On the Right to Repair Agricultural Equipment

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1 Introduction

Does a competitive market for equipment preclude market power or anticompetitive practices in the aftermarket for repairs? Suppose equipment and repairs are homogeneous, consumers are forward looking, and they obtain reasonably substantial utility from repairs. Then because repair conscious consumers would prefer to purchase equipment with the weakest restrictions on repairs and lowest repair price, we might expect competition for new equipment sales to disincetivize profit maximizing manufacturers from restricting third-party repairs or charging repair prices above marginal cost. Yet, there is substantial anecdotal evidence that manufacturers in competitive equipment markets are restricting and charging markups on repairs, particularly in the market for agricultural equipment like tractors.

In a 2018 interview with VICE Media, Nebraskan farmer Tom Schwarz describes the essential role tractors and other agricultural equipment play in his business and everyday life (VICE 2020). They are necessary for time-sensitive operations like planting or harvesting, as well as regular farm upkeep. Tom reminisces about an era where repairing a tractor was a simple exercise in ordering mechanical parts and applying elbow grease. Yet, this era of easy repairs and unambiguous ownership has long since passed following advancements in tractor technology over the last four decades.

Tractor engines and other components are now controlled by sophisticated computers and proprietary software. Farmers complain that tractor manufacturers are locking them out of this software, restricting access to diagnostics, and adding clauses to end-user license agreements requiring them to obtain repairs from only authorized dealerships. If a tractor experiences a mechanical breakdown or software error, only a technician from a manufacturer-authorized dealership can perform the needed repairs. Tom pointedly states, “What we’ve had develop is essentially a monopoly on repair.” These restrictions on repairs can be prohibitively costly to a farmer, particularly during time-sensitive operations. They may also incentivize farmers to replace their equipment earlier than necessary, which may have significant consequences for the environment and agrifood economy.

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 mechanisms and practices manufacturers can employ to limit competition (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 repairs—such as when tractor companies block farmers from repairing their own tractors." The right to repair movement covers a broad range of durable goods, like smartphones and ventilators, but 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. Farmers have also filed class action lawsuits alleging a large U.S. tractor manufacturer violate the Sherman Act.

The FTC report and subsequent executive order are the first major federal efforts to address the right-to-repair movement. However, the FTC report and its empirical data do not provide robust peer-reviewed evidence identifying the need for regulation, nor whether these policies would improve overall welfare. Though the report catalogues a large number of reasons for supracompetitive repair prices, it does not provide direct evidence identifying repair prices in excess of marginal costs for manufacturers. Repairs can be expensive for reasons besides market power. For example, durable good repairs may require more skilled labor as technology advances. If this skilled labor is relatively scarce, then we would expect high repair prices consistent with high labor costs.

I argue that one of the first steps in addressing the right to repair issue is understanding the economics underlying the incentives for manufacturers to restrict and markup repairs. Manufacturers argue that restrictions on repairs can improve repair quality, prohibit tampering (emissions, resale market), protect their intellectual property, and provide other benefits. In contrast, I develop a theoretical model that solely focuses on identifying a rent-seeking incentive to restrict or markup repairs. Since their are usually multiple providers of relatively similar equipment, we must look at this incentive in the context of a competitive equipment market. Preliminary results suggest that a monopolist has a clear incentive to restrict repairs, while the incentive for duopolists is less clear.

The model I present also serves as an initial step contributing towards our understanding of how various market, consumer, and equipment characteristics determine to what extent manufacturers are incentivized to restrict and markup repairs, which may explain why the right to repair may be a bigger issue in some industries compared to others. Finally, this work aims to inform future empirical analysis of the right to repair by providing a framework for evaluating policy counterfactuals, welfare implications, and testable hypotheses regarding consumer and manufacturer repair choices.

2 Literature

Economic literature directly addressing the right-to-repair is scarce. Kahane (2021) is the only article which 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 percentage 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 percentages of repair shops by approximately 3 percentage points. It is not clear how substantial this impact is for consumers and third-parties from a welfare perspective, nor whether these benefits exceed the costs to manufacturers and regulators.

Jin et al. (2022) is the only study that directly addresses the right to repair in terms of economic theory. Their model focuses on a monoopolist equipment provider. One of their conclusions is that future work should consider the right to repair in the context of competitive equipment markets. Their work was only recently published and I plan to incorporate their complete findings in the next version of this paper.

The FTC report primarily describes repair restrictions as a form of product tying, a mechanism for which there exists a large body of literature which branches from economic theories of vertical integration and restraints, franchises, and general antitrust law. Whinston (1990) summarized this literature at that point in time, noting an ongoing debate over whether tying is an anti-competitive barrier to entry that harms consumers, or if tying benefits society through economies of scale, risk sharing, and/or other channels. He presents a model wherein product tying is a profitable strategy for a monopolist in one market to foreclose sales of a rival's product in a secondary market, regardless of whether the products are independent or complementary. In the context of right-to-repair, Whinston (1990) shows anti-competition incentives may motivate tying of new equipment sales to manufacturer-authorized repairs. The monopolist obtains another monopoly in the equipment market, which potentially harms consumers by subjecting them to more monopoly pricing, though Whinston (1990) concludes that the total welfare effect is ambiguous because monopolies may be more efficient in markets with scale economies and where consumers benefit from price discrimination.

The result that product tying leads to a successive monopoly became very important in the following years. In *Eastman Kodak Co. v. Image Technical Servs.*, Inc., 504 U.S. 451 (1992), Kodak argued that their refusal to sell their proprietary parts to independent repair providers was not a case of product tying because they didn't have a monopoly over equipment and parts that they could tie to equipment service. Their argument was based on the basic economic theory of perfect competition: competition for equipment sales precludes market power in the service aftermarket because rational consumers will purchase equipment with lower repair costs, ceteris paribus (Klein, 1993). The U.S. Supreme Court ruled against Kodak, deciding that if consumers are sufficiently "locked-in" by high costs of switching between manufacturers, then competition for equipment does not preclude market power in the aftermarket.

This decision reverberated through the field of economics (Klein, 1993; Chen and Ross, 1993; Shapiro and Teece, 1994; Shapiro, 1995; Borenstein et al., 2000). Klein (1993) argues that Kodak harmed consumers by creating an illegal hold up problem, changing their original contractual agreement and imposing an unexpected tie (John Deere EULA update 2016). Chen and Ross (1993) dissent, noting that Kodak's refusal to deal in the aftermarket may be necessary to discriminate in price between high-intensity and low-intensity service consumers in a manner that increases total welfare. Under their assumptions, right-to-repair policies could potentially reduce welfare as prices rise for some consumers when manufacturers can no longer price discriminate.

Shapiro and Teece (1994) and Shapiro (1995) address some of these post-*Kodak* theories of market power in aftermarkets. They argue that the "surprise" theory advanced by Klein (1993) does not hold up in the long-run. They also argue that the price discrimination theory discussed by Chen and Ross (1993) does not apply when the manufacturer does not have market power in the equipment market. Borenstein et al. (2000) provide an analysis focused on Kodak's competition argument. They model equipment manufacturers as a differentiated Bertrand duopoly who compete in both equipment and aftermarket service prices with heterogeneous consumers "locked-in" by high switching costs. They find that a highly competitive equipment market does not rule out market power in the aftermarket in this case. Instead, each manufacturer's aftermarket price is increasing in the degree of equipment market competition and even when differentiation goes to zero, which is perfect competition in the limit, manufacturers find it optimal to set aftermarket prices above marginal cost. Thus, Borenstein et al. (2000) provide theoretical evidence that the right-to-repair may be relevant even in industries with competitive equipment markets. Overall, the post-Kodak literature suggests that the incentives to restrict repairs and their effects on welfare are ambiguous. The potential impact of right-to-repair policies is therefore also ambiguous and may depend on complex market factors and how competition in the equipment market relates to competition in the repair market.

3 Manufacturers Restricting Consumer Repairs

In this chapter, I aim to build a theoretical framework that addresses whether manufacturers have an incentive to restrict consumer repairs. The framework is most similar to Borenstein et al. (2000) with the addition of repair restrictions modeled as a simple continuous choice variable for manufacturers. 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. I consider different industry structures with increasing degrees of competition and heterogeneity in the primary/new equipment market to address whether primary market competition disincentivizes restricting repairs to any extent or if there exists an incentive to restrict repairs under competition. I make significant assumptions about market conditions and equipment/repair characteristics to focus the model on the repair restriction mechanism and reduce solution complexity.

3.1 Theoretical Framework, Analysis, and Results

Consider a 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. We assume that equipment and repair purchases are compulsory and consumers do not have an alternative or reservation utility in either period. In the first period, they purchase the equipment and obtain a fixed amount of utility from it. In the second period, their equipment will always break down or depreciate, reducing their utility 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 repair themselves. An equipment manufacturer chooses their prices for new equipment and repairs, as well as the degree they want to restrict consumer repairs. The latter takes the form of a markup on the consumer's cost of self-repair.

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, θ is the price of new equipment, δ is the consumer's discount rate, h is the utility loss due to equipment breakdown or depreciation, and P is price of manufacturer repairs. Their total utility if they instead 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 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 specialized tools to access and repair their devices. In previous versions of this work I've considered alternative functional forms for repair restrictions. For example, I initially used a constant multiplier on consumer costs (e.g. $(1-\gamma)c$. This version uses just a cost markup to simplify later derivations. Future versions may consider other functional forms or return to the multiplier form.

To introduce consumer heterogeneity with an eye towards deriving positive market shares for both consumer and manufacturer repairs, suppose that the consumer repair cost c is uniformly distributed on the closed interval 0 and 1, i.e. $c \in U[0,1]$. Note that throughout this article, the M index will denote repairs obtained from a manufacturer and the C index will denote repairs obtained from the consumer.

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 sections I derive equilibrium market shares, prices, and levels of repair restriction under both monopoly and duopoly competition in the primary equipment market. In all cases, manufacturers face competition from consumers in the aftermarket for repairs.

3.1.1 Equipment Monopoly

Suppose a single manufacturer supplies equipment to consumers. The monopolist chooses θ, P and γ to maximize profits. For now I assume that the monopolist's production and repair costs are zero. I also assume that purchase of equipment is compulsory and that θ is chosen by the monopolist 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 we have a single supplier of equipment, their market share for equipment is restricted to 1. By imposing this restriction, we can ignore the monopolist's choice of θ because it is independent of our primary outcomes of interest, the market share for and price of repairs, provided all consumers purchase their equipment.

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 such that they know how their choices affect consumer demand for manufacturer repairs. To derive consumer demand and market shares for each repair option, we find the c that identifies the consumer who's 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 cost line and indicates the section of the line that defines the market share for manufacturer repairs, i.e the consumers with a higher c than the indifferent consumer and choose to purchase repairs from the manufacturer.

Given the consumer demand function for manufacturer repairs $q_M(p, \gamma)$, the monopolist's 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, we examine when consumers have the full right-to-repair, e.g. $\gamma = 0$. In this case the monopolist's repair price is $P^{RtR} = \frac{1}{2}$ with profit $\Pi^{RtR} = \frac{1}{4}$. 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 $\Pi^* = \frac{1}{3}$ Therefore, in this highly simplified framework, we've shown that a monopolist has a profit maximizing incentive to restrict consumer repairs when consumers don't have the right-to-repair.

3.1.2 Equipment Duopoly

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. For example, John Deere, the farm equipment firm that is most often associated with repair restrictions in the media, accounted for approximately 56% of total sales revenue for farm equipment in the first quarter of 2019 (Equipment Dealers Association 2019). The smartphone industry appears even more competitive with Samsung leading the industry with approximately 22% market share in Q1 2021 (Counterpoint Research 2021). 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 other manufactures over supplying bundles of new equipment and repairs.

In this section, I follow Borenstein et al. (2000) to 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, which permits positive market shares for both manufacturers in equilibrium. Under this duopoly, the consumer has four choices:

Purchase new equipment and repairs from A:

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

Purchase new equipment from A and self-repair:

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

Purchase new equipment and repairs from B:

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

Purchase new equipment from B and self-repair:

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

where the A and B indices denote firms and the C and M indices denote whether the consumer or manufacturer provide the necessary repairs in the second period. Λ will denote the utility from quality of equipment manufactured by A and I assume that the corresponding quality value for equipment manufactured by B is zero. α will denote a consumer's intensity of preference for equipment quality. As with consumer repair costs, we assume $\alpha \in U[0,1]$. 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, we assume manufacturer A has a quality advantage over B, e.g $\Lambda > 0$. In the monopoly case, we derive market shares for each consumer choice by identifying the indifferent consumers across all pairs of choices and plotting them on the consumer cost line. Accordingly, we 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) describe each consumer's trade-off between manufacturer and self-provided repairs. 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 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) combine the trade-offs between repair choices and manufacturers.

The conditions described in Equations (3) through (8) are linear functions of c and α, which we 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 we can identify market shares for each choice. For each distinct region we 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. (Note that we can only plot all of these lines neatly within the unit square under strict assumptions regarding their intercepts and slopes, which I don't explicitly outline here.)

One complication of this approach is that the choice that dominates some of these regions depends on variables endogenous to the manufacturers. Specifically, the ratio 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 $c \in [P_A - \gamma_A, P_B - \gamma_B]$ are choosing 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 other consumer options with utility U_{MA} and U_{CB} dominate across all consumers with $c \in [P_A - \gamma_A, P_B - \gamma_B]$. Instead, if $P_A - \gamma_A > P_B - \gamma_B$ then Equation (8) binds and consumers consider purchasing repairs from B vs. 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 we define market shares by the sum of the area of each distinct region where a choice dominates, and these dominant regions differ across the three cases described above, our market 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) $P_A - \gamma_A = P_B - \gamma_B$.

It remains to be shown whether we can eliminate one or more of these cases when we consider each manufacturer's profit-maximization problem and their strategic interactions. The colored 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.

3.1.2.1 Comparative Analysis of Market Shares

Before discussing each manufacturer's optimal pricing and repair restriction choices, we can get a sense of some of the trade-offs and incentives affecting their choices by observing how our market share plots adjust to arbitrary changes in endogenous variables. In this section I argue that my model admits some ambiguity in a manufacturer's choices because there are potential gains in market share from restricting repairs. There are many combinations of these cases with directions of shifts in manufacturer choice variables, some of which are more interesting than others. For this, I restrict the analysis to arbitrary changes in manufacturer B's actions and take manufacturer A's choices as given. I focus on shifts in repair price and restrictions because these are the most directly relevant for my research question. I've chosen the directions of each shift in B's endogenous variables for each case to focus on a "competitive" motive where B tries to adjust their price or restriction to provide a bundle of equipment and repairs more comparable to manufacturer A's. For example, if A is providing a cheaper bundle than B, I consider a reduction in B's price. Figures 6 through 9 visualize how market shares adjust following a change in B's repair price or restriction for cases (i) and (ii). Drawing these plots is just an exercise in observing how the slopes and intercepts of each indifference line (Equations (3) through (8)) are congruent with the shift in B's price/restriction, and noting which market shares expand or contract.

First, suppose that that we start in case (i) with $P_A - \gamma_A < P_{B0} - \gamma_B$ and manufacturer B reduces their repair price from P_{B0} to P_{B1}. Figure 6 shows that some consumers who would have purchased equipment from B and provided their own repairs now instead choose to purchase both equipment and repairs from B. This is depicted in the shaded region E of Figure 6. Additionally, some consumers of manufacturer repairs, particularly those with average to low preference for quality, choose to purchase equipment from B instead of A, which is depicted by region F. Thus, by reducing the repair price, B's bundle of equipment and repairs is more competitive with both manufacturer A's bundle price and some consumers providing their own repairs for B's equipment. In this instance, B gains both repair and equipment market share. This is a relatively standard result in the manner of Bertrand competition, and we would expect this trade-off between manufacturer B's repair price and market share to drive them to bring their price closer to A's repair price because it unambiguously increases their market share. Whether or not this movement is optimal would require considering B's complete profit maximization problem.

Consider next what happens to market shares when B increases their restriction of consumer repairs from γ_{B0} to γ_{B1} while remaining in case (i). Figure 7 shows that some consumers of B's equipment with relatively low preference for quality switch from self-repair to manufacturer repair, expanding B's repair market share as in the previous example. This is depicted in region I of Figure 7. Note that B's equipment market share does not change in this region; only their repair market share increases and the monetary gain from this portion of the shift is limited to their price of repairs multiplied by the change in their repair market share. B also losses some ground amongst consumers with average to high preference for equipment quality who provide their own repairs. These consumers switch to purchasing equipment from A, with some even choosing to purchase repairs from A when they originally would have provided their own repairs (region H of Figure 7). Region G depicts the share of consumers that switched to manufacturer A but continue to provide their own repairs. Thus, A gains market share from multiple market segments when B chooses to make their own equipment harder to repair. Since B both loses and gains repair market share following this shift, it's not at all obvious ex ante whether B has a positive incentive to restrict repairs. Depending on how these trade-offs resolve given market conditions and consumer characteristics, it may be optimal for B to differentiate from A with regard to their restriction of repairs. The existence of these effects on market shares for arbitrary values of choice variables suggests that a profit maximizing manufacturer may face a trade-off between increasing repair restrictions to gain repair market share or reducing their restriction to compete with other manufacturers for consumers that provide their own repairs. While we have not yet shown that this is a profit-maximizing solution, it illustrates the possibility that competition may not necessarily drive manufacturers to provide the same level of repairability in market equilibrium.

We now switch our focus to shifts in B's choices under case (ii) when A provides a more expensive and less restrictive bundle of equipment and repairs. We begin by considering an increase in B's repair price from P_{B0} to P_{B1} such that they provide a bundle more similar to A. This shift is depicted in Figure 8. In this instance, B loses some of their market shares to all other options. Some consumers with low preference for quality still purchase equipment from B, but now choose to provide their own repairs, resulting in a loss of repair market share (region L). Consumers with average or high preferences for quality switch entirely to purchasing equipment from A (region K), with some also shifting from manufacturer to self-repair depending on A's level of repair restriction (region J). It is clear then that B has no market share incentive to raise their repair price when they are already providing a more competitive bundle than A, but we cannot rule out a profit incentive with this exercise.

Now suppose that B instead reduces their repair restriction from γ_{B0} to γ_{B1} under case (ii). This instance is depicted in Figure 9. As with an increase in repair price, improving repairability by reducing the restriction on repairs leads to an increase in the share of consumers of B's equipment who provide their own repairs. B loses some repair market share to consumer self-repairs (region W). However, B also gains some equipment market share from self-repairing consumers who had originally purchased from A and now purchase from B while continuing to self-repair(region N). Thus, we cannot conclude that a reduction in repair restriction would benefit, or harm, B.

Though I do not illustrate an increase in repair restrictions under case (ii), the trade-offs associated with this shift are similar to instances discussed previously. When B provides equipment that is already cheaper to repair than A, either by the consumer or through a manufacturer, an increase in B's repair restriction would lead to some originally self-reliant consumers instead obtaining repairs through B, which is a net gain in market share. However, B would also lose some self-reliant consumers to A and again we cannot determine whether it is in B's best interest to restrict repairs for a net increase in market share.

The above analysis of manufacturer B's choices under cases (i) and (ii) suggests that while B doesn't appear to have a market share incentive to raise their repair price relative to their competitor A, whether they have a market incentive to restrict repairs is inconclusive. However, this analysis does show that this model provides the potential for a manufacturer to have a profit incentive to restrict repairs in an effort to preclude competition from self-repairs, even when faced with a competing manufacturer that provides a cheaper or more repairable bundle of equipment and repairs. The next step is to examine the duopolist profit maximization problem and identify whether such an incentive exists.

3.1.2.2 Duopolist Choice Problem and Strategies

Whereas defining market shares for our equipment duopolists was substantially more complex than for our monopolist, defining each manufacturer's profit maximization problem is much simpler. In fact, the most complex components of these problems are the market share functions themselves. For each case, the market share functions are the integral representation of their respective areas of the unit square plotted in these figures. For the sake of brevity and reasonable formatting, I do not write out these functions in their entirety for each manufacturer's profit function. Instead, I just refer to the relevant market shares S by the indexing scheme used in the figures, e.g. S_{MA} is the share of consumers that purchase both equipment and repairs from manufacturer A.

Given their respective market share functions, manufacturers' choice problems are

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

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

where the marginal cost of restricting repairs is k, which is identical for the manufacturers.

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 problems more tractable. We also assume that the manufacturers make their pricing and restriction choices simultaneously and 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 each manufacturer's profit maximization problem gives us their best response functions from which we can derive a Nash equilibrium at their intersection. To answer my first research question, my primary objective is to prove that a Nash equilibrium either does or does not exist where one or both manufacturers restrict consumer repairs and/or set their repair price above marginal cost, e.g $\gamma_i > 0$ and/or $P_i > 0$ for $i \in \{A, B\}$.

3.1.2.3 Analytical Solution to Duopolist Equilibrium

Deriving an analytical solution for this equipment duopoly equilibrium is a challenge. Both manufacturers have three choice variables, two of which determine which of the three market share cases will hold. One difficulty arises when determining where manufacturer best response functions intersect as there is no guarantee that they intersect at all. For example, it may be optimal for A to be in case (i), but B's best response is then to adjust their price/restriction till case (ii) holds. Thus, deriving a best response function requires checking all feasible combinations of cases and competitor choices, of which there are many and our market share functions are generally not well-behaved. The FOCs that define optimal choices within each case are also highly nonlinear. Additionally, their is a possibility of a mixed strategy equilibrium which further complicates deriving a solution analytically.

Because showing that a single equilibrium with positive repair restrictions or supracompetitive prices exists provides sufficient evidence for addressing our first research question, I address this objective with a computer simulation or gird search. Results from such a simulation may identify or support some ways of paring down agent choices or cases in our model while retaining the trade-offs and ambiguity of restricting repairs. A simulation will also permit exploring more realistic distributions of consumer costs, as well as potential evidence in favor of eliminating a case. Finally, I'm also working on applying computational game theory methods for discontinuous payoff functions using a custom algorithm and the NLSolve package in Julia.

3.1.2.4 Simulating Duopolist Equilibria PRELIMINARY RESULTS

My preliminary approach to simulating the equipment duopoly follows the analytical setup discussed above. The grid search/simulation is coded in R and begins by defining the functions for each indifference line as described in Equations (3) through (8). As the market share functions under cases (i) through (iii) are represented by integrals of the areas within the unit square in Figures 3 through 5, I numerically approximate these integrals for each case using the cubature R package for quadrature methods. Thus, given any set of exogenous parameters (δ, Λ, and k) and endogenous variables (θ_A, θ_B, P_A, P_B, γ_A, and γ_B) the simulation will output market shares for each consumer choice.

Table 1 reports the set of exogenous variables chosen for the baseline simulation. The marginal cost of restricting repairs is relatively small compared to other variables used in the simulation, enabling costs to scale reasonably well with equipment and repair revenues. Table 2 reports the values of the endogenous variables chosen for the baseline simulation. This is a substantial limitation of the simulation as we have to limit manufacturers to a small set of discrete choices for prices and repair restrictions. Adding just one additional choice to these sets drastically increases the computational complexity of the simulation because our approach considers all possible combinations for manufacturer A and B's choices, i.e we run into the curse of dimensionality. With these sets alone there are 11^6 possible combinations. I've restricted each choice to the interval $[0, 1]$ to keep the price/restriction ratios reasonably within the unit square. To address the first research question, the simulation must show that an optimal repair restriction or price is non-zero when zero is a feasible option.

Given these sets of exogenous and endogenous variables, I generate a data set which covers all possible combinations of the latter. Then for each combination I compute market shares for each consumer choice and the corresponding profits for each manufacturer according to Equations (15) and (16). An approximate best-response function for each manufacturer $i \in \{A, B\}$ is generated 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. All simulation code is available upon request.

I run three different versions of the simulation. First, I run a baseline simulation as described above with variables described in Tables 1 and 2. Second, I run a simulation where both manufacturers cannot restrict repairs, e.g. $\gamma_A = \gamma_B = 0$. Third, I run the baseline simulation without a cost to restrict repairs, e.g. $k = 0$. Table 3 provides the Nash equilibrium for each of these simulations.

For the baseline simulation, I find that both firms find it optimal to restrict repairs and charge a repair price above their marginal cost of zero. Case (i) prevails as manufacturer A finds it optimal to restrict consumer repairs of their equipment more than B, i.e. $P_A - \gamma_A < P_B \gamma_B$. Manufacturer A, the equipment quality leader, obtains the largest total market share for equipment, approximately 70%. 92% of all consumers choose to obtain repairs from the manufacturer rather than provide their own labor. This result provides computational evidence that it can be optimal for manufacturers to restrict repairs and charge supracompetitive prices even when facing a direct competitor that could undercut them by setting a lower price of repairs or building more repairable equipment. The finding that A charges a higher price for equipment, obtains a larger equipment market share, and earns greater profits than B is consistent with A's quality advantage for a vertically differentiated durable good. Figure 10 provides a plot of market shares and indifference lines for the baseline Nash equilibrium.

Simulation 2 considers a setup where manufacturers cannot restrict repairs, which is consistent with a complete right-to-repair for consumers, e.g. $\gamma = 0$. In this setting I find that both manufacturers charge the same equipment and repair prices as in the baseline simulation. Without a restriction on self-repairs for equipment from either manufacturer, more consumers choose to self-repair, about 10%. Hence, these consumers are better off because they obtain repairs at a lower cost. Because A provided less repairable equipment in the baseline scenario, we see an increase in the share of consumers of equipment A that provide their own repairs when they have the full right-to-repair. Manufacturers are worse off because of their loss of repair market share to consumers. This right-to-repair equilibrium is plotted in Figure 11.

Finally, simulation 3 considers a setup where there is no constraint on each manufacturer's right-to-restrict due to costs or government intervention, e.g. $\gamma = 1$. In this instance both manufacturers find it profitable to charge a higher price for repairs when consumer repairs are heavily restricted. We see no change in market shares relative to simulation 2 with the right-to-repair. This right-to-restrict Nash equilibrium is plotted in Figure 12.

Why are repair restrictions profitable under the assumptions of this model? My hypothesis is that either restricting repairs and lowering the price of repairs can increase a manufacturer's share in the repair market, but restricting repairs is more profitable than lowering prices. Making equipment purchases compulsory and allowing manufacturers to restrict consumer repairs at relatively little cost likely drives this result. Increasing the cost of restricting repairs even slightly causes manufacturers to eliminate their restrictions on repairs.

Why does manufacturer A find it profitable to restrict repairs of their equipment more than manufacturer B? Since manufacturer A and manufacturer B only differ in their equipment's quality, it must be that A can get away with selling less repairable equipment because some consumers would still purchase their equipment for additional utility from greater equipment quality. This is consistent with results from basic vertical differentiation models where the firm with a higher-quality product is able to charge a higher price in market equilibrium.

3.1.2.5 Conclusion

This analysis addresses the question: Do equipment manufacturer have an incentive to restrict competition from consumers for repairs and set supracompetitive repair prices?

While there is anecdotal 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 is driving these manufacturer practices. Manufacturers argue that these practices help them provide safer and higher quality equipment. At first glance, the existence of multiple independent manufacturers for durable goods like tractors and smartphones suggests that 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 appears to agree and the executive branch, Congress, and some state legislatures are considering right-to-repair policy and legal action.

I contribute to this important and timely debate by addressing this question with a novel theoretical model of consumer repair choices when manufactures have the option to restrict repairs. Preliminary results from simulations of this model's equilibria suggest that, under specific conditions that need to be studied further, manufacturers may have an anticompetitive incentive to restrict repairs. The anti-competitive adjective here is vital as it suggests that these practices are harmful to consumers and supports the need for additional studies of the potential for right-to-repair polices to address these competition precluding practices. Note that the next steps of this work will include a more robust computational/numerical solution to the duopolist profit maximization problem which may refute these preliminary results.

In my future work on the economic theory of 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 number of potential third-party entrants in the repair market, the primary equipment or product's expected lifespan, and the 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 an alternative structural models which may also be easier to solve analytically or bring to data, 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.

4 Tables & Figures

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

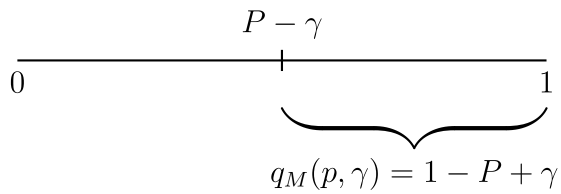

Figure 2: Indifference Lines and Dominant Consumer Choices When $P_A - \gamma_A < P_B - \gamma_B$

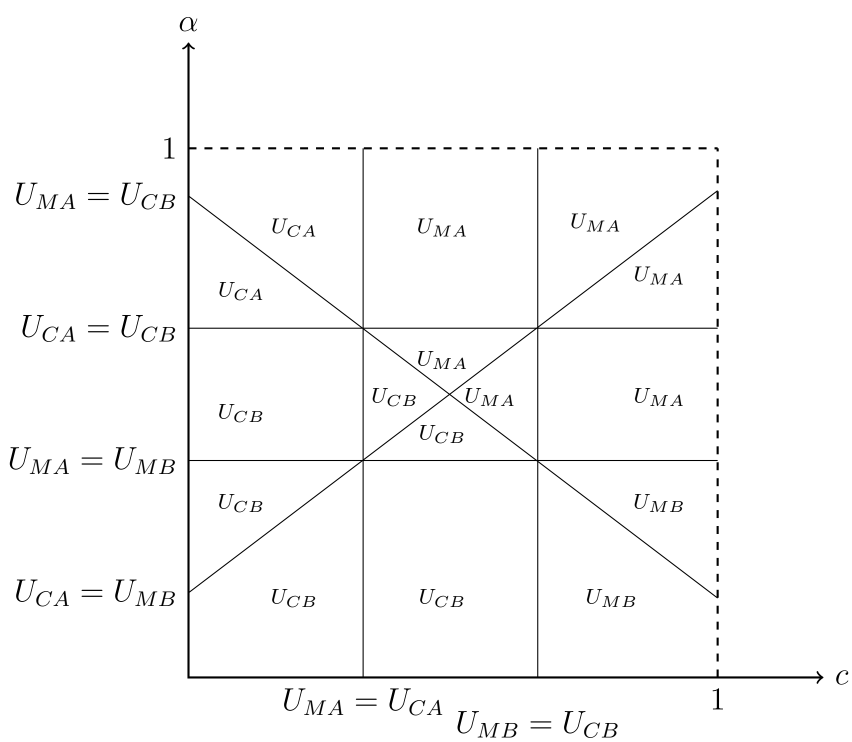

Figure 3: Market Shares Case (i): $P_A - \gamma_A < P_B - \gamma_B$

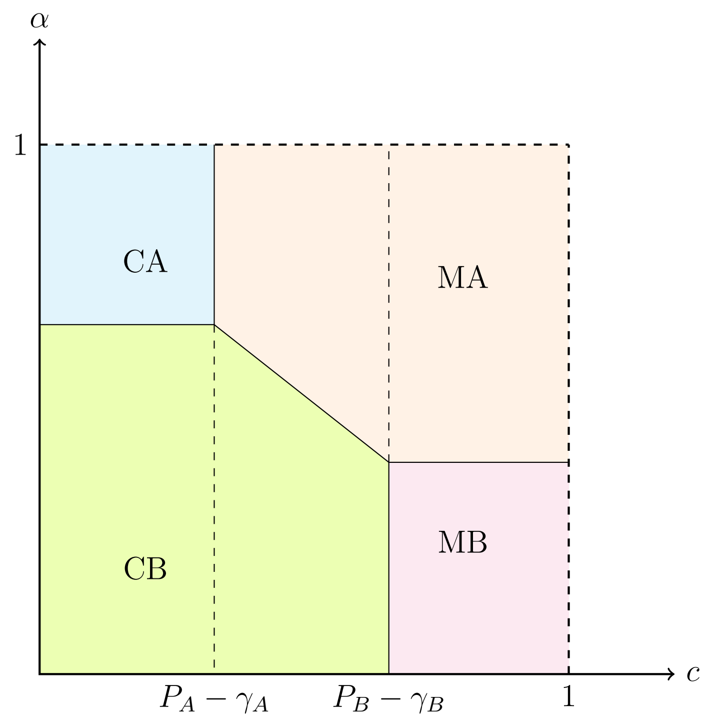

Figure 4: Market Shares Case (ii): $P_A - \gamma_A > P_B - \gamma_B$

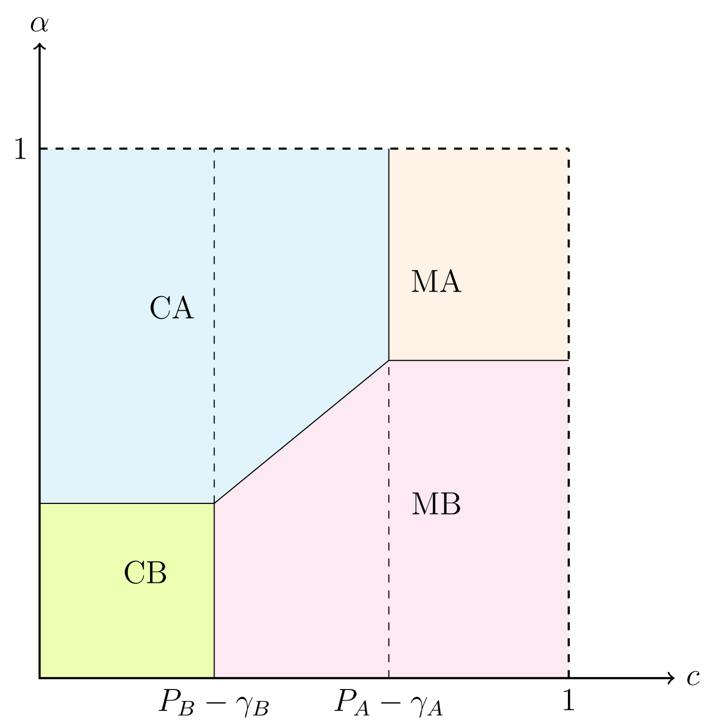

Figure 5: Market Shares Case (iii): $P_A - \gamma_A = P_B - \gamma_B$

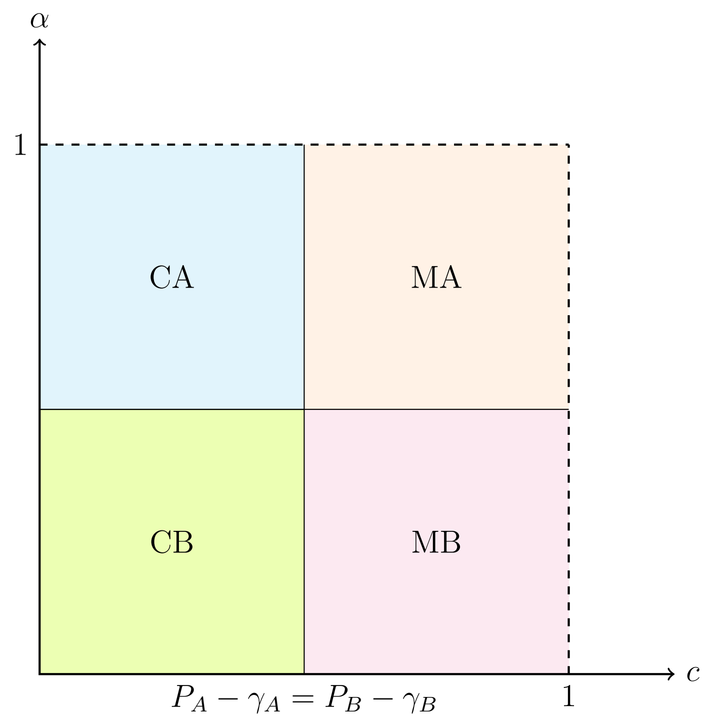

Figure 6: Reduction in Manufacturer B's Repair Price When $P_A - \gamma_A < P_{B0} - \gamma_B$

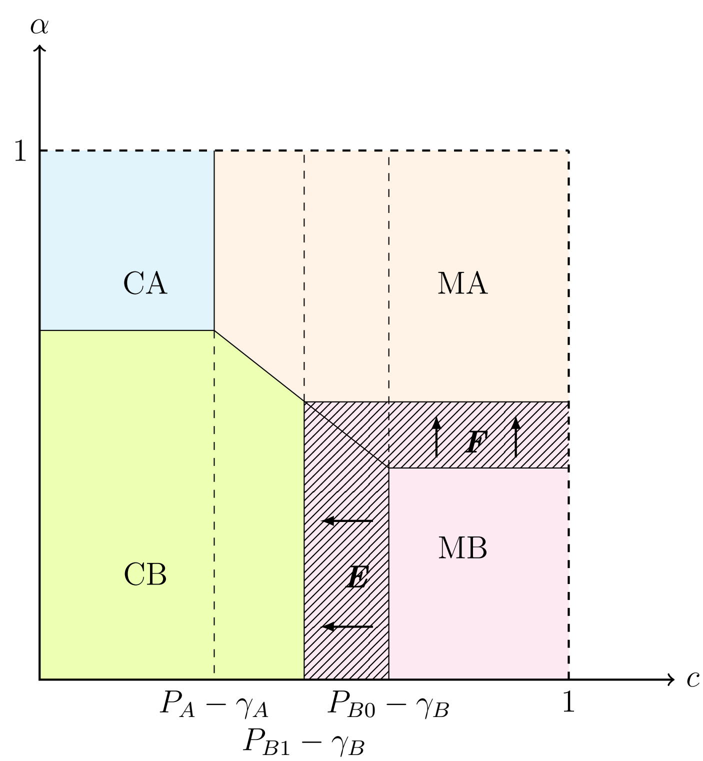

Figure 7: Increase in Manufacturer B's Repair Restriction When $P_A - \gamma_A < P_B - \gamma_{B0}$

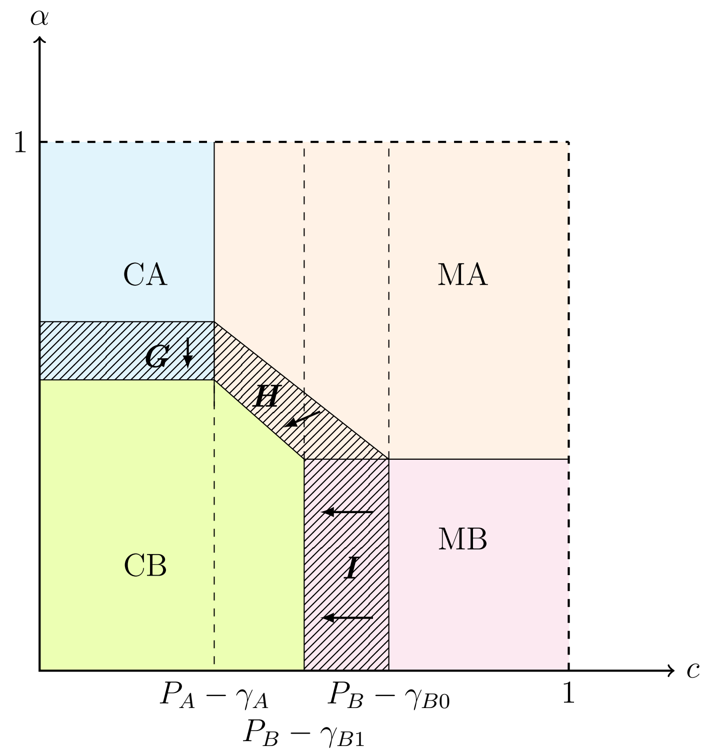

Figure 8: Increase in Manufacturer B's Repair Price When $P_A - \gamma_A < P_{B0} - \gamma_B$

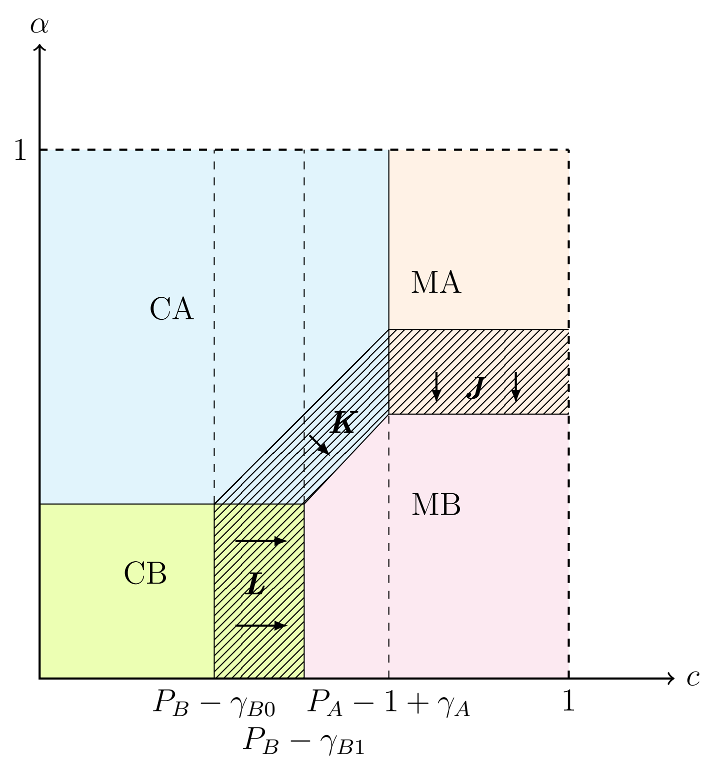

Figure 9: Reduction in Manufacturer B's Repair Restriction When $P_A - \gamma_A > P_B - \gamma_{B0}$

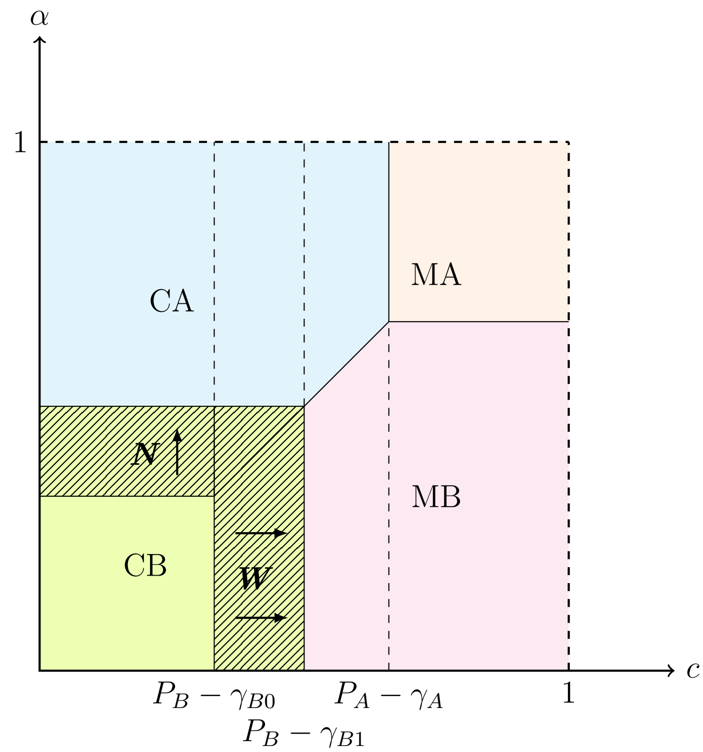

Figure 10: Increase in Manufacturer A's Repair Restriction When $P_A - \gamma_{A0} > P_B - \gamma_B$

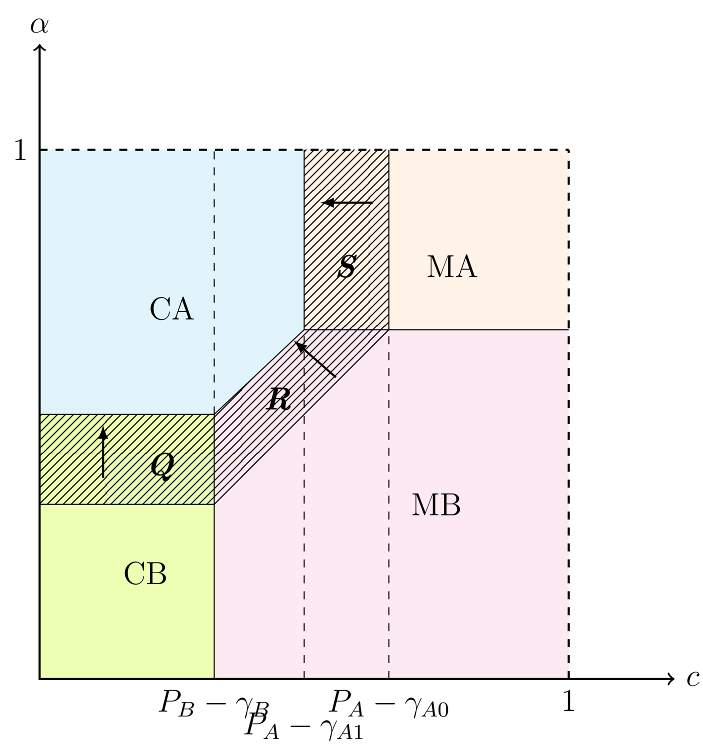

Table 1: Baseline Simulation: Exogenous Variables

δ	0.9
Λ	1
k	0.01

Table 2: Baseline Simulation: Endogenous Variables

θ_A	$(0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0)$
θ_B	$(0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0)$
P_A	$(0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0)$
P_A	$(0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0)$
γ_A	$(0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0)$
γ_B	$(0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0)$

Table 3: Nash Equilibrium

Sim	θ_A^*	P_A^*	γ_A^*	θ_B^*	P_B^*	γ_B^*	CA Share	MA Share	CB Share	MB Share	Π_A	Π_B
1	0.6	0.1	0.3	0.3	0.1	0.1	0.0533	0.6461	0.0279	0.2727	0.4838	0.1174
2	0.6	0.1	0	0.3	0.1	0	0.0700	0.6300	0.0300	0.2700	0.4832	0.1170
3	0.5	0.2	1	0.2	0.2	1	0.0700	0.6300	0.0300	0.2700	0.4764	0.1141

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