into a "best-response" data set. Finally, I derive the Nash equilibrium computationally by identifying the common elements of these best-response data sets for the two manufacturers. The resulting Nash equilibrium is presented in Table 3. Figure 7 depicts this equilibrium using the market share plot. As restricting repairs is free and following the economic intuition discussed previously, we see complete foreclosure of consumer DIY repairs in this example. The checkered pattern across the plot area represents the coarseness of the grid.

[5]The grid search is written in R. All simulation code is available upon request.

Table 1: Grid Search: Nash Equilibrium

θ_A^*	P_A^*	γ_A^*	θ_B^*	P_B^*	γ_B^*	CA Share	MA Share	CB Share	MB Share	Π_A	Π_B
0	0.8	0.8	0	0.4	0.4	0.0	0.64	0.0	0.36	0.512	0.144

Figure 7: Numerical Nash Equilibrium Market Share Plot



It is also necessary to verify that this Nash equilibrium maximizes each manufacturer's profits given their competitor's choices. I do so visually, though another reasonable approach would be to report a gradient value and hessian matrix eigenvalues to verify the FOC and SOC for the optimum. Figures 8 and 9 plot profits for manufacturer A and B, respectively, with all variables other than P_i and γ_i fixed at their Nash equilibrium values.

Figure 8: Manufacturer A's Profits

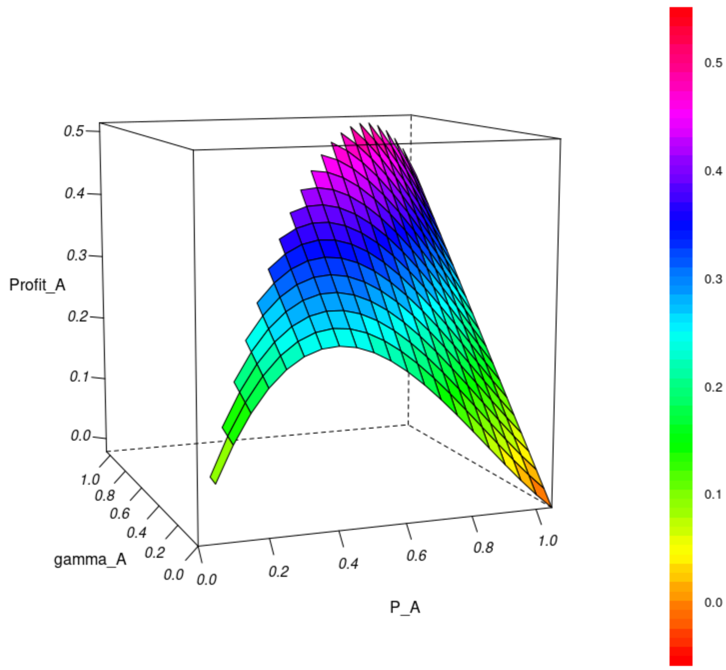
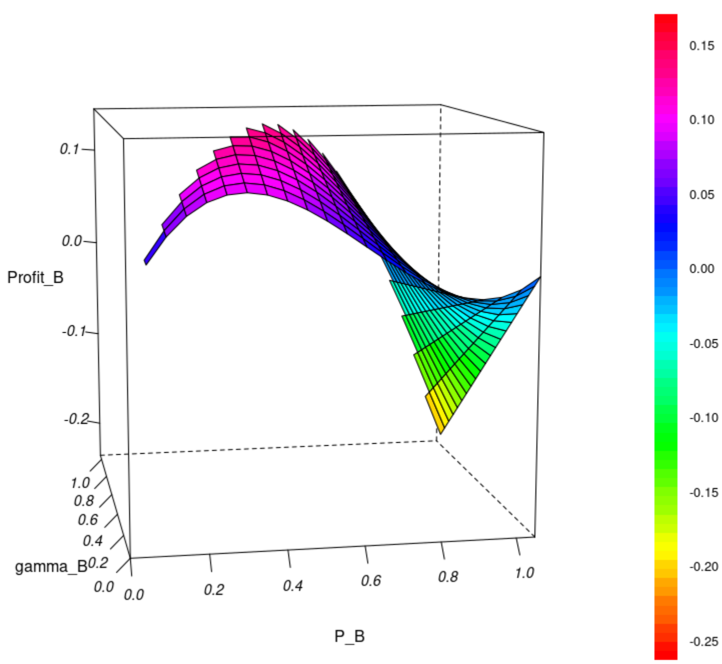


Figure 9: Manufacturer B's Profits



The jagged edge of the plots results from the discreteness of the sample grid and the constraint that $P_i - \gamma_i \geq 0$. One key takeaway from both profit plots is that both firms profits are maximized along the 45 degree line where $P_i = \gamma_i$. Manufacturer A's profit function given B's choices appears concave or at least quasiconcave such that, for every P_A, setting $\gamma_A = P_A$ generates the most profit. This also suggests that A has a dominant strategy. Manufacturer B's profit function exhibits a similar patter but has an inflection point at some point $P_B > P_A^*$ because B can increase their profits within this price regime by selling a more repairable product than A at a higher price. Yet this region of B's profit is not a global maximum. The concavity in B's profit function around the maximum also suggests B will have a dominant strategy, so mixed strategy Nash equilibrium is unlikely.

3.3 Analytical Proof

Lemma 3.3.1. *$P_i^* = \gamma_i^*$ for $i \in \{A, B\}$ for any Nash equilibrium on the unit square when.*

Proof. Follows from the economic intuition and numerical evidence presented in the previous subsections. All $P_i < \gamma_i$ would be off the unit square and each manufacturer only needs to restrict up to $P_i = \gamma_i$ to completely foreclose consumer DIY repairs. Restricting beyond P_i incurs additional cost with no additional revenue, so $P_i^* < \gamma_i^*$ cannot be a Nash equilibrium.

$P_i > \gamma_i$ cannot be a Nash equilibrium. This follows from the same logic used to prove that prices are set at marginal cost under classic Bertrand competition, but the minimum price is just γ_i. Manufacturer can always increase its profits by reducing P_i by some ϵ up to the point $P_i = \gamma_i$.

□

Theorem 3.3.2. *There exist conditions where manufacturer A can increase their profits by restricting repairs ($\gamma_A > 0$) given manufacturer B's best response. Thus, not restricting repairs is not always a Nash equilibrium.*

Proof. Assume there exist a pair of strategies $(\nu_A^0; \nu_B^0) = (\theta_A^*, 0, 0; \theta_B^*, 0, 0)$ where not restricting repairs is a Nash equilibrium. Now suppose we increase P_A and γ_A by a small amount denoted by $\epsilon > 0$. Lemma 1 implies these choice variables must be increased in tandem. Then we have

$$\begin{aligned}\Pi_A(\theta_A^*, \theta_B^*, \epsilon, 0, \epsilon, 0) = &\quad (\theta_A + \epsilon)\left(1 - \frac{\theta_A - \theta_B + \delta\epsilon}{\Lambda}\right) \\ \Pi_A(\theta_A^*, \theta_B^*, 0, 0, 0, 0) = &\quad \theta_A\left(1 - \frac{\theta_A - \theta_B}{\Lambda}\right)\end{aligned}$$

For $(\theta_A^*, \theta_B^*, P_A^* = 0, P_B^* = 0, \gamma_A^* = 0, \gamma_B^* = 0)$ to be a Nash equilibrium, it must be the case that

$$\Pi_A(\theta_A^*, \theta_B^*, \epsilon, 0, \epsilon, 0) - \Pi_A(\theta_A^*, \theta_B^*, 0, 0, 0, 0) \leq 0.$$

Thus, the additional profit of restricting repairs must be nonpositive. Solving for the additional profit, we have

$$\begin{aligned}&\Pi_A(\theta_A^*, \theta_B^*, \epsilon, 0, \epsilon, 0) - \Pi_A(\theta_A^*, \theta_B^*, 0, 0, 0, 0) \\ = &\quad (\theta_A + \epsilon)\left(1 - \frac{\theta_A - \theta_B + \delta\epsilon}{\Lambda}\right) - \theta_A\left(1 - \frac{\theta_A - \theta_B}{\Lambda}\right) \\ = &\quad \epsilon\left(1 - \frac{(1+\delta)\theta_A - \theta_B + \delta\epsilon}{\Lambda}\right)\end{aligned} \tag{11}$$

which is not necessarily nonpositive. For an equlibrium to be on the unit square the intercept of the indifference lines must satisfy $0 \leq 1 - \frac{\theta_A - \theta_B}{\Lambda} \leq 1$. Provided this term is relatively close to one, Equation 11 will be positive. Consequently, A has a profit-maximizing incentive to deviate, contradicting that $(\nu_A^0; \nu_A^0)$ is always a Nash equilibrium. □

3.4 Analysis

There are three immediate implications for right-to-repair policy. First, the theoretical result does not support the argument that competitive markets for durable goods like agricultural or medical equipment prohibits repair restrictions. I demonstrate that even under conditions where new equipment and aftermarket competition precludes charging supracompetitive repair costs, under some conditions manufacturers may have incentives to leverage their capacity to restrict repairs to exert market power over consumer DIY repairs and increase profits.

Second, I find that the incentive to restrict repairs likely depends on how consumers perceive the difference in durable good quality between manufacturers and their discount rate for repairs in the future. Additional profit from restricting repairs for each manufacturer increases with the degree of equipment differentiation and decreases with the consumer discount rate. If manufacturers A and B produce equipment of very similar quality, that is Λ is small, the profit incentive to restrict repairs is small and non positive. When consumers are myopic so δ is small, the profit incentive is relatively large. These results suggest that impacts of right-to-repair policy will depend on market and industry characteristics. If these characteristics are such that manufacturers do not have a preexisting incentive to restrict repairs then right-to-repair policy addressing this incentive is not warranted. This result provides an explanation for why right-to-repair legislation focusing on specific industries like cars or agricultural equipment has seen greater progress than broad legislation in state legislatures and antitrust litigation. For example, video game consoles can be as repairable as other electronics and equipment but the discount rate for playing video games in the future is likely lower than the discount rate for having a working tractor in an upcoming growing season.

Third, the scale of the difference in new equipment prices is likely to have a substantial impact on the incentives to restrict repairs. One of the unit square conditions requires that $\theta_A \geq \theta_B$, which implies that a greater difference in equipment prices would decrease additional profits from restricting repairs all else equal.

4 Discussion

Importantly, these results do not support any unconditional conclusions for right-to-repair policy. The main result is indeterminate regarding whether or not strategic competition between manufacturers modulates the incentive to restrict repairs; it depends on market characteristics. Nonetheless, I've presented a theoretical framework which we can use to identify testable hypotheses regarding the impacts of right-to-repair policy for future research. Further, to estimate potential welfare impacts, the model could be extended to consider key factors like the nonuniform distribution of consumer DIY costs and outside options for repairs like scrapping broken equipment and buying new again.

The model is not without limitations. Clearly representing repair restrictions as a markup on consumer DIY repair costs influences the results. I cannot yet rule out that considering an alternative representation, like $(\frac{1}{1+\gamma})c$ would drastically change the results. One approach to address this concern is to consider a more general model that does not require an explicit functional form for the repair restriction and instead relies only on assumed properties of a consumer DIY cost function. The computational evidence suggests that concavity or quasiconcavity in the relationship between manufacturer repair prices, repair restrictions, and profits is a necessary property to consider in a more general theoretical framework.

Another limitation is the lack of explicit consideration for more competitive market structures as my analysis only addresses equipment monopoly and duopoly. Markets for tractors, phones, and other durable goods generally have more than just two competing manufacturers. The two dimensional market share model can hypothetically be used to consider N firms with the market being increasingly divvied up as N increases. Yet adding even just one more manufacturer sharply increases the number of consumer choices and subsequent indifference conditions. A more general framework could again be the solution here, as shown in Borenstein et al. (2000) who take a limit as N goes to infinity to study incentives under perfect competition. Another option would be to consider an equipment market with a competitive fringe.

Additional limitations include the strict constraints on manufacturer choices being within the unit square and abstracting from the fact that equipment breakdowns are the result of a complex stochastic process that interacts with equipment quality.

5 Conclusion

While there is evidence that manufacturers are restricting repairs by requiring specialized tools or limiting access to diagnostic software and manuals, there is no evidence in the economic literature that precluding competition from consumers or third-party repair providers drives any manufacturer incentives to restrict repairs. Manufacturers argue that these practices help them provide safer and higher quality equipment. Upon initial inspection, the existence of multiple independent manufacturers for durable goods like tractors and smartphones suggests that strategic competition for equipment sales should preclude any incentive to provide less repairable equipment. However, consumers across a wide range of durable good industries have argued that these practices are increasing their costs by limiting their repair options. The Federal Trade Commission agrees and the executive branch, Congress, and some state legislatures are considering right-to-repair policy and legal action.

Using a theoretical framework in which differentiated Bertrand durable good duopolists strategically choose whether or not to limit competition from durable good owners in the aftermarket for repairs, I find that a profit incentive to restrict consumer DIY repairs may exist when the durable goods are vertically differentiated and consumers are myopic. This result suggests that the impact of right-to-repair policy can substantially vary across industries. In industries with a strong profit incentive to restrict repairs, right-to-repair policy may reduce repair prices and expand repair choices for consumers. In contrast, right-to-repair policy may be detrimental if applied to industries without such incentives and the policy is costly to enforce. Future research is needed to quantify the potential welfare impacts of right-to-repair policy and this theoretical framework presented in this work can serve as a starting for more structural and empirical work addressing this policy issue.

In my future work on repair restrictions and the right to repair, I plan to further explore how certain characteristics or parameters that vary across industries can augment manufacturer incentives. These include, but are not limited to, the expected lifespan of equipment or distribution of consumer self-repair costs. I'd also like to further explore how the number and dynamics of repair choices affect manufacturer incentives and consumer outcomes. These ideas will be examined with either direct extensions to the above model, or the development of a structural econometric model like a Berry-Levinsohn-Pakes (BLP) model of discrete choice in repair markets. Finally, a more immediate direction for my modeling efforts is to relax some of the assumptions in the original model, like adding an outside option to make equipment purchasing noncompulsory. Finally, I believe there is some potential to improve on how market shares for each combination of repairability are determined in the model, and to what extent they could be estimated empirically. Methods from computational geometry, voronoi diagrams for example may permit identification and visualization of market shares accounting for trade offs in characteristics like repairability, equipment quality, emissions levels, or price. See Merlo and Paula (2017) for an application of these methods in identifying the distribution of preferences for political candidates.

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