Trade Liberalization and Aftermarket Services for Imports*

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January 30, 2013

Abstract

We analyze the provision of repair services (aftermarket services that are required by a certain fraction of durable units after sales) through an international duopoly model in which a domestic firm and a foreign firm compete in the domestic market. Trade liberalization in goods, if not accompanied by the liberalization of service FDI, induces the domestic firm to establish service facilities for repairing the foreign firm's products. This weakens their competition in the product market, and the resulting collusive effect hurts consumers and reduce world welfare. The negative effects of trade liberalization are driven by time inconsistency problem on the side of consumers, which is difficult to be resolved because numerous consumers must collectively commit to their behavior in the aftermarket. Liberalization of service FDI helps resolve the problem because it induces the foreign firm to establish service facilities for its own products.

1 Introduction

Aftermarket services, such as repair and maintenance services, refer to services used together with durable equipment but purchased after the consumer had acquired the equipment. In this

*We thank Kenzo Abe, Masahiro Ashiya, Richard Baldwin, Taiji Furusawa, Jun-ichiro Ishida, Hiroshi Kinokuni, Kazuharu Kiyono, Kaz Miyagiwa, Ryosuke Okamoto, Makoto Okamura, Takao Ohkawa, Tetsuo Ono, Kentaro Tachi, Mike Waldman and seminar participants at National Graduate Institute for Policy Studies (GRIPS), Osaka University, the JEA Spring Meeting, and Hitotsubashi COE Conference on International Trade and FDI 2010 and 2012 for their helpful comments and suggestions. The usual disclamer applies.

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paper, we focus on aftermarket services that are required by a certain fraction of durable units after sales. Repair services are aftermarket services of this kind, given that durable goods often (but not always) break down and broken units require repair services for continued usage. One might feel that repair services are not an activity of much economic significance. This, however, is not at all the case. Eschenbach and Hoekman (2005), for example, reports that distribution and repair services account for about 10% to 20% of the stock of inward service FDI in the Central and Eastern European countries and the South East European countries. A number of antitrust cases, including the influential 1992 US Supreme Court decision in *Eastman Kodak Company v. Image Technical Services, Inc, et al.*, concern the behavior of durable goods producers in the market for repairs of their products (see, for example, Chen, Ross, and Stanbury, 1998; Waldman, 2003).[1]

We analyze the provision of repair services in the context of international trade and explores its welfare consequences and policy implications. To perform repair services effectively, proximity between service providers and consumers is a critical element. In the context of international trade, this implies that foreign durable-goods producers have a disadvantage in performing repair services in the domestic country. Foreign producers can overcome this disadvantage by establishing local service facilities through foreign direct investments (FDIs), but FDI may be very costly due not only to direct investment costs but also to a variety of regulatory impediments. Foreign producers may therefore choose not to establish local service facilities, and their broken units may remain unrepaired as a consequence.[2]

This is the context in which domestic durable goods producers often perform repair services for their foreign rivals' products, the practice often observed in reality. The repair services for competitors' products are provided "voluntarily" in the sense that they are conducted without the consent of the original producers.[3]

[1]The demands for repairs have been also increasing. For instance, it is reported that the number of the requests for repairing which Panasonic receives is 130,000 in 1995 and 370,000 in 1999, and the ACT of Consumer Electronics implemented in 2001 had been expected to increase the demand for repair service (*Nikkei Ecology*, April, 2001). Canon receives 1,000,000 inquiries that are associated with repairing (*Nikkei Joho Strategy*, December, 2003). Louis Vuitton Japan repaired 330,000 garments in 2006 (*Nikkei Business*, June 11, 2007).

[2]For example, although some imported infrared heaters had a problem and they were subject to a product recall in Japan, some foreign producers were not able to provide repair services for their own products in Japan. Even though foreign producers perform repair services in their own countries, it involves significant inconvenience and costs for consumers to ship broken units back and forth between different countries.

[3]For example, in Japan, Nidec Sankyo Service Engineering Corporation, which is a domestic subsidiary of the Japanese machine-tool company, Nidec Sankyo Corporation, is providing maintenance and repair services for competitors' products including imported products. Two Japanese companies, Maruju Ironworks and Masuda Ironworks, are providing the maintenance and repairs of machines, dies and molds produced by other companies.

We analyze the provision of repair services through an international duopoly model in which a domestic firm (firm D) and a foreign firm (firm F) produce differentiated products (good D and F) in their own countries and compete in the domestic market. Both goods break down with a certain probability, and broken units require repair services for usage. Firm D has already established its facilities to perform repair services for good D. Firm F can establish its own service facilities in the domestic country by incurring a fixed cost K_F. Also, firm D can establish facilities for repairing good F by incurring a fixed cost K_D. Depending on parameterization, the model exhibits one of the following three types of equilibrium: (i) Rival's Repair equilibrium in which firm D performs repair services for good F, (ii) Own Repair equilibrium in which firm F performs repair services for good F, and (iii) No Repair equilibrium in which neither firm performs repair services for good F.

Through analyzing our model, we investigate the effect of trade liberalization in goods in its connections to the effect of trade liberalization in services, with the following reality as a background. The Uruguay Round negotiations of General Agreement on Tariffs and Trade (GATT) succeeded in establishing the framework of liberalizing cross-country transaction of services, that is, the General Agreements on Trade in Services (GATS). The progress of liberalization in service sectors, however, has been limited compared to the degree of trade liberalization in goods. For instance, People's Republic of China has prohibited foreign firms' provisions of after-sales services including repair services until 2001. Indonesia and Thailand limit the foreign equity ownership of maintenance and repair services up to 49%. Even if the provisions of repair services by foreign companies are legally allowed, the foreign producer may not secure skilled workers by the regulation on the posting of workers across borders.

Regulatory impediments such as the ones mentioned above would keep the costs for service FDI high. This is captured by a high fixed cost for firm F to establish service facilities, K_F, in our model, where the liberalization of service FDI reduces K_F and the liberalization of goods trade reduces the tariff rate.

We demonstrate that trade liberalization in goods may hurt domestic consumers and lower world welfare, and that these negative effects are turned into positive ones if service FDI is also liberalized. The main logic behind this result can be explained as follows. Suppose that initially both the tariff rate and firm F's fixed cost K_F are high. Under the high tariff rate, neither firm establishes service facilities in the equilibrium (the No Repair equilibrium). Because of the high tariff, the domestic country's imports of good F is small. Hence the number of broken units of

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Fuji Xerox provides the maintenance and repair services of office equipment even if customers use the equipment of other firms. Several IT companies including IBM and Fujitsu provide repair services for competitors' network products. NEC supports other companies' products.

good F that requires repair is also small, implying that neither firm can recover the fixed cost by performing repair services for good F.

Now suppose that the liberalization of the trade in goods gradually reduces the tariff rate. The reduction of the tariff rate eventually switches the equilibrium from the No Repair equilibrium to the Rivals' Repair equilibrium. Lower tariff increases imports of good F. When the tariff rate becomes sufficiently low, firm D can recover the fixed cost since there is sufficient demand for repairing good F, whereas firm F cannot recover the fixed cost K_F which is assumed to be high.

Once firm D establishes service facilities for repairing good F, firm D can earn profit not only from selling good D but also from performing repair services for good F. Then, an increase in the sales of good D reduces consumers' willingness to pay for good F, which in turn decreases firm D's profit from performing repair services for good F. Hence, firm D is less willing to increases the sales of good D in the Rival's Repair equilibrium than in the No Repair equilibrium, implying that competition between firms D and F in the product market is weaker in the Rival's Repair equilibrium than in the No Repair equilibrium. We call this effect as *collusive effect* of the rival firm's provision of repair services.

We find that, because of the collusive effect, the switch from the No Repair equilibrium to the Rival's Repair equilibrium hurts consumers and firm F, and reduces world welfare, although it benefits firm D. It is worth emphasizing that a time inconsistency problem on the side of consumers is a key driving force of the negative effects on consumers and world welfare. To see this, suppose that consumers can collectively commit not to repair broken units of good F. If this commitment is credible, neither firm establishes service facilities, and hence the collusive effect never arises in the equilibrium. Hence, tariff reduction always benefit consumers and increase welfare. Such a collective commitment, however, is difficult to be made credible because, once service facilities are established, it is each consumer's benefit to renege on the commitment and repair their broken units.

We find that, in the presence of the time inconsistency problem, the negative effects of trade liberalization in goods just mentioned are turned into positive ones if service FDI is also liberalized. This is because the liberalization of service FDI reduces K_F, which in turn induces firm F to establish its own service facilities. Trade liberalization in goods now switches the No Repair equilibrium into the Own Repair equilibrium. The collusive effect does not arise in the Own Repair equilibrium because firm D cannot earn any profit by repairing good F, and hence the positive welfare effects of trade liberalization in goods are preserved.

1.1 Contributions and relationship to the literature

There have been several studies that investigate the connection between international trade and service sectors.[4] However, to our best knowledge, the present paper and another paper of ours (Ishikawa, Morita, and Mukunoki, 2010) are the only studies that investigate the link between trade liberalization in goods and liberalization of FDI for services that are performed after production of goods (referred to as "post-production services" in what follows).

The present paper is a companion paper of Ishikawa, Morita, and Mukunoki (2010), henceforth IMM, in the sense that these two papers analyze two different types of post-production services. IMM have analyzed an international duopoly model in which post-production services (such as sales and distribution) must be performed before goods are purchased. The foreign firm has an option of outsourcing post-production services to its domestic rival by paying royalties or providing those services by itself in the domestic market.

A fundamental difference between the present paper and IMM is that the present paper analyzes the provision of post-production services that are required only by a certain fraction of units after sales of goods (aftermarket services), whereas IMM analyzes the provision of post-production services that must be performed for all units before sales of goods. Despite the difference, we obtain the main policy implication that is similar to the one obtained in IMM. That is, these two papers together identify the importance of the liberalization of service FDI by showing, for both types of post-production services, that trade liberalization in goods may hurt domestic consumers and lower world welfare, and that these negative effects are turned into positive ones if service FDI is also liberalized. This is the first contribution of the present paper.

Our second contribution is that we identify time inconsistency problem on the side of consumers as a key driving force of the main results. Time inconsistency has been a central issue in the microeconomic theory of durable goods since the seminal work by Coase (1972).[5] The problem arises because durable goods sold in the future affect the future value of units sold today, and in the absence of the ability to commit, the monopolist does not internalize this externality (Waldman, 2003). This is problematic for the monopolist, because the lack of commitment reduces its overall profitability.[6]

[4] See Djajić and Kierzkowski (1989) , Markusen (1989), Francois (1990), Markusen, Rutherford and Tarr (2005), Wong, Wu and Zhang (2006), and Francois and Wooton (2010), among others.

[5] See also, for example, Stockey (1981), Bulow (1982), Gul, Sonnenschein and Wilson (1986), and Ausubel and Deneckere (1989).

[6] Based on the analysis of Bulow (1982), Waldman (2003) explains Coase's argument as follows. Bulow considers a monopolist of a perfectly durable good who sells output in each of two periods. In this model, if the firm in the first period can commit to a production level for the second period, then the firm's profit maximizing first-period choices are to commit to selling zero in the second period and to produce the monopoly output level and sell it

Time inconsistency is an important issue when we analyze durable-goods producers' behavior in aftermarkets. Consider situations in which consumers are locked in once they purchase a new unit from a durable-goods producer. Borenstein, Mackie-Mason and Netz (1995) argue that the durable-goods producer will charge a price for its aftermarket products and services in excess of marginal cost to exploit consumers' locked-in positions. The higher aftermarket price creates an efficiency loss because it reduces consumption of aftermarket products and services. The efficiency loss, in turn, reduces the producer's overall profitability because consumers anticipate this behavior and pay less for a new unit. The producer will be better off if it can credibly commitment to charge lower aftermarket prices, but Borenstein, Mackie-Mason and Netz argue that such commitments are often difficult in reality due to time inconsistency.

However, it seems that at least under some circumstances, durable-goods producers can commit their behavior in aftermarkets through long-term contracts as pointed out by Shapiro (1995), Chen and Ross (1998), and Waldman (2003).[7] Chen and Ross (1998) address the commitment problem focusing on an aftermarket of repair services. They consider a durable-goods monopolist who produces durable units that break down with a certain probability, where repaired units and unbroken units are perfect substitute.[8] Chen and Ross show that the durable-goods monopolist's inability to commit to its behavior in the aftermarket creates no efficiency loss and no reduction in the monopolist's overall profit, because all broken units are repaired in equilibrium whether or not the monopolist can commit.[9]

We contribute to the literature by showing that time inconsistency of consumers can be an

at the monopoly price. But what if commitment is not possible? Then, if the firm tries to sell the monopoly output in the first period, consumers will be unwilling to pay the monopoly price. The reason is that consumers fear the firm will collect the monopoly price in the first period and then produce additional units in the second period, thus driving down the second-period value of the used units that the consumers own. The result is each consumer's willingness to pay in the first period is reduced, and overall monopoly profitability falls.

[7]Shapiro (1995) has shown that the efficiency loss associated with durable-goods producers' inability to commit to their behavior in aftermarkets can be "far smaller" than traditional monopoly deadweight losses.

[8]Chen and Ross (1994) also consider durable products that break down with a certain probability. A monopolist produces such a durable product, and its repair services require the monopolist's proprietary parts. It is assumed that the monopolist can commit to its repair price at the time of original purchase. Chen and Ross show that the durable-goods monopolist can effectively price discriminate between high-intensity users and low-intensity users by monopolizing the repair market. See Chen and Ross (1999) for a related analysis in which the primary market is competitive rather than monopolistic.

[9]The demand for repairs becomes inelastic below the threshold price of repairs under which all broken units are repaired, because the amount of broken units is fixed in the aftermarket. Even if the aftermarket is monopolized by a single firm, the monopolist would set the threshold price because the marginal revenue of repairs always exceeds the marginal cost of them. This means that the monopolist's inability to commit in the aftermarket does not generate any efficiency loss. By the same reason, the competition in the aftermarket does not directly lead to efficiency gains.

important issue, whereas previous analyses in the literature have focused on time inconsistency of producers. Following Chen and Ross (1998), we consider a product that breaks down with a certain probability and requires repair services for usage. We find that all broken units are repaired in Rival's Repair equilibrium as well as Own Repair equilibrium, and hence, as in Chen and Ross (1998), producers' inability to commit does not cause efficiency losses in our model. Time inconsistency problem on the side of consumers arises because we consider durable goods producers' strategic interactions in the context of international trade. In our model, firm D provides repair services for good F unless consumers can collectively commit not to repair their broken units of good F, if firm F's fixed cost for establishing service facilities, K_F, is high. And the resulting collusive effect hurts consumers and reduces world welfare in the Rival's Repair equilibrium. This problem is resolved when liberalization of service FDI reduces K_F to a sufficiently low level.[10]

Time inconsistency problem of consumers seem much more difficult to be resolved compared to time inconsistency problem of producers. This is because numerous consumers must collectively commit to their behavior in the aftermarket to resolve the former problem, whereas such a collective commitment is not required for the latter problem and hence long-term contracts could enable producers to make commitment credible. This observation in turn suggests that liberalization of service FDI is an important way to resolve the time inconsistency problem identified through our analysis.

The reminder of the paper is organized as follows. Section 2 formally develops an international duopoly model of durable-goods producers and aftermarket services, and derives the equilibrium of the model. Section 3 investigates the effects of the liberalization of trade in goods, the liberalization of FDI for repair services, and their connection. Section 4 discuss the robustness of the results under alternative setups. Section 5 summarizes the paper and offers concluding remarks. The Appendix contains Proofs of Lemmas and Propositions.

[10]In contrast, post-production services in IMM do not cause time inconsistency problems because they must be performed for all units before sales. In IMM, the direct effect of a tariff reduction is beneficial for consumers and the foreign firm, and is harmful for the domestic firm. However, the domestic firm can mitigate the negative effect of a tariff reduction by raising the price it charges the foreign firm for post-production services, and the higher service price works in the direction of raising goods prices. IMM show that, from the welfare standpoint, the latter effect can overshadow the former effect so that the tariff reduction actually hurts consumers and reduces world welfare in equilibrium. Importantly, if the fixed cost for service FDI is also reduced, the domestic firm has less room to increase the service price in response to the tariff reduction, and a sufficient reduction of the fixed cost converts the negative welfare effect of tariff reduction into a positive effect.

2 The model and equilibrium

A domestic firm (firm D) and a foreign firm (firm F) engage in Cournot competition in the domestic market by producing horizontally differentiated products.[11] Let x_i ($i = D,\ F$) denote the amount of good i produced by firm i. The domestic government levies a specific tariff, t, in the imports of good F. The utility of a representative consumer is given by $U(d_D, d_F, Z) = V(d_D, d_F) + Z$ where d_i and Z denote the consumption of good i and a numeráire good, respectively. Define $V_F(d_D, d_F) \equiv \partial V(d_D, d_F)/\partial d_i$ and $V_{ij}(d_D, d_F) \equiv \partial^2 V(d_D, d_F)/\partial d_i \partial d_j$ ($i, j \in \{D, F\}$). We assume $V_i(d_D, d_F) > 0$ and $V_{ij}(d_D, d_F) < 0$ hold.[12]

Following Chen and Ross (1998), we assume that, after consumers purchase the goods, a fraction $(1 - q)$ ($q \in (0, 1)$) of each good i breaks down immediately because of imperfect quality control. That is, qx_i units of good i works correctly whereas $(1 - q)x_i$ units require repair. Unbroken units and repaired broken units are perfect substitutes. Without repair, broken units are useless with zero scarp values.

In order to perform repair services for good i, service facilities for good i must be established in the domestic country. We suppose that firm D has already established its facilities to perform repair services for good D and provides a full warranty when it sells good D. Firm F can establish its own service facilities by incurring a fixed cost K_F and provide a full warranty for good F. Also, firm D can establish facilities for repairing good F by incurring a fixed cost K_D and charge r to repair a broken unit of good F. The full-warranty assumption is for simplifying the analysis, and main results of the paper (all propositions and lemmas) would remain unchanged in the absence of this assumption (see Section 4.2 for details).

We consider a three-stage game. In stage 1, the two firms simultaneously decide whether they provide the repair services for good F. When firm i ($i \in \{D, F\}$) provides the services, it must incur a fixed set-up cost K_i. The fixed cost is a sunk cost. The fixed cost for firm D, K_D (≥ 0), should represent the costs of establishing additional facilities, those of learning the details of the competitor's product, and those of preparing the proper parts and components for repairing good F. Meanwhile, K_F includes the costs of establishing the facilities by undertaking FDI in repair services. We assume $K_D \leq K_F$, which reflects the presumption that the costs of establishing new facilities outside the home country are higher than the costs of expanding the existing facilities in the home country.

In stage 2, the two firms produce and supply the goods to the domestic market and the

[11] The main results of our paper would be preserved even if the firms engage in Bertrand competition.

[12] To ensure that the marginal revenue of each firm is decreasing in its sales, we also assume $2V_{ii}(d_D, d_F) + (\partial V_{ii}(d_D, d_F)/\partial d_i)\, d_i < 0$ holds.

domestic consumers purchase them. The two firms have the identical marginal cost of production, which is denoted by c. The domestic government levies a non-negative, specific tariff, t, on the imports of good F.[13]

In stage 3, consumers find some units of the purchased goods are broken down. If the repair services are provided by the original producer, broken units are subject to free repairs because of the full warranty. If firm D provides the repair services for good F, it charges the service price r per-unit of repairs. The level of r is chosen by firm D. Given this, consumers choose whether they order the repairs of the broken units if the repair services are provided. Let R_F ($\in [0, (1-q)x_F]$) denote the amount of repaired broken units of good F. Due to the economies of scope between the repair services and the production activities, each firm has a cost advantage over its rival in the repairs of its own product. Specifically, the marginal cost of repairing its own product, m_L, is no higher than the cost of repairing the rival's product, m_H. We assume $m_L \leq m_H \leq c$ holds so that the costs of repairs are no higher than the production cost. We also assume the producers' cost advantage in aftermarket services is large enough to exclude the entries of ISOs.[14]

The operating profits of each firm (i.e., the profits gross of the fixed costs of establishing service facilities) are denoted by Π_i ($i \in \{D, F\}$). We assume the second-order conditions of profit maximizations, $\partial^2\Pi_i/\partial x_i \partial x_i < 0$ holds. We use the backward induction to derive the sub-game perfect equilibrium.

2.1 Repair services and product market competition

Here, we analyze the market equilibrium given the firms' decisions made in stage 1. We should first mention that all broken units of good F are repaired by firm F in equilibrium if firm F undertakes service FDI, even if firm D also establishes the service facilities for repairing good F. Suppose both firms have established the service facilities for good F. Since firm F provides a full warranty for good F, firm D cannot attract consumers in stage 3 unless the service price is negative, $r < 0$. Since the marginal cost of providing services is positive, firm D has no incentives to set a negative price for repairing good F.

[13] By regarding t as the degree of cost disadvantages of the foreign firm, we can interpret the situation as if the two firms are heterogenous in the production cost. The main results of this paper would be mostly unchanged with this alternative set-up. However, the welfare property of the model need to be slightly modified because the higher cost of the foreign firm no longer works as a transfer from the foreign country to the domestic country as the tariff does.

[14] Main results of the paper would be unchanged even if we assume the producers of goods can exploit the profits of ISOs by selling parts and other components that are indispensable to provide repair services. If ISOs are completely free from the producers' influences, however, there are some results specific to ISOs. See Section 4.1 for details.

Firm F that undertook service FDI, on the other hand, always has an incentive to provide a full warranty when it sells good F. While a full warranty generates negative profits in the aftermarket, it increases firm F's profits in the product market because it increases the consumer's willingness to pay for good F in the product market and so does the price of good F that firm F can charge. As long as firm F provides the repair services for good F, the loss in the aftermarket coincides with the gain in the product market, and the full warranty has no effect on firm F's overall profits. As we will see below, firm D's repairs of good F *hurts* firm F. Therefore, firm F is willing to use the full warranty as a strong tool to force firm D out of the aftermarket for good F.[15]

The strong position of firm F in the service market implies that the following three cases are possible equilibrium outcomes: (i) **Rival's Repair (RR) equilibrium** where only firm D provides the repair services for good F, (ii) **Own Repair (OR) equilibrium** where only firm F provides repair services for good F, and (iii) **No Repair (NR) equilibrium** where no repair services are provided for good F.

2.1.1 The RR equilibrium

First, let us consider the RR subgame. In stage 3, each consumer maximizes $V(x_D, qx_F + R_F) - rR_F$ with respect to R_F given $R_F \leq (1-q)\,x_F$, which determines the demand for repairs regarding good F. If $V_F(x_D, qx_F + R_F) \geq r$ holds at $R_F = (1-q)\,x_F$, which means that $V_F(x_D, x_F) \geq r$ holds, the consumer orders firm D to repair all broken units. If $V_F(x_D, qx_F) \geq r > V_F(x_D, x_F)$ holds, on the other hand, a certain fraction of the broken units remains unrepaired. In this case, the inverse demand for repairs is given by $r = V_F(x_D, qx_F + R_F)$. Since $V_{FF} < 0$ holds, the demand for repairs is decreasing in the repair price for $R_F \in (0, (1-q)x_F)$.

Given the demand for repairs, firm D determines r so that it maximizes the profit from providing the repair services for good F. Firm D's maximization problem is written by

$$\max_{r}\,(r - m_H)\,R_F \quad \text{s.t.} \quad R_F \leq (1-q)\,x_F. \tag{1}$$

Let $\widehat{r}$ denote the solution to this maximization problem. Then, the equilibrium amount of repaired units, $\widehat{R}_F$ ($\in [0, (1-q)x_F]$) is given by solving $\widehat{r} = V_F(x_D, qx_F + \widehat{R}_F)$.

In stage 2, the consumer maximizes $V(x_D, qx_F + \widehat{R}_F) + Z$ with respect to x_D and x_F, subject to $p_D x_D + p_F x_F \leq I - \widehat{r}\widehat{R}_F$, where I denotes the income of the representative consumer. The inverse demand for good D and that for good F are respectively given by $p_D = V_D(x_D, qx_F + \widehat{R}_F)$ and $p_F = qV_F(x_D, qx_F + \widehat{R}_F)$. Given these demand functions, the two firms respectively maximize

[15] By the same reason, the equilbrium properties of our model are unchaged even if firms cannot provide a full warranty, and the two firms engage in price competition in the aftermarket. See Section 4.2 for details.

$\Pi_D = [p_D - \{c + (1-q)\, m_L\}]x_D + (\widehat{r} - m_H)\widehat{R}_F$ and $\Pi_F = \{p_F - (c+t)\}x_F$ with respect to x_D and x_F. The two firms' profit maximization constitutes the equilibrium sales of each good. The equilibrium sales in turn determine the equilibrium amount of repaired units, $\widehat{R}_F$, and the equilibrium repair price, $\widehat{r}$. We have the following lemma.

Lemma 1 *Even if the repair services for good F are provided by firm D, all broken units of the good are repaired in equilibrium.*

Intuitive explanation is as follows.[16] Because an unbroken unit and a repaired unit of the same good are perfect substitutes, the firm D's repair of a broken unit of good F is regarded as if firm D sells an extra unit of good F. Because we have assumed that $m_H \le c$ holds, $m_H \le c+t$ always holds so that firm D's unit cost of repairing good F is lower than firm F's unit cost of selling good F. Besides that, the "quality" of repaired unit of good F is higher than that of the purchased unit of good F in the sense that the latter can break down after the purchase. This means that consumer's willingness to pay for an extra unit of good F is higher for the repaired unit than for the originally purchased unit. Therefore, if evaluated at the $\widehat{R}_F = 0$, firm D's marginal revenue from repairing an extra unit is higher than firm F's marginal revenue from selling an extra unit of good F. Because of these properties, the marginal revenue of firm D from repairing an extra unit of good F is always larger than the marginal cost.

Meanwhile, firm D anticipates that its repairs of good F in stage 3 increases the attractiveness of good F in the product market and thereby decreases its profits from selling good D in stage 2. However, we find that the positive effect of repairs on profits in the aftermarket always dominates the negative effect in the product market. Furthermore, it is not profitable for firm F to manipulate x_F so that it prevents the full-repairs of good F by firm D. Consequently, all broken units of good F are repaired in the RR equilibrium.

Since $\widehat{R}_F = (1-q)x_F$ holds, the equilibrium service price is given by $\widehat{r} = V_F(x_D, x_F)$. Then, the first-order conditions of the firms' profit maximizations, $\partial\Pi_D/\partial x_D = 0$ and $\partial\Pi_F/\partial x_F = 0$, can be written as

$$V_D(x_D, x_F) + V_{DD}(x_D, x_F)x_D + (1-q)V_{FD}(x_D, x_F)x_F = c + (1-q)\, m_L, \tag{2}$$

$$q\,[V_F(x_D, x_F) + V_{FF}(x_D, x_F)x_F] = c + t. \tag{3}$$

The equilibrium sales, (x_D^{RR}, x_F^{RR}), are derived by solving the above two equations and the equilibrium prices of the two goods and the equilibrium repair-price are respectively given by $p_D^{RR} = V_D(x_D^{RR}, x_F^{RR})$, $p_F^{RR} = qV_F(x_D^{RR}, x_F^{RR})$, and $r^{RR} = V_F(x_D^{RR}, x_F^{RR})$.

[16] This equilibrium property is the same as that of Chen and Ross (1998), though the logic behind our model is slightly different because the rival producer, rather than the original producer, provides the repair services.

2.1.2 The OR equilibrium

Suppose firm F undertakes FDI in services to provide the repair services for good F by itself and gives a full-warranty to each buyer of good F. In stage 2, the consumer anticipates that all broken units of good F are freely repaired in stage 3. This means that $R_F = (1-q)\,x_F$ holds, and the consumer maximizes $V(x_D, x_F) + Z$ subject to $p_D x_D + p_F x_F \leq I$ in stage 2. The first-order condition yields the inverse demand-function for each good as $p_D = V_D(x_D, x_F)$ and $p_F = V_F(x_D, x_F)$. The two firms' problems become:

$$\max_{x_D} \Pi_D = [p_D - \{c + (1-q)\,m_L\}]x_D = [V_D(x_D, x_F) - \{c + (1-q)\,m_L\}]x_D,$$
$$\max_{x_F} \Pi_F = [p_F - \{c + t + (1-q)\,m_L\}]x_F = [V_F(x_D, x_F) - \{c + t + (1-q)\,m_L\}]x_F.$$

Then, the first-order conditions are given by

$$V_D(x_D, x_F) + V_{DD}(x_D, x_F)x_D = c + (1-q)\,m_L, \tag{4}$$
$$V_F(x_D, x_F) + V_{FF}(x_D, x_F)x_F = c + t + (1-q)\,m_L. \tag{5}$$

The equilibrium sales are derived by solving (4) and (5), which are denoted by (x_D^{OR}, x_F^{OR}). The equilibrium prices of the goods are respectively given by $p_D^{OR} = V_D(x_D^{OR}, x_F^{OR})$ and $p_F^{OR} = V_F(x_D^{OR}, x_F^{OR})$.

2.1.3 The NR equilibrium

Suppose neither firm D nor firm F establishes the repair facilities for good F in Stage 1. In this case, all broken units of good F remain unrepaired ($R_F = 0$), which means that $d_F = qx_F$ holds.[17] In Stage 2, the consumer maximizes $V(x_D, qx_F) + Z$ subject to $p_D x_D + p_F x_F \leq I$. The first-order condition yields the demand for each good, which is respectively given by $p_D = V_D(x_D, qx_F)$ and $p_F = qV_F(x_D, qx_F)$.

Given these inverse demand functions, the firms' maximization problems are given by

$$\max_{x_D} \Pi_D = [V_D(x_D, qx_F) - \{c + (1-q)\,m_L\}]x_D,$$
$$\max_{x_F} \Pi_F = \{qV_F(x_D, qx_F) - (c + t)\}x_F.$$

The first-order conditions of profit maximizations are as follows:

$$V_D(x_D, qx_F) + V_{DD}(x_D, qx_F)x_D = c + (1-q)\,m_L, \tag{6}$$
$$q\,[V_F(x_D, qx_F) + qV_{FF}(x_D, qx_F)x_F] = c + t. \tag{7}$$

[17] The outcomes of the NR equilibrium would be unchanged even if we allow the repurchase of good F or the refund by firm F after consumers find the broken units. See Section 4.3 for details.

By solving these equations, we obtain the equilibrium sales of goods, which are denoted by (x_D^{NR}, x_F^{NR}). The equilibrium prices are respectively given by $p_D^{NR} = V_D(x_D^{NR}, x_F^{NR})$ and $p_F^{NR} = qV_F(x_D^{NR}, qx_F^{NR})$.

2.2 The effects of repair services

Here, we explore the effects of repair services for good F on the product market competition by comparing the three sub-game equilibria just mentioned. The comparisons are essential for understanding the effects of trade liberalization in goods discussed in the next section, because a shift of the regime in the aftermarket, which is induced by trade liberalization, is an important factor to distinguish between welfare-reducing trade liberalization and welfare-improving trade liberalization.

We first examine how the repair services change the demand for good F in the product market, holding x_D constant. Then, we discuss how they change the strategic interaction between the two firms.

2.2.1 Market-contraction effect and valuation effect

In the NR subgame, if the consumer were to consume $\widetilde{d}_F$ of good F, she must purchase $\widetilde{d}_F/q$ unit in the product market because a fraction of good F fails and remains unrepaired. When $\widetilde{d}_F/q$ units of good F are sold, the corresponding market price is given by $p_F = qV_F(x_D, \widetilde{d}_F)$ (see point A in Figure 1). The RN curve in Figure 1 represents the relationship between the price and the sales of good F in the NR subgame, holding x_D constant.

[Figure 1 around here]

In the OR subgame, the consumption of good F, $\widetilde{d}_F$, coincides with the sales of good F because firm F repairs good F without charge. In this case, the price of good F is given by $p_F = V_F(x_D, \widetilde{d}_F)$ (see point C in Figure 1). Holding x_D constant, the relationship between the price and the sales of good F in the OR subgame is depicted as OR curve in Figure 1.

Starting from no repairs for good F, the repair services by firm F shift the demand for good F from the RN curve to the OR curve. Accordingly, given that the consumption of good F is $\widetilde{d}_F$, the price and the sales of good F moves from point A to point C in Figure 1. To decompose the movement into two effects, let point B in Figure 1 be the intersection of $\widetilde{d}_F$ and $qV_F(x_D, \widetilde{d}_F)$.

As is mentioned above, the consumer makes a precautionary purchase of good F in NR subgame because she anticipates that a fraction of the purchased units of good F will fail and remain unworkable. Given $\widetilde{d}_F$ and the price of good F, the amount of the extra purchase of good

F is given by $\widetilde{d}_F/q - \widetilde{d}_F = (1-q)\widetilde{d}_F/q$. The increased durability of good F with repair services for good F eliminates this precautionary purchase of good F. From the viewpoint of firm F, this means that its sales of good F decreases. We call the effect the *market-contraction effect* of repair services. In Figure 1, the movement from point A to point B represents the market-contraction effect.

The increased durability of good F also raises the attractiveness of good F for the consumer and her willingness to pay for the good. Therefore, repair services increase the price of good F that realize $\widetilde{d}_F$ units of consumption from $qV_F(x_D, \widetilde{d}_F)$ to $V_F(x_D, \widetilde{d}_F)$. We call this effect the *valuation effect*. The difference in the price, $(1-q)\,V_F(x_D, \widetilde{d}_F)$, captures the valuation effect. In Figure 1, the movement from point B to point C corresponds to the valuation effect.

The valuation effect increases the price that can be charged while the market-contraction effect decreases the amount of sales to achieve $\widetilde{d}_F$. Although the overall effect on the total revenue and the profit captured by firm F seems to be ambiguous, we can easily verify that the shift from the NR subgame to the OR subgame does not change the total revenue (and so the total expenditure of consumers) while it always increases the profit of firm F, if x_D and $\widetilde{d}_F$ are kept constant.

2.2.2 "Business-stealing" by the rival firm

Next, we consider the effect of the shift from the OR subgame to the RR subgame on the price and the sales of good F. In the OR subgame, firm F repairs good F and it captures the benefit from the valuation effect in the product market. If firm D repairs good F, however, the benefit from the valuation effect is captured by firm D in the aftermarket. In the RR subgame, each consumer anticipates at the time of purchasing good F that she will pay $(1-q)\,\widehat{r}x_F$ in the aftermarket. Given that the consumption of good F is $\widetilde{d}_F$, the consumer's marginal willingness to pay for good F, $V_F(x_D, \widetilde{d}_F)$, should be equal to the sum of p_F and $(1-q)\,\widehat{r}$. Since firm D sets $\widehat{r} = V_F(x_D, \widetilde{d}_F)$ in stage 3, the price of good F in the product market becomes $p_F = V_F(x_D, \widetilde{d}_F) - (1-q)\,\widehat{r} = qV_F(x_D, \widetilde{d}_F)$. The expected price of repair services in the aftermarket makes the price of good F in the product market smaller than the price of good F in the OR subgame, $V_F(x_D, \widetilde{d}_F)$.

Note that the expected repair price, $(1-q)\,\widehat{r} = (1-q)\,V_F(x_D, x_F)$, coincides with the magnitudes of the valuation effect. This means that the benefit from the valuation effect is completely stolen by firm D. As a result, the price of good F declines from point C to point B in Figure 1, given $\widetilde{d}_F$. The RR curve, which is shifted downward from the OR curve by the same amount as the valuation effect, represents the relationship between the price and the sales of good F in the product market in the RR subgame.

It is apparent that, holding x_D and $\widetilde{d}_F$ constant, the shift from the OR subgame to the RR subgame reduces both the total revenue and the profit captured by firm F, while it does not change the total expenditure of consumers.

Up to this point, we have investigated the demands for good F in each subgame holding x_D is constant. In the equilibrium analysis, however, firm D strategically chooses x_D in each subgame. If we consider changes in x_D, there emerges a collusive effect in the RR subgame. The detailed explanation will be made in the following subsection, which discusses the strategic interaction between the two firms.

2.2.3 Interaction between firms and collusive effect

Bearing the above-mentioned effects in mind, now we compare the equilibrium outcomes with taking into account the changes in firm D's incentives and the strategic interactions between the two firms. As have mentioned earlier, only the workable units of each good are substitutes for consumers. Therefore, the product market competition in the NR subgame can be regarded as if the two firms compete in x_D and qx_F. Firm D's reaction curve is derived from (6) and it is depicted as the dd line in Figure 2. Similarly, firm F's reaction curve is derived from (7) and it is depicted as the ff line in Figure 2. The equilibrium amounts of workable units, (x_D^{NR}, qx_F^{NR}), are determined at the intersection of the dd line and the ff line.

[Figure 2 around here]

How the equilibrium amount changes in the RR subgame? The firm F's reaction curve in the RR subgame is the same as that in the NR subgame. In the RR subgame, firm F cannot capture the valuation effect of repairs due to the business-stealing by firm D. Therefore, given x_D and the amount of the workable units of good F, d_F, the price of good F in the product market is given by $qV_F(x_D, d_F)$ in both subgames (see Figure 1 and the discussion of Sections 2.2.1 and 2.2.2). As a result, given $d_F = x_F$ holds in the RR subgame and $d_F = qx_F$ holds in the NR subgame, firm F's reaction function with respect to d_F become the same (see (3) and (7)). Therefore, the ff line also represents the firm F's reaction curve in the RR subgame.

The firm D's reaction curve in the RR subgame, on the other hand, shifts to the Dd line which locates inside the dd line. In the RR subgame, an increase in the sales of good D reduces firm D's profits from the repair services since it decreases both imports of good F and the equilibrium repair price it will change in the next stage. Hence, firm D becomes less willing to increase x_D. The effect, which we call the *collusive effect,* decreases firm D's optimal supply of good D given x_F. More specifically, the Dd line is derived from (2) and the third-term of the right-hand side of the equation, which is negative because $V_{FD} < 0$, represents the collusive effect.

The equilibrium workable units of each good which should be equal to the equilibrium sales, (x_D^{RR}, x_F^{RR}), are determined at the intersection of the Dd line and the ff line. As is seen in the figure, the collusive effect makes both $x_D^{RR} < x_D^{NR}$ and $x_F^{RR} > qx_F^{NR}$ hold in equilibrium. Note that if the collusive effect were absent, the repair services by firm D would have no effect on the equilibrium amount of workable units. Also, note that even if the amount of the workable units of good F remain unchanged, the market contraction effect of repair services makes the amount of the sales of good F decline. We can confirm that, although the collusive effect makes the workable units of good F larger, the market contraction effect dominates it and the equilibrium sales of good F actually declines in equilibrium: $x_F^{RR} < x_F^{NR}$.

Next, we discuss how the shift from the NR subgame to the OR subgame changes the equilibrium amount. In both subgames, firm D cannot capture any rents from the repair services of good F. Therefore, firm D's reaction function in the OR subgame becomes the same as that in the NR subgame, which has been depicted as the dd curve in Figure 3.

[Figure 3 around here]

Firm F's reaction function, on the other hand, changes because now she can capture the rents from the valuation effect of repair services. The firm F's reaction curve which is derived from (5) is depicted as the FF line in Figure 3. Although the unit cost of supplying good F is also increased from $c+t$ to $c+t+(1-q)m_L$, we can confirm that an increase in the marginal revenue due to the valuation effect always dominates the increase in the unit cost. Therefore, the FF line locates outside the ff line. The shift of firm F's reaction curve makes $x_D^{OR} < x_D^{NR}$ and $x_F^{OR} > qx_F^{NR}$ hold.

Note that the ranking between x_F^{RR} and x_F^{OR} and between x_D^{RR} and x_D^{OR} are ambiguous and they depend on the relative magnitudes of the valuation effect in the OR subgame and the collusive effect in the RR subgame. In sum, we have the following proposition as to the equilibrium amount of the working units and the equilibrium amount of the sales of the two goods.[18]

Proposition 1 *Given the tariff level, (i)* $qx_F^{NR} < \min[x_F^{RR}, x_F^{OR}]$*, (ii)* $\max[x_D^{RR}, x_D^{OR}] < x_D^{NR}$*, and (iii)* $x_F^{RR} < x_F^{NR}$ *hold.*

[18]To make the proof of the following propositions as simple as possible, we use a standard quadratic form as the sub-utility function from here on: $V(d_D, d_F) = a(d_D + d_F) - (d_D^2 + d_F^2)/2 - bd_Dd_F$ where b represents the substitutability of the two products and we assume $b \in (0,1)$. Note that $V_{FF} = V_{DD} = -1$ and $V_{FD} = V_{DF} = -b$ hold under this form. Even if we consider the other forms of the sub-utility function, the basic results of our paper would be unchanged.

This proposition implies that the repair services for good F always: (i) increase the equilibrium workable unit of good F, (ii) decrease the equilibrium sales as well as the equilibrium workable unit of good D, and (iii) decrease the equilibrium sales of good F if firm D provides the repair services.

2.2.4 Consumer surplus and firms' profits

Having analyzed the effects of repair services on the equilibrium sales and the equilibrium workable units, we now turn to the effects on consumers and the firms. Let CS^k denote the consumer surplus in the k ($k \in \{RR, OR, NR\}$) equilibrium. We have the following proposition.

Proposition 2 *Given the tariff level,* $CS^{RR} < CS^{NR} < CS^{OR}$ *holds.*

Compared to the NR subgame, the valuation effect increases firm F's marginal gains from selling a workable unit of good F in the OR subgame. Therefore, the product market competition becomes more intense in the OR subgame and consumers prefer the OR equilibrium to the NR equilibrium.

On the contrary, the collusive effect generated by the rival's repairs weakens the product market competition in the RR subgame. This effect raises the equilibrium price of good D, while it also increases the equilibrium workable units of good F. The latter positive effect, however, is relatively small because it is the second-order effect and an import tariff makes the market-size of good F being weakly smaller than that of good D. Therefore, the former negative effect dominates the latter positive effect and consumers prefer the NR equilibrium to the RR equilibrium.

Regarding the firms' profits, let Π_i^k denote the operating profits of firm i ($i \in \{D, F\}$) in the k ($k \in \{RR, OR, NR\}$) equilibrium. We have the following proposition.

Proposition 3 *Given the tariff level,* $\Pi_F^{RR} < \Pi_F^{NR} < \Pi_F^{OR}$ *and* $\Pi_D^{OR} < \Pi_D^{NR} < \Pi_D^{RR}$ *hold.*

If we move from the NR equilibrium to the RR equilibrium, the rent from the valuation effect is captured by Firm D, and only the market-contraction effect matters for firm F, which has a negative effect on the profit of Firm F by reducing the sales of good F without affecting the workable unit of good F. Although the collusive effect works in favor of firm F, it is the second-order effect and dominated by the market-contraction effect. By contrast, the market-contraction effect does not matter for firm D since it is unrelated to the equilibrium workable units of good F, while the valuation effect and the collusive effect work in favor of firm D. Hence, we have $\Pi_F^{NR} > \Pi_F^{RR}$ and $\Pi_D^{RR} > \Pi_D^{NR}$.

In the OR equilibrium, on the other hand, firm F can capture the rents associated with the valuation effect, and its positive effect on the profits always outweighs the negative effect due to the market-contraction effect. Besides that, the increase in the workable units of good F by its own repairs ($qx_F^{NR} < x_F^{OR}$) has a strategic effect in the product market which shifts rents from firm D to firm F. As a result, we have $\Pi_F^{OR} > \Pi_F^{NR}$ and $\Pi_D^{NR} > \Pi_D^{OR}$.

2.2.5 A time inconsistency problem of consumers

In Section 3.2.4, we have shown that the repairs of the imported good by the domestic rival firm cause a collusive effect and hurt consumers, compared to the case without repair services. The consumer's loss is due to a time inconsistency problem on the side of the consumers.

In Stage 3, given that consumers have already purchased the goods and hold the broken units of good F, purchasing the repair services from firm D benefits them. However, the consumers' repairs in Stage 3 causes the collusive effect and reduces firm D's supply of good D in Stage 2, and the weaker product market competition hurts consumers.

Since the latter effect dominates the former effect, if consumers could pre-commit whether they utilize the repair services for good F provided by firm D in the RR subgame, they would commit not to utilize them in order to avoid the collusive effect. In this case, the equilibrium outcomes of the RR equilibrium coincides with those of the NR equilibrium. However, it seems more realistic that consumers are unable to make such a commitment credibly before they purchase the goods. Therefore, we assume that consumers cannot pre-commit the utilization of repair services.

In the absence of pre-commitment, even if consumers *ex-ante* anticipate that the repairs of imports by the domestic rival firm cause the collusive effect which increases the price of good D and eventually hurts them, they cannot refrain from ordering repairs to the domestic firm in the aftermarket because the repairs *ex-post* benefit consumers given the prices of the goods. Due to this time-inconsistency problem, consumers cannot avoid the negative welfare effect of repair services conducted by firm D.

2.3 Entry into the repair services for good F

To derive the equilibrium of the entire game, we examine the firms' entry decisions in stage 1. The two firms simultaneously decide whether they provide the repair services for good F by incurring the cost of entry, K_i ($i \in \{D, F\}$), given the choice of the rival firm. If firm F provides the service by undertaking a service FDI, firm D does not provide it because she cannot earn positive operating profits in the repair market for good F to cover the fixed cost. Hence, Firm D enters the repair market only if firm F does not enter.

Given that firm F does not undertake a service FDI, firm D's gains in operating profits from providing the repair services for good F is given by $\Delta\Pi_D = \Pi_D^{RR} - \Pi_D^{NR}$. Since we can confirm that $\partial\{\Delta\Pi_D\}/\partial t < 0$ holds, we have the following lemma.

Lemma 2 *If firm F does not provide the repair services for good F, a tariff reduction increases firm D's gains from providing the repair services.*

A tariff reduction increases the imports of good F. This increases the amount of the broken units of good F, making it more attractive for firm D to earn profits from repairing the rival's product. The lemma means that, as long as $K_D < \overline{K}_D \equiv \Delta\Pi_D|_{t=0}$ holds, there exists a threshold value of tariff, $t_D > 0$, such that $\Delta\Pi_D > K_D$ holds if and only if $t < t_D$.[19] For expositional simplicity, we set $t_D = 0$ if $K_D \geq \overline{K}_D$ holds.

Regarding firm F's gains from the entry, let $\Delta\Pi_F$ denote its gains in operating profits from undertaking a service FDI and providing the repair services. Because firm F provides a full-warranty if she undertook a service FDI, its strong position in the repair services of good F means that she always enters the repair market if $\Delta\Pi_F > K_F$ holds, regardless of firm D's entry decisions. We have the following proposition.

Proposition 4 *The equilibrium of the entry game becomes: (i) the OR equilibrium if $\Delta\Pi_F > K_F$ holds, (ii) the RR equilibrium if $\Delta\Pi_F \leq K_F$ and $t < t_D$ hold, and (iii) the NR equilibrium otherwise.*

Given $K_D < \overline{K}_D$ holds, Figure 4 depicts the possible equilibrium outcomes in the (t, K_F) space.[20][21] When K_F is high, if is unprofitable for firm F to undertake a service FDI. Under this situation, if t is high, the imports of good F are small and an increase in Π_D by providing repair services for good F cannot exceed the fixed cost, K_D. Therefore, repair services for good F are

[19] Lemma 2 implies that $\Delta\Pi_D$ is maximized at $t = 0$. Let $\bar{t}$ denote the minimum level of tariff that eliminates the imports of good F under the RR equilibrium and the NR equilibrium. Clearly, $\Delta\Pi_D = 0$ holds if $t = \bar{t}$. Therefore, if K_D satisfies $K_D < \overline{K}_D$, there exists a threshold value of tariff, t_D, such that $\Delta\Pi_D < K_D$ holds for $t \in (t_D, \bar{t})$, $\Delta\Pi_D = K_D$ holds for $t = t_D$, and $\Delta\Pi_D > K_D$ holds for for $t \in [0, t_D)$.

[20] We can see that $\Delta\Pi_F$ jumps up at $t = t_D$. If firm F does not provide the services, the equilibrium of the entire game becomes the NR equilibrium for $t \geq t_D$ and the RR equilibrum for $t < t_D$. Hence, $\Delta\Pi_F = \Pi_F^{OR} - \Pi_F^{NR}$ holds for $t \geq t_D$ and $\Delta\Pi_F = \Pi_F^{OR} - \Pi_F^{RR}$ holds for $t < t_D$. By Proposition 3, $\Pi_F^{NR} > \Pi_F^{RR}$ holds which implies that firm F has a stronger incentive to undertake a service FDI if she faces a potential entry of the rival firm.

[21] It is ambiguous whether $\Delta\Pi_F$ is decreasing or an inverse-U shaped curve in t. The increased imports from a tariff reduction increase firm F's gains from the entry, but there is an additional effect. In the RR subgame and the NR subgame, because firm F cannot capture the rents associated with the broken units, the demand curves are flatter than those in the OR case (see Figure 1). Hence, the tariff reduction increases x_F less in the OR subgame than it does in the RR and the NR subgame. If the cost of providing services (m_L) is sufficiently large and that of supplying the goods (c and t) is sufficiently small, the latter effect dominates the former effect and trade liberalization undermines firm F's entry. See the Appendix for details. In Figure 4, we depict the case where $\Delta\Pi_F$ is an inverse U-shaped curve in t. The shape of $\Delta\Pi_F$ does not affect the main results of the paper.

not provided in equilibrium when both t and K_F are high (the region "NR" in the figure). When K_F is high while t is low, it becomes profitable for firm D to provide repair services for good F, and the aftermarket for good F is monopolized by firm D (the region "RR"). When both K_F and t are low, however, $\Delta\Pi_F > K_F$ holds and Firm F can increase its overall profit by establishing service facilities and selling its product with full warranty. The full warranty ensures that firm D never establish service facilities whenever firm D anticipates that firm F will establish service facilities.[22] Therefore, the repairs for good F are sorely provided by firm F in equilibrium if $\Delta\Pi_F > K_F$ holds (the region "OR").

[Figure 4 around here]

3 Liberalization of goods trade and service FDI

In this section, we examine the welfare effects of trade liberalization in goods and its connection to the structure of the aftermarket service. Trade liberalization, represented by a decline in t, affects welfare within each regime of the aftermarket services, and it may also affect welfare by inducing a switch of the regime.[23] Here, we will show that the overall effects of trade liberalization drastically differ depending on the extent to which service FDI is liberalized.

To describe the different effects of trade liberalization, we first compare the two specific cases: (i) the fixed cost of service FDI is high enough so that trade liberalization induces firm D's entry, (ii) it is low enough so that trade liberalization induces firm F's entry. Then, we explain a general property of lowering the fixed cost.

3.1 Trade liberalization when the fixed-cost of service FDI is high

Let K_F^0 and t_0 respectively denote the initial level of the fixed costs for FDI in services and the initial level of tariff. Suppose $\Delta\Pi_F < K_F^0$ and $t_0 > t_D$ hold so that the entry into the repair services for good F are unprofitable for both firm D and firm F. In this case, the equilibrium of the entire game is initially the NR equilibrium (see Point A of Figure 4). Starting from t_0, if the tariff is gradually reduced, we have the following welfare effect within the NR equilibrium.

Within the NR equilibrium, trade liberalization has standard effects which increase the imports, benefits consumers and firm F, and hurts firm D. However, it may worsen world welfare because the "quality" of good F is inferior to that of good D. The quality of good F is inferior

[22] The entry decisions of the two firm does not depend on the full-warranty assumption. See Section 4.2 for details.

[23] See the Appendix for the detailed calculations of the effects of trade liberalization within each regime.

in the sense that a fraction of good F fails and remains unrepaired. Trade liberalization has the substitution effect which increases the consumption of good F and decreases that of good D, and the effect reduces consumers' gains from trade liberalization. As a result, firm D's profit loss can outweigh the consumers' gains. As tariff is reduced, the imports of good F increase and the gains from entry into the service market for good F become larger. When the tariff reaches $t = t_D$, the further reduction of t induces entry of firm D and switches the equilibrium from the NR equilibrium to the RR equilibrium. The switch to the RR equilibrium causes the collusive effect which reduces the extent of the product-market competition and discontinuously hurts consumers (see Proposition 2).

As has been discussed in Section 2.2.5, the consumer's loss is due to a time inconsistency problem on the side of the consumers. Even if consumers *ex ante* anticipate that the repairs of good F by firm D raise the price of good D in the product market and eventually become harmful for them, they can't help but repair good F after they purchased good F. This is because, given consumers hold the broken units of good F, it is *ex post* optimal for them to purchase the repair services from firm D.

By using Propositions 1 and 3, we can also confirm that the switch discontinuously reduces the imports, hurts and firm F, while it does not affect firm D. The loss of firm F is due to the market-contraction effect which outweighs the collusive effect. The switch has no effect on firm D's net profit (i.e., the operating profits minus the fixed cost of FDI) because $\Delta\Pi_D = K_D$ holds at $t = t_D$.

As a result, the negative effects of the equilibrium shift on consumer surplus ($CS^{RR} < CS^{NR}$), tariff revenues induced by the reduced imports ($t_D x_F^{RR} < t_D x_F^{NR}$), and firm F's profits $\Pi_F^{RR} < \Pi_F^{NR}$ lead to a decline in world welfare.

Once the RR equilibrium is realized, further reductions of t within the RR equilibrium increases the imports of good F and benefits consumers and firm F. However, it is ambiguous whether the trade liberalization benefits or hurts firm D. Trade liberalization decreases the sales of good D and thereby lowers the profits in the product market, while it increases the sales of good F and so does firm D's profits in the after-service market. Therefore, the overall effect on firm D's profits depends on the relative magnitudes of these two effects. Furthermore, it is also ambiguous whether trade liberalization improves or worsens world welfare within the RR equilibrium. This is because it increases the sales of good F and reduces the sales of good D and the higher cost of repairing good F ($m_H \geq m_L$) worsens the overall efficiency of the economy. Due to these effects, trade liberalization may worsen world welfare within the RR equilibrium.

Table 1 summarizes the effects of trade liberalization when $K_F = K_F^0$.

[Insert Table 1 around here]

If the effect of the regime switch outweighs the effect within each regime, the overall effect of trade liberalization from $t_0 \in (t_1, \bar{t})$ to $t_1 \in [0, t_D)$ reduces imports and hurts consumers and firm F, and worsens world welfare. Besides that, if trade liberalization increases the profit of firm D within the RR equilibrium, there is a case where the same tariff reduction benefits firm D.

3.2 Trade liberalization when the fixed-cost of service FDI is low

Next, suppose the fixed cost is reduced from K_F^0 to K_F^1 so that $K_F^1 < \min[\Delta\Pi_F|_{t=0},\ \Delta\Pi_F|_{t=t_D}]$ holds (see Point B of Figure 4). In this case, there exists a unique threshold value of tariff, t_F $(\in (t_D, \bar{t}))$, such that $\Delta\Pi_F > K_F$ holds if and only if $t < t_F$. As tariff is reduced from t_0 and becomes lower than $t = t_F$, it becomes profitable for firm F to undertake service FDI. Because firm F offers a full-warranty on good F at the point of selling good F, firm D has no way to win the competition with firm F in the aftermarket, the RR equilibrium is no longer a possible equilibrium outcome for any $t \in [0, t_D)$.[24] Consequently, the trade liberalization shifts the equilibrium from the NR to the OR equilibrium.

By using Propositions 2 and 3, we can confirm that the switch intensifies market competition and discontinuously benefits consumers, hurts firm D, and improves world welfare.[25] It does not affect firm F because $\Delta\Pi_F = K_F$ holds at $t = t_F$ in this case. Once the service FDI is undertaken, the further trade liberalization within the OR equilibrium always has a standard effect which increases imports, benefits consumers and firm F, hurts firm D, and improves world welfare. Table 2 summarizes the effects of trade liberalization in this case.

[Insert Table 2 around here]

If K_F is low enough so that trade liberalization induces firm F's service FDI while excluding firm D's entry, the overall effect of trade liberalization from $t_0 \in (t_1, \bar{t})$ to $t_1 \in [0, t_D)$ always benefits consumers and hurts firm D. Regarding world welfare, although the shift from the NR to the OR equilibrium improves world welfare, the overall effect of trade liberalization can be negative if a tariff reduction worsens world welfare within the NR equilibrium. However, as K_F^1 becomes smaller, the cut-off level of tariff, t_F, becomes larger and approaches t_0. In particular, if K_F^1 is small enough to make $t_0 \leq t_F$ hold, the equilibrium regimes before the tariff reduction

[24] See the first two paragraphs of Section 2.1. A full-warranty assumption does not affect the result as long as $m_H \geq m_L$ holds. See Section 4.2 for details.

[25] It is ambiguous whether the switch increases the imports of good F, though it always increases the consumption of good F (see Proposition 1).

also becomes the OR equilibrium and any tariff reductions always have a positive effect on world welfare.

3.3 The role of liberalization in service FDI

The above two examples imply that consumer-hurting, welfare-reducing trade liberalization can be transformed into a consumer-benefiting, welfare-improving liberalization by liberalizing FDI in aftermarket services. This transformation is not a special case and has a general validity, as the following proposition states.

Proposition 5 *If $t_D > 0$ and $K_F^0 > \Delta\Pi_F$ holds for some t in $t \in [0, t_D)$, then a tariff reduction from $t_0 \in (t_1, \overline{t})$ to $t_1 \in [0, t_D)$ may decrease imports, hurt consumers and firm F, benefits firm D, and/or worsen world welfare, holding K_F fixed at $K_F = K_F^0$. In this case, there always exists a unique cut-off level of K_F, $\widetilde{K}_F$ $(\leq K_F^0)$, such that the same tariff reduction necessarily increases imports, benefits consumers and firm F, and improves world welfare for all $K_F < \widetilde{K}_F$.*

This proposition suggests that any consumer-hurting, welfare-reducing trade liberalization turns into consumer-benefiting and welfare-improving one if K_F is reduced through liberalization of service FDI. If the fixed cost is high enough, trade liberalization induces the entry of firm D into the aftermarket. The entry entails the collusive effect which hurts consumers and worsens world welfare. If the fixed cost is sufficiently lowered, however, trade liberalization induces the entry of firm F into the aftermarket. The entry not only blocks the potential entry of firm D that causes the collusive effect, but also increases the marginal gains from selling good F in the product market because firm F can capture the valuation effect of repairs. This makes firm F supply good F more, given the supply of good D. As a result, trade liberalization which induces the entry of firm F intensifies the product market competition and benefits consumers and improves world welfare.

The result suggests that promoting FDI in aftermarket services is important to make trade liberalization in goods consumer-benefiting and welfare-improving.

4 Discussion

We have shown that the provision of aftermarket services conducted by the other firm, with whom the original producer competes in the product market, has a collusive effect and hurts consumer and worsens world welfare. Even if consumers anticipate this effect and it is *ex ante* beneficial for them to stop utilizing the services, it is *ex post* beneficial for them to purchase the services in the aftermarket once they find the broken units of good F. Because of the time inconsistency problem on the side of consumers, trade liberalization in goods that induces the service provisions by the rival firm may hurt consumer and worsen world welfare. The liberalization of service FDI, however, converts the same trade liberalization into a consumer-benefiting, welfare-improving liberalization. In this section, we explore the robustness of these results by relaxing some assumptions made in the basic model.

4.1 Repair services by ISOs

Up to this point, we have assumed that only firm D and firm F can provide the repair services. In this section, we consider the case in which Independent Service Organizations (ISOs) may also provide the repair services for good F. Under this alternative set-up, many potential ISOs, firm F, and firm D simultaneously decide whether they provide the repair services for good F in stage 1. If an ISO enters the repair market, it must incur the fixed cost. For simplicity, we assume the ISO incurs the same unit cost, m_H, and the same fixed cost, K_D, as those of firm D.[26]

We can confirm that, even if ISOs enter the repair market, all broken units of good F are repaired in equilibrium.[27] Then, how does the presence of ISOs affect the equilibrium of the product market? Given that firm F does not undertake service FDI, if more than two ISOs or an ISO and firm D enter the repair markets for good F, then the price competition in the aftermarket leads to the marginal-cost pricing in equilibrium: $r = m_H$. As long as $K_D > 0$, it is unprofitable for each ISO to enter the repair market if other ISOs or firm D enter the repair market. This means that at most a single ISO enters the aftermarket in equilibrium. We call the equilibrium where a single ISO monopolizes the aftermarket **the ISO equilibrium**.

Given that a single ISO monopolizes the repair services for good F, it sets $r = V_F(x_D, x_F)$ to maximize its profit and the inverse demand for good F are given by $p_F = qV_F(x_D, x_F)$. The equilibrium operating profit of the ISO is given by $\Pi_{ISO} = \{V_F(x_D, x_F) - m_H\}(1-q)x_F$. In stage 2, firm D sets x_D such that it maximizes $\Pi_D = [V_D(x_D, x_F) - \{c + (1-q)m_L\}]x_D$ and firm F sets x_F such that it maximizes $\Pi_F = [qV_F(x_D, x_F) - (c+t)]x_F$.

[26] Since the firms which produce goods have better knowledge about the goods, the unit cost and the fixed cost of each ISO in the aftermarket may be higher than those of firm D. Or they may be lower if each ISO has better knowledge and higher skills on repairing goods. Although different service costs between firm D and ISOs make each ISO's entry more difficult or easiler, the qualitative nature of our analysis would remain unchanged.

[27] Suppose a single ISO monopolizes the repair services for good F. The ISO's profit-maximization problem in stage 3 is the same as that of firm D in the RR case. The ISO sets r such that $R_F = (1-q)x_F$ holds. Besides that, the repair price becomes lower if more than two ISOs or both an ISO and firm D enter the repair market. This means that all broken units will be repaired in equilibrium if at least one ISO enters the repair market. See Appendix for details.

Because firm F cannot capture the rents associated with the repairs, its maximization problem becomes the same as the RR subgame. Meanwhile, firm D cannot capture any rents from the repair services for good F either, and so its maximization problem is the same as that in the OR subgame. Hence, firm F's reaction curve becomes the ff line in Figures 2 and 3, while firm D's reaction curve becomes the dd line in these figures. The equilibrium sales of the two goods under the ISO equilibrium, which are denoted as x_D^{ISO} and x_F^{ISO}, are obtained at the intersection of the ff line and the dd line. It is obvious that the equilibrium sales satisfy $x_D^{ISO} = x_D^{NR}$ and $x_F^{ISO} = qx_F^{NR}$. The equilibrium consumer surplus and the firm's profits are respectively denoted by CS^{ISO}, Π_D^{ISO}, and Π_F^{ISO}.

Because the valuation effect is captured by the ISO and the collusive effect is absent in this case, holding t fixed, the equilibrium workable units of both goods become the same between the NR equilibrium and the ISO equilibrium. This means that consumer surplus and firm D's profits also remain unchanged (i.e., $\Pi_D^{ISO} = \Pi_D^{NR}$ and $CS^{ISO} = CS^{NR}$ given t). Because of the market-contraction effect, however, the switch reduces the volume of imports (i.e., $x_F^{ISO} = qx_F^{NR} < x_F^{NR}$) and hurts firm F ($\Pi_F^{ISO} < \Pi_F^{NR}$). Note that the lack of the collusive effect means that the entry of the ISO into the aftermarket for good F hurts firm F more than the entry of firm D does ($\Pi_F^{ISO} < \Pi_F^{RR}$). The loss of firm F and the decline in tariff revenue mean that world welfare in the ISO equilibrium is lower than that in the NR equilibrium if the net profit of the ISO, $\Pi_{ISO} - K_D \geq 0$, is small.

We have compared the NR equilibrium and the ISO equilibrium given the tariff level. Now we examine the effect of trade liberalization in the presence of ISOs. We can confirm that a tariff reduction increases an ISO's gains from providing the repair services (i.e, $\partial\{\Delta\Pi_{ISO}\}/\partial t < 0$). The following proposition suggests that the ISO equilibrium can be the equilibrium of the entire game.

Proposition 6 *If $\Delta\Pi_F \leq K_F$ and $\Pi_{ISO}|_{t=0} > K_D$ hold, then there exists a threshold value of tariff, $t_{ISO} \in (0, \bar{t})$, such that the equilibrium of the entry game becomes: (i) the NR equilibrium if $\max[t_{ISO}, t_D] \leq t$ holds, (ii) the RR equilibrium if $t_{ISO} \leq t < t_D$ holds, (iii) the ISO equilibrium if $t_D \leq t < t_{ISO}$ holds, and (iii) either the ISO equilibrium or the RR equilibrium if $0 \leq t < \min[t_{ISO}, t_D]$ holds.*

When the tariff level is high, the import of good F is small and the ISO's operating profit from providing repair services does not exceed the fixed cost, K_D. If the tariff is sufficiently reduced, however, the market size for repair services become sufficiently large and it becomes profitable for an ISO to enter the aftermarket if both firms or other ISOs do not enter.

Proposition 6 implies that, given that the fixed cost of service FDI and the import tariff initially satisfy $\Delta\Pi_F < K_F^0$ and $t_0 > \max[t_{ISO}, t_D]$, a tariff reduction from t_0 to $t_1 \in [0, t_{ISO})$ may switch the equilibrium from the NR to the ISO equilibrium. Since a tariff reduction in each equilibrium benefits consumers and hurts firm D while the switch from the NR to the ISO equilibrium does not affect consumer surplus nor firm D given t, the trade liberalization always benefits consumers and hurts firm D. Although a tariff reduction always benefits firm F within each zregime, the switch from the NR to the ISO equilibrium hurts firm F given t, and if this effect dominates the effects within each regime, the trade liberalization from $t_0 \in (\max[t_{ISO}, t_D], \bar{t})$ to $t_1 \in [0, t_{ISO})$ hurts firm F. Furthermore, if the difference between t_1 and t_{ISO} is small enough, the profit loss of firm F dominates the profit gain of the ISO from the trade liberalization.[28] Furthermore, trade liberalization may worsen world welfare within the ISO equilibrium by the same reason as it does in the RR equilibrium. Consequently, trade liberalization from t_0 to t_1 may hurt firm F and worsens world welfare, while it always benefits consumers and hurts firm D.

Under this situation, if the fixed cost of service FDI is sufficiently reduced, the same tariff reduction induces service FDI by firm F and becomes consumer-benefiting and welfare-improving. These results suggest that even if the presence of ISOs prevent the repairs by the rival firm, trade liberalization could still worsen world welfare and the liberalization of service FDI is still important to guarantee welfare-improving trade liberalization.

4.2 Full-warranty assumption

We have assumed that firm D and firm F provide a full warranty if they provide the repair services for their own products. In this subsection, we show that our main results remain unchanged if they cannot provide a full warranty.

Consider a variant of the model in which firm i ($i \in \{D, F\}$) cannot provide a full warranty for its own product, and instead charges consumers a fee for repairing good i. Let s_i denote the price that firm i sets for repairing good i in Stage 3. Consider a subgame in which only firm F establishes the facilities for repairing good F in Stage 1 (the OR subgame). It sets s_F in Stage 3 such that it maximizes the profit from the repair services. In Stage 2, each consumer anticipates that she will pay s_F in Stage 3 per unit of repairs if the purchased unit is defective. The prospect of paying the repair price diminishes each consumer's willingness to pay in the product market. Then, firm F maximizes its profits with respect to x_F anticipating that its decision in the product market affects the profit from the repair services in Stage 3.

In the equilibrium of the OR subgame, firm F always sets s_F such that all broken units,

[28] Since $\Pi_{ISO} = K_D$ holds at $t = t_{ISO}$, $\Pi_{ISO} - K_D$ becomes smaller if t_{ISO} approaches t_1.

$(1-q)x_F$, are repaired. This means that each consumer's willingness to pay for good F in the product market decreases by $(1-q)s_F$. Specifically, each consumer maximizes $V(x_D, x_F)+Z$ with respect to x_D and x_F, subject to $p_D x_D + p_F x_F \leq I-(1-q)s_F x_F$. The demand for good D and for good F are respectively determined by $p_D = V_D(x_D, x_F)$ and $p_F = V_F(x_D, x_F)-(1-q)s_F$. Then, firm F's maximization problem in stage 2 is to maximize $\Pi_F = \{p_F - (c+t)\}x_F + (s_F - m_L)(1-q)x_F = [V_F(x_D, x_F) - \{c+t+(1-q)m_L\}]x_F$, which is independent of s_F and exactly the same as firm F's maximization problem in the OR subgame of the base model (see Eq.(5)). In other words, the "full price" of good F that each consumer pays and firm F receives, $p_F + (1-q)s_F$, becomes the same as the price of good F under the full-warranty assumption. Similarly, the "full price" of good D is unaffected by the absence of the full-warranty.

Therefore, each firm's equilibrium profit in the OR subgame of this variant of the model is identical to the one in the base model, and the same property holds for the RR and the NR subgames. This in turn implies that all propositions and lemmas would remain unchanged in the absence of the full-warranty assumption.

As in the base model, there does not exist an equilibrium of the entire game in which both firms establish their facilities for repairing good F. To see this, suppose both firms D and F have established service facilities for good F in Stage 1. They then engage in Bertrand competition in the aftermarket for good F. Because $m_H \geq m_L$ holds, the equilibrium prices satisfy $s_F = s_D = m_H$. This means that firm D cannot earn positive profits in the aftermarket and the collusive effect does not emerge. Firm D's profit in the aftermarket also becomes small or even zero, but it still has the same incentive to enter the repair market as the OR subgame because Firm D can fully compensate a decrease in s_F by increasing p_F. Therefore, even if firm F does not provide a full warranty, firm D does not enter into the aftermarket for good F whenever firm F does it.[29]

We have assumed that firm F does not repair good D after it undertakes FDI. Even if firm F could repair good D by incurring a fixed cost in stage 1, it would not do that because the firm cannot earn positive profit in the aftermarket of good D by the same reason as described above.

4.3 Repurchase of good F

Here, we consider the case where each consumer is able to repurchase good F from firm F if she found the unit of good F she purchased is broken down and the repair services for good F are not provided. We can show that the equilibrium outcomes in this situation coincides with

[29] We have assumed that $m_H \geq m_L$ holds. If instead $m_H < m_L$, then firm D wins the price competition in repairing good F, but the main results would still remain unchanged. A detailed explanation will be provided upon request.

those under the NR equilibrium (see Appendix for details). If consumers can repurchase good F under no repair services, ceteris paribus, they reduce the amount of the original purchase of good F because they no longer need to make a precautionary purchase. However, the reduction in the original purchase of good F coincides with the amount of good F consumers repurchase in equilibrium. In other words, the precautionary purchase of good F in the NR subgame fully supplements the repurchase of good F.

Therefore, the qualitative nature of the results would remain unchanged even if we allow the repurchase of good F.[30]

5 Conclusion

We have analyzed the provision of repair services in an international duopoly model with differentiated products. We have shown that the liberalization of the trade in goods, if not accompanied by the liberalization of service FDI, induces firm D to establish service facilities for repairing good F. Firm D's provision of repair services for its rival's products results in the collusive effect, which hurts consumers and firm F, and reduces world welfare. The negative effects on consumers and world welfare are driven by time inconsistency problem on the side of consumers. This is a new perspective on durable-goods producers' behavior in aftermarkets, given that previous analyses on this topic have focused on time inconsistency problem of producers rather than consumers.

Time inconsistency problem of consumers seems particularly difficult to be resolved because numerous consumers must collectively commit to their behavior in the aftermarket. This observation highlights the importance of liberalization of service FDI as a way to resolve the time inconsistency problem and turn the negative effects of trade liberalization in goods into positive ones. If service FDI is also liberalized, it is firm F, not firm D, that establishes services facilities for repairing good F, as liberalization of the trade in goods makes progress. The collusive effect is eliminated when firm F provides repair services for its own products.

There are several directions in which our analysis can be extended. Our results indicate that a tariff-jumping FDI in production may make consumers worse off by inviting the domestic firm's entry into the aftermarket. To guarantee consumer's benefits of a tariff-jumping FDI, it should be accompanied by FDI in repair services. Considering the problem of parallel imports in our framework would be an interesting extension since the original producers sometimes refuse to repair the broken units sold by unauthorized distributors.

[30] Furthermore, if the imported good is sold as a limited version with special specifications, the repurchase of the good is impossible.

Appendix

Proof of Lemma 1

At stage 3, the firm D's maximization problem is to choose r that maximizes $(r - m_H)\, R_F$ subject to $R_F \leq (1-q)\, x_F$. Let the Lagrangian function as $L = (r - m_H)\, R_F + \lambda\{(1-q)\, x_F - R_F\}$ where λ is the Lagrangian multiplier. The first-order conditions are given by

$$V_F(x_D, qx_F + R_F) + V_{FF}(x_D, qx_F + R_F)R_F = m_H + \lambda; \tag{A1}$$

$$(1-q)\, x_F - R_F \geq 0; \lambda \geq 0; \lambda\, [(1-q)\, x_F - R_F] = 0.$$

(i) **Suppose** $\lambda > 0$. This implies that $\widehat{R}_F = (1-q)\, x_F$ and $\widehat{r} = V_F\,(x_D, x_F)$ hold at stage 3. At stage 2, the representative consumer anticipates that all broken units will be repaired and its maximization problem is given by $\max_{x_D, x_F} V(x_D, qx_F + (1-q)\, x_F) + Z$ subject to $p_D x_D + p_F x_F \leq I - \widehat{r}\,(1-q)\, x_F$. The first-order conditions yield $p_D = V_D(x_D, x_F)$, $p_F + (1-q)\,\widehat{r} = V_F(x_D, x_F)$. The profit-maximization problems of firm D and firm F are respectively given by

$$\begin{aligned}
\max_{x_D} \Pi_D &= (p_D - c - (1-q)\, m_L)\, x_D + (1-q)\,(\widehat{r} - m_H)\, x_F \\
&= \{V_D(x_D, x_F) - c - (1-q)\, m_L\} x_D + (1-q)\,(V_F(x_D, x_F) - m_H)\, x_F \\
\max_{x_F} \Pi_F &= \{p_F - (c+t)\} x_F = \{qV_F(x_D, x_F) - (c+t)\} x_F
\end{aligned}$$

By solving the first-order conditions, the optimal sales of the two firms, (x_D^{RR}, x_F^{RR}), must satisfy

$$V_D(x_D^{RR}, x_F^{RR}) + V_{DD}(x_D^{RR}, x_F^{RR})x_D^{RR} + (1-q)\, V_{FD}(x_D^{RR}, x_F^{RR})x_F^{RR} = c + (1-q)\, m_L, \tag{A2}$$

$$V_F(x_D^{RR}, x_F^{RR}) + V_{FF}(x_D^{RR}, x_F^{RR})x_F^{RR} = \frac{c+t}{q}. \tag{A3}$$

By (A1), (A3), and $c \geq m_H$,

$$\lambda = V_F(x_D^{RR}, x_F^{RR}) + V_{FF}(x_D^{RR}, x_F^{RR})x_F^{RR} - m_H = \frac{c+t}{q} - m_H > 0.$$

Therefore, (x_D^{RR}, x_F^{RR}) and $R_F^{RR} = (1-q)\, x_F^{RR}$ actually constitute an equilibrium.

(ii) **Suppose** $\lambda = 0$. This means that firm D sets R_F so that only a part of the broken units is repaired (i.e., $R_F < (1-q)\, x_F$). By (A1),

$$V_F(x_D, qx_F + R_F) + V_{FF}(x_D, qx_F + R_F)R_F = m_H \tag{A4}$$

holds. Since we have assumed that $V_{FF}(d_D, d_F) < 0$ and $2V_{FF}(d_D, d_F) + (\partial V_{FF}(d_D, d_F)/\partial d_F)d_F < 0$ hold, $2V_{FF}(d_D, d_F) + (\partial V_{FF}(d_D, d_F)/\partial d_F)D < 0$ holds for any $D \in (0, d_F]$. Combined this property with (A3) and $c \geq m_H$, we have

$$\begin{aligned} V_F(x_D, qx_F + R_F) + V_{FF}(x_D, qx_F + R_F)R_F &> V_F(x_D, x_F) + (1-q)\, V_{FF}(x_D, x_F)x_F \\ &> V_F(x_D, x_F) + V_{FF}(x_D, x_F)x_F \\ &= \frac{c+t}{q} > m_H. \end{aligned}$$

This inequality contradicts (A4). Therefore, $\lambda = 0$ cannot hold in equilibrium. ■

Proof of Proposition 1

By solving (2) and (3), we have the equilibrium sales in the RR case as

$$x_D^{RR} = \frac{2\{a - c - (1-q)\, m_L\}q - ab\left(2 - q^2\right) + (2-q)\, b\, (c+t)}{\{4 - (2-q)\, b^2\}q}, \tag{A5}$$

$$x_F^{RR} = \frac{(2-b)\, qa + bq\{c + (1-q)\, m_L\} - 2\, (c+t)}{\{4 - (2-q)\, b^2\}q}. \tag{A6}$$

To guarantee $x_D^{RR} > 0$ and $x_F^{RR} > 0$, we assume $a > \underline{a} := [2\,(c+t) - bq\{c + (1-q)\, m_L\}]/(2-b)q$ are satisfied.

By solving (4) and (5), we have the equilibrium sales in the OR case as

$$x_D^{OR} = \frac{(2-b)\, \{a - c - (1-q)\, m_L\} + bt}{4 - b^2}, \tag{A7}$$

$$x_F^{OR} = \frac{(2-b)\, \{a - c - (1-q)\, m_L\} - 2t}{4 - b^2}. \tag{A8}$$

We can easily confirm that $x_D^{NR} > 0$ and $x_F^{NR} > 0$ hold as long as $x_D^{RR} > 0$ and $x_F^{RR} > 0$ hold.

By solving (4) and (5), and using (A5) and (A6), the equilibrium sales in the NR case are given by

$$x_D^{NR} = x_D^{RR} + \frac{2b\,(1-q)}{(4-b^2)\, q} x_F^{RR}, \quad x_F^{NR} = \frac{\{4 - (2-q)\, b^2\}}{(4-b^2)\, q} x_F^{RR}. \tag{A9}$$

By (A9), it is obvious that $x_D^{RR} < x_D^{NR}$ and $x_F^{RR} < x_F^{NR}$ hold. By (A5) and (A6), and (A9), we have $x_D^{RR} - x_D^{NR} = -\,(1-q)\, b\, (c - qm_L + t)\, /\{\left(4 - b^2\right) q\} < 0$, $x_F^{RR} - qx_F^{NR} = (1-q)\, qb^2 x_F^{NR}/\{4 - (2-q)\, b^2\} > 0$, and $x_F^{RR} - qx_F^{NR} = 2\,(1-q)\,(c - qm_L + t)/\{\left(4 - b^2\right) q\} > 0$. ■

Proof of Proposition 2

The equilibrium consumer surplus under the quadratic utility function in the k ($k \in \{RR, OR, NR\}$) case is given by

$$CS^k = \frac{(d_D^k)^2 + (d_F^k)^2}{2} + b(d_D^k)(d_F^k).$$

Since all broken units of good F are repaired both in the RR case and in the OR case, $d_i^{RR} = x_i^{RR}$ and $d_i^{RR} = x_i^{RR}$ hold for $i \in \{D, F\}$. In the NR case, on the other hand, $d_D^{NR} = x_D^{NR}$ and $d_F^{NR} = qx_F^{NR}$ hold because the broken units of good F remain unrepaired. We have

$$CS^{RR} - CS^{NR} = -\frac{(1-q)\, bB_2 x_D^{RR}}{2\left(4-b^2\right)^2 \{4-(2-q)\, b^2\} q}$$

where $B_2 = q\,(2-b)\,\{16+4b-16b^2-b^3+4b^4+qb\left(4+4b-b^2-2b^3\right)\}a + 2b\{4-7b^2+2b^4-\left(4-3b^2+b^4\right)q\}t - q\left(4-3b^2\right)(1-q)\{8-b^2(3-q)\}m_L + \{2b\left(4-7b^2+2b^4\right) - b^2\left(4-3b^2\right)q^2 - q\,(2+b)\left(16-4b-16b^2+5b^3+2b^4\right)\}c$. We can verify that $\partial B_3/\partial a > 0$ holds. Hence, we have $B_3 > B_3|_{a=\underline{a}} = 2\,(2+b)\left(2-b^2\right)\{4-b^2(2-q)\}\{(1-q)(c-qm_L)+t\} > 0$ and so $CS^{RR} < CS^{NR}$ holds. Similarly, we have

$$CS^{OR} - CS^{NR} = \frac{(1-q)\,(t+c-qm_H)\, B_3}{2\left(4-b^2\right)^2 q^2}$$

where $B_3 = 2q\,(b+1)\,(2-b)^2 a - \{\left(4-3b^2\right)(1+q)+2b^3q\}c - \left(4-3b^2\right)(1+q)\,t - (4-3b^2+2b^3)\,(1-q)\,qm_L$. Since B_4 is decreasing in a, we have $B_3 > B_3|_{a=\underline{a}} = (1-q)\,(4+4b-b^2)\,(c-qm_L) + \{4+4b-b^2-q\left(4-3b^2\right)\}t > 0$. Consequently, we have $CS^{RR} < CS^{NR} < CS^{OR}$. ■

Proof of Proposition 3

Under the quadratic utility function, the operation profit of firm D in each equilibrium is calculated as follows: $\Pi_D^{RR} = \left(x_D^{RR}\right)^2 + (1-q)\left[\left(x_F^{RR}\right)^2 + \{(c+t)/q - m_H\}x_F^{RR} + bx_D^{RR}x_F^{RR}\right]$, $\Pi_D^{OR} = \left(x_D^{OR}\right)^2$, and $\Pi_D^{NR} = \left(x_D^{NR}\right)^2$. Similarly, the operation profit of firm F is given by: $\Pi_F^{RR} = q\left(x_F^{RR}\right)^2$, $\Pi_F^{OR} = \left(x_F^{OR}\right)^2$, $\Pi_F^{NR} = \left(qx_F^{NR}\right)^2$. In the RR case, in addition to the profit from selling good D presented in the first term, firm D can grab a part of the profits generated from the consumption of good F by providing the repairs services for good F. This is reflected in the second term of the first equation.

(i) We have $\Pi_F^{RR} - \Pi_F^{NR} = -(1-q)\{16\left(1-b^2\right)+(4-q)\,b^4\}\left(x_F^{RR}\right)^2/\left(4-b^2\right)^2 < 0$ and $\Pi_F^{OR} - \Pi_F^{NR} = 4\,(1-q)\,(c+t-qm_L)\,[\{a(2-b)+bc\}q - q\,(1-q)\,(1-b)\,m_L - (q+1)\,(c+t)]/\{(4-b^2)^2q^2\} > 4\,(1-q)^2\,(c+t-qm_L)^2/\{(4-b^2)^2q^2\} > 0$ where the inequalities are due to $a > \underline{a}$. Hence, $\Pi_F^{RR} < \Pi_F^{NR} < \Pi_F^{OR}$ is satisfied.

(ii) We have $\Pi_D^{RR} - \Pi_D^{NR} = \{(1-q)\,B_1 x_F^{RR}\}/\left(4-b^2\right)^2\{4-(2-q)\,b^2\}q$ where $B_1 = a\,(2-b)\,\{4\,(1-b)\,(2+b)^2 + (3+2b)\,b^4 + \left(4-2b^2-b^3\right)b^2q\}q + 2\{16-20b^2+5b^4+2(2-b^2)b^2q\}t + bq\,(1-q)\,\{16-4\,(1-q)\,b^2 - b^4\}m_L - \left(4-b^2\right)^2\{4-(2-q)\,b^2\}qm_H + \{2\left(16-20b^2+5b^4\right) + (2+b)\,(8-2b^2-b^3)bq + 4b^3q^2\}c$. By using $a > \underline{a}$ and $c > m_H$, we can confirm that $B_1 > (2+b)\{4-(2-q)\,b^2\}\{(8-4b-2b^2+b^3q)c - (2+b)\,(2-b)^2\,qm_H + 2\left(4-2b-b^2\right)t + b^3\,(1-q)\,qm_L\} > (2+b)\{4-(2-q)\,b^2\}\{2c\left(4-2b-b^2\right)((1-q)\,c+$

$t)+b^3(1-q)qm_L\} > 0$. The inequality means that $\Pi_D^{RR} > \Pi_D^{NR}$ holds. Besides that, $x_D^{OR} < x_D^{NR}$ (see Proposition 1) implies that $\Pi_D^{OR} < \Pi_D^{NR}$ holds. Consequently, we have $\Pi_D^{OR} < \Pi_D^{NR} < \Pi_D^{RR}$. ■

Proof of Lemma 2

We have $\partial\{\Pi_D^{RR}-\Pi_D^{NR}\}/\partial t = -2(1-q)B_4/[(4-b^2)^2\{4-(2-q)b^2\}^2 q^2]$ where $B_4 = (2-b)\{8-2(2+b)b+(2-q)b^3\}b^2qa+4\{16-20b^2+5b^4+2b^2(2-b^2)q\}t-(4-b^2)^2\{2(2-b^2)+b^2q\}qm_H+2b^3\{8-(3-q)b^2\}q(1-q)m_L+4(1+b)(2-b^2)b^2q+b^5(1+q)q\}c$. Since $\partial B_5/\partial a > 0$ holds, $B_5 > B_5|_{a=\underline{a}} = (2+b)\{4-b^2(2-q)\}[(8-4b-2b^2+b^3q)(c-m_H)+2(4-2b-b^2)\{t+(1-q)m_H\}+(1-q)qb^3m_L] > 0$. Hence, $\partial\{\Pi_D^{RR}-\Pi_D^{NR}\}/\partial t < 0$ is satisfied. ■

The effect of tariff on $\Delta\Pi_F$

Firm F's gains from entry is given by $\Delta\Pi_F = \Pi_F^{OR} - \Pi_F^{NR}$ if $\Delta\Pi_F \leq K_F$ and $\Delta\Pi_F = \Pi_F^{OR} - \Pi_F^{RR}$ otherwise. We have $\partial^2(\Pi_F^{OR}-\Pi_F^{NR})/(\partial a\partial t) = 4(1-q)/\{q(2-b)(b+2)^2\} > 0$ and $\partial^2(\Pi_F^{OR}-\Pi_F^{RR})/(\partial a\partial t) = 4(1-q)\{8-b^2(3-q)\}b^2/[(2-b)(2+b)^2\{4-b^2(2-q)\}^2] > 0$. Besides that, we have $\partial(\Pi_F^{OR}-\Pi_F^{NR})/\partial t\big|_{a=\underline{a}} = \partial(\Pi_F^{OR}-\Pi_F^{RR})/\partial t\big|_{a=\underline{a}} = -8(1-q)\{c+t-qm_L\}/\{q(4-b^2)^2\} < 0$. Hence, we can derive the unique cutoff level of a, $\widetilde{a}^N = [c\{2+(2-b)q\}+2(1+q)t-\{2q+(1-q)b\}qm_L]/\{(2-b)q\}$, such that $\partial(\Pi_F^{OR}-\Pi_F^{NR})/\partial t > 0$ holds for $a > \widetilde{a}^N$, $\partial(\Pi_F^{OR}-\Pi_F^{NR})/\partial t = 0$ holds for $a = \widetilde{a}^N$, and $\partial(\Pi_F^{OR}-\Pi_F^{NR})/\partial t < 0$ holds for $a \in (\underline{a}, \widetilde{a}^N)$. Similarly, we can derive $\widetilde{a}^E = [2\{(4-b^2)^2+b^2q(8-b^2(3-q))\}t+(2-b)\{2(2-b)(2+b)^2+b^2q(8-b^2(3-q))\}c-(2-b)\{16+8b-12b^2-2b^3+3b^4+b^2q(8-b^2(4-q))\}qm_L]/\{(2-b)(8-b^2(3-q))b^2q\}$ such that $\partial(\Pi_F^{OR}-\Pi_F^{RR})/\partial t > 0$ holds for $a > \widetilde{a}^E$, $\partial(\Pi_F^{OR}-\Pi_F^{RR})/\partial t = 0$ holds for $a = \widetilde{a}^E$, and $\partial(\Pi_F^{OR}-\Pi_F^{RR})/\partial t < 0$ holds for $a \in (\underline{a}, \widetilde{a}^E)$.

We can easily confirm that $\partial\widetilde{a}^N/\partial c > 0$, $\partial\widetilde{a}^E/\partial c > 0$, $\partial\widetilde{a}^N/\partial t > 0$, $\partial\widetilde{a}^E/\partial t > 0$, $\partial\widetilde{a}^N/\partial m_L < 0$, and $\partial\widetilde{a}^E/\partial m_L < 0$. Hence, $\partial(\Delta\Pi_F)/\partial t > 0$ (resp. $\partial(\Delta\Pi_F)/\partial t < 0$) is more likely to hold as c and t become smaller (resp. large) and m_L becomes larger (resp. small).

Proof of Proposition 4

Let $\sigma_i \in \{E, N\}$ denote firm i's ($i \in \{D, F\}$) action and $\Delta\Pi_i(\sigma_{-i}, t)$ denote firm i's gains in operating profits from providing the repair services for good F given the action of the other firm, σ_{-i}, and the tariff level. The firm D's gains are given by $\Delta\Pi_D(N,t) = \Pi_D^{RR} - \Pi_D^{NR}$ and $\Delta\Pi_D(E,t) = 0$. We have $\Delta\Pi_D(E,t) = 0$ because firm D cannot earn positive profits from the repair services if firm F chooses $\sigma_F = E$. Regarding firm F's gains from the entry, we have $\Delta\Pi_F(N,t) = \Pi_F^{OR} - \Pi_F^{NR}$ and $\Delta\Pi_F(E,t) = \Pi_F^{OR} - \Pi_F^{RR}$. Since $\Pi_F^{NR} > \Pi_F^{RR}$ holds given t,

$\Delta\Pi_F(E,t) > \Delta\Pi_F(N,t)$ holds which means that firm F's gains from the entry are larger when firm D also chooses the entry.

First, we consider firm D's best response to firm F's action. Because $\Delta\Pi_D(E,t) = 0 < K_D$ holds, firm D's best response is $\sigma_D = N$ if firm F chooses $\sigma_F = E$. Firm D enters the service market only if firm F chooses $\sigma_F = N$. When $\Delta\Pi_D(N,0) > K_D$ is satisfied, there exists a unique cut-off level of t, denoted by t_D, such that

$$\begin{cases} \Delta\Pi_D(N,t) > K_D & \text{for} \quad t \in [0, t_D) \\ \Delta\Pi_D(N,t) = K_D & \text{for} \quad t = t_D \\ \Delta\Pi_D(N,t) < K_D & \text{for} \quad t \in (t_D, \bar{t}) \end{cases}$$

holds. For tractability, we set $t_D = 0$ if $\Delta\Pi_D(N,0) \leq K_D$ holds. Hence, firm D's best response is $\sigma_D = E$ if firm F chooses $\sigma_F = N$ and the tariff level is less than t_D, and it is $\sigma_D = N$ otherwise. Given firm D's action, firm F's gains from entry is expressed as

$$\Delta\Pi_F = \begin{cases} \Delta\Pi_F(E,t) & \text{for} \quad t \in [0, t_D) \\ \Delta\Pi_F(N,t) & \text{for} \quad t \in [t_D, \bar{t}) \end{cases}.$$

(i) Suppose $\Delta\Pi_F > K_F$ holds. In this case, choosing $\sigma_F = E$ becomes the firm F's dominant strategy. Since $\Delta\Pi_D(E,t) = 0 \leq K_D$ is always satisfied, the firm D's best response to firm F's entry is to choose $\sigma_D = N$. As a result, the OR case become the unique equilibrium outcome.

(ii) Suppose $t < t_D$ holds. In this case, $\Delta\Pi_D(N,t) > K_D$ is satisfied. Since $\Delta\Pi_F = \Delta\Pi_F(E,t) < K_F$ is also satisfied, choosing $\sigma_F = N$ becomes the firm F's dominant strategy and firm D's best response is to choose $\sigma_F = E$. As a result, the RR case becomes the unique equilibrium outcome.

(iii) Suppose $t \geq t_D$ holds. In this case, $\Delta\Pi_D(N,t) \leq K_D$ is satisfied. Since $\Delta\Pi_F = \Delta\Pi_F(N,t) < K_F$ holds, choosing $\sigma_F = N$ becomes the firm F's dominant strategy and firm D's best response is to choose $\sigma_F = N$. As a result, the OR case becomes the unique equilibrium outcome. ■

The effects of trade liberalization within each regime

(i) **Consumer surplus**: By (A6), (A8), and (A9), we can easily verify that $\partial x_F^{RR}/\partial t < 0$, $\partial x_F^{OR}/\partial t < 0$, and $\partial x_F^{NR}/\partial t < 0$ hold. Hence, given the structure of the repair market, trade liberalization in goods always increases the imports of good F. Regarding the profit of firm F, we have $\partial\Pi_F^{RR}/\partial t = 2qx_F^{RR}(\partial x_F^{RR}/\partial t) < 0$ because $\partial x_F^{RR}/\partial t < 0$ holds in the RR case. Regarding the consumer surplus, we have $\partial CS^{RR}/\partial t = [q\{2\left(1-b^2\right)(2-b) + b\left(2-b^2\right)q + b^2q^2\}a - c\,(1+b)\{2\,(1-b)\,(2-qb) + b\,(2-b)\,q^2\} + bq\,(1-q)\{2\left(1-b^2\right) - q\left(2-b^2\right)\}m_L - \{4\left(1-b^2\right) +$

$b^2q^2\}t]/[2\{4-(2-q)\,b^2\}^2q^2] > \partial CS^{RR}/\partial t\big|_{a=\underline{a}} = -b\{(1-q)\,(c-qm_L)+t\}/[(2-b)\,q\{4-(2-q)\,b^2\}] < 0$. Hence, $\partial CS^{RR}/\partial t < 0$ holds.

In the OR case, since $\partial x_F^{OR}/\partial t < 0$ holds, we have $\partial \Pi_F^{OR}/\partial t = 2x_F^{OR}(\partial x_F^{OR}/\partial t) < 0$. Besides that, we have $\partial CS^{OR}/\partial t = -[(1+b)\,(2-b)^2\,\{a-c-(1-q)\,m_L\} - \left(4-3b^2\right)t]/(4-b^2)^2 < \partial CS^{OR}/\partial t\big|_{a=\underline{a}} = -[2\,(1+b)\,(2-b)\,(1-q)\,(c-qm_L) + \{4\,(1-q)\left(1-b^2\right) + (2+(2-q)b)b\}t]/\{(4-b^2)^2q\} < 0$. Hence, $\partial CS^{OR}/\partial t < 0$ holds.

Lastly, in the NR case, since $\partial x_F^{NR}/\partial t < 0$ holds, we have $\partial \Pi_F^{NR}/\partial t = 2q^2x_F^{NR}(\partial x_F^{NR}/\partial t) < 0$. In addition, $\partial CS^{NR}/\partial t = -[q(1+b)(2-b)^2a - \{4-b^2(3-bq)\}c - b^3q(1-q)m_L - (4-3b^2)t]/\{(4-b^2)q\}^2 < \partial CS^{NR}/\partial t\big|_{a=\underline{a}} = -b\{(1-q)\,(c-qm_L)+t\}\,(2+b)\,/\{(4-b^2)q\}^2 < 0$. Hence, $\partial CS^{NR}/\partial t < 0$ holds.

(ii) **Firms' profits:** In the RR case, we have $\partial^2\Pi_D^{RR}/(\partial a \partial t) = 2b\{2-b\,(2-q)\}/[q\{4-(2-q)\,b^2\}^2] > 0$ and

$$\left.\frac{\partial(\Pi_D^{RR})}{\partial t}\right|_{a=\underline{a}} = \frac{2[(1-q)\,\{2\,(1-b)\,(c-m_H)+bqm_L\} + \gamma\{t+(1-q)m_H\})]}{q^2\,(2-b)\,\{4-(2-q)\,b^2\}}$$

where $\gamma := 2\,(1-b) - (2-b)\,q$. Suppose $2\,(1-b)\,/\,(2-b) \geq q$ holds so that $\gamma \geq 0$ holds. In this case, $\partial(\Pi_D^{RR})/\partial t\big|_{a=\underline{a}} > 0$ and so $\partial(\Pi_D^{RR})/\partial t > 0$ holds irrespective of the other parameter values. Alternatively suppose $2\,(1-b)\,/\,(2-b) < q$ holds so that $\gamma < 0$ holds. In this case, $\partial(\Pi_D^{RR})/\partial t\big|_{a=\underline{a}} < 0$ holds if c and m_L are sufficiently small and t and m_H are sufficiently large. This means that $\partial(\Pi_D^{RR})/\partial t < 0$ can hold if a, q, c, and m_L are small and t and m_H are large.

In the OR case and in the NR case, since $\partial x_D^{OR}/\partial t > 0$ and $\partial x_D^{NR}/\partial t > 0$ hold, we have $\partial \Pi_D^{OR}/\partial t = 2x_D^{OR}(\partial x_D^{OR}/\partial t) > 0$ and $\partial \Pi_D^{NR}/\partial t = 2x_D^{NR}(\partial x_D^{NR}/\partial t) > 0$.

(iii) **World welfare:** Regarding the effects on world welfare, we have $\partial(WW^{OR})/\partial t = -[(2-b)^2\,\{a-c-(1-q)\,m_L\}+\left(4-3b^2\right)t]/\left(4-b^2\right)^2 < 0$. In the NR case, we have $\partial(WW^{NR})/\partial t = -[aq\,(b-2)^2-\{4\,(1-bq)+b^2\}c+(4-3b^2)t+4bq\,(1-q)\,m_L]/\{q^2\left(4-b^2\right)^2\}$. Hence, $\partial(WW^{NR})/\partial t \geq 0$ holds if $a \leq \widehat{a} := [\{4\,(1-bq)+b^2\}c - \left(4-3b^2\right)t - 4b\,(1-q)\,qm_L]/\{q\,(2-b)^2\}$ holds. Since $\widehat{a}-\underline{a} = (2+b)\,[b(1-q)(c-qm_l) - (4-3b)\,t]/\{q\,(2-b)^2\}$ holds, $\widehat{a} > \underline{a}$ is satisfied if c is large and m_L and t are small. Putting it altogether, $\partial(WW^{NR})/\partial t \geq 0$ holds if c is large enough and a, m_L, and t are small enough. Otherwise, $\partial(WW^{NR})/\partial t < 0$ holds.

In the RR case, we have $\partial(WW^{RR})/\partial t = -B_5/[q^2\{4-b^2\,(2-q)\}^2]$ where $B_5 := aq\{2\,(2+b)\,(1-b)^2 + \left(2+2b-3b^2\right)bq-(1-b)\,b^2q^2\}+\{4\left(1-b^2\right)-2\,(1-b)\left(4+b-b^2\right)q-(1-b)\,(3b+2)\,bq^2-b^3q^3\}c + \left(4-4b^2+b^2q^2\right)t-2\,(1-q)\,(4-2b^2+b^2q)qm_H+(1-q)\,\{2\left(3-b^2\right)-\left(2-3b^2\right)q-b^2q^2\}bqm_L$. Hence, $B_5 \leq 0$ holds if $a < \widehat{a}' := -[\{4\left(1-b^2\right)-2\,(1-b)\left(4+b-b^2\right)q-(1-b)\,(3b+2)\,bq^2 - b^3q^3\}c + \left(4-4b^2+b^2q^2\right)t - 2(1-q)(4-2b^2+b^2q)qm_H + (1-q)\,\{2\left(3-b^2\right)-\left(2-3b^2\right)q - b^2q^2\}bqm_L]/[q\{2\,(2+b)\,(1-b)^2 + (2+2b-3b^2)bq - (1-b)\,b^2q^2\}]$ is satisfied. Since we have $\widehat{a}'-\underline{a} = \{4-b^2\,(2-q)\}[2\,(1-q)\,(2-b)\,qm_H-\{4\,(1-b)+bq\}\{(1-q)\,c+t\}-b\,(1-q)\,(2-q)\,qm_L]$

$/[q\,(2-b)\,\{2\,(2+b)\,(1-b)^2 + (2+2b-3b^2)bq - (1-b)\,b^2q^2\}]$ and $(\widehat{a}' - \underline{a})|_{m_H=c,t=0,m_L=0} = [q\,(4-3b) - 4\,(1-b)](1-q)\{4-b^2\,(2-q)\}c/[q(2-b)\{2(2+b)(1-b)^2 + (2+2b-3b^2)bq - (1-b)\,b^2q^2\}]$, $\widehat{a}' > \underline{a}$ holds if t and m_L are sufficiently small, m_H is sufficiently large, and q is large enough to satisfy $q > 4\,(1-b)\,/\,(4-3b)$. In sum, $\partial(WW^{RR})/\partial t \geq 0$ holds if a, t, and m_L are small enough and m_H and q are large enough. Otherwise, $\partial(WW^{RR})/\partial t < 0$ holds. ■

Proof of Proposition 5

(i) To prove the proposition, we provide a numerical example in which trade liberalization reduces the imports of good F, hurts consumers and firm F, and worsens world welfare. Parameters are set at $a = 20$, $c = 5$, $m_H = 2$, $m_L = 1$, $q = 0.5$, $b = 0.5$, and $K_D = 18$. Under the parameterization, we have $t_D = 0.35634$ and $\Delta\Pi_F(E, 0) = 22.08 < \Delta\Pi_F(E, t_D) = 22.401$.

(a) **The shift from the NR case to the RR case by a tariff reduction.** Consider a tariff reduction from $t_0 = 0.4$ to $t_1 = 0$ and suppose $K_F^0 > \min[\Delta\Pi_F(E, 0), \Delta\Pi_F(E, t_D)]$ holds. Since $t_0 > t_D$ holds, $\Delta\Pi_F(N, t_0) < \Delta\Pi_F(E, t_D)$ is satisfied. Because $\Delta\Pi_F(E, 0) < \Delta\Pi_F(E, t_D) < K_F^0$ holds under the parameterization, the equilibrium service regime becomes the NR case at $t = t_0$ and the RR case at $t = t_1$. The changes in the amount of imports, consumer surplus, the profit of each firm, and world welfare are respectively given by $x_F^{RR}|_{t=t_1} - x_F^{NR}|_{t=t_0} = -2.429\,4 < 0$, $CS^{RR}|_{t=t_1} - CS^{NR}|_{t=t_0} = -1.057\,4 < 0$, $(\Pi_D^{RR}|_{t=t_1} - K_D) - \Pi_D^{NR}|_{t=t_0} = 0.31014 > 0$, $\Pi_F^{RR}|_{t=t_1} - \Pi_F^{NR}|_{t=t_0} = -2.\,6552 < 0$, and $WW^{RR}|_{t=t_1} - WW^{NR}|_{t=t_0} = -5.7812 < 0$.

(b) **The shift from the OR case to the RR case by a tariff reduction.** Suppose $K_F^0 = 22.2$ and a tariff reduction from $t_0 = 0.2$ to $t_1 = 0$. Since $t_0 < t_D$ and $\Delta\Pi_F(E, 0) = 22.08 < K_F^0 < \Delta\Pi_F(E, t_1) = 22.\,259$ hold, the equilibrium regime under $t = t_1$ and under $t = t_0$ respectively becomes the OR case and the RR case. The changes in the amount of imports, consumer surplus, the profit of each firm, and world welfare are respectively given by $x_F^{RR}|_{t=t_1} - x_F^{OR}|_{t=t_0} = -2.429\,4 < 0$, $CS^{RR}|_{t=t_1} - CS^{OR}|_{t=t_0} = -15.\,564 < 0$, $(\Pi_D^{RR}|_{t=t_1} - K_D) - \Pi_D^{OR}|_{t=t_0} = 8.696\,8 > 0$, $\Pi_F^{RR}|_{t=t_1} - \left(\Pi_F^{OR}|_{t=t_0} - K_F\right) = -4.0286 < 0$, and $WW^{RR}|_{t=t_1} - WW^{OR}|_{t=t_0} = -12.035 < 0$.

As these numerical examples show, there exists a case where the tariff reduction reduces the imports, decreases consumer surplus and the profits of the foreign firm, increases the profits of the domestic firm, and worsens world welfare.

(ii) If a tariff reduction from $t_0 \in (t_1, \overline{t})$ to $t_1 \in [0, t_D)$ given $K_F = K_F^0$ increases the imports, consumer surplus, the profits of firm F, and improve world welfare, we have the same effects for all $K_F \in (K_D, K_F^0]$. In this case, $\widetilde{K}_F = K_F^0$ holds.

Next consider the case where $\widetilde{K}_F = K_F^0$ does not hold. Suppose the case where the tariff reduction improves world welfare at $K_F = K_F^0$. Note that if K_F satisfies $K_F < \Delta\Pi_F(E, t_1)$, the post-liberalization regime is the OR case. By combining Propositions 2 and 4, $K_F < \Delta\Pi_F(E, t_1)$ is necessary and sufficient so that the tariff reduction always increases the imports, consumer surplus, and the profits of firm F irrespective of the pre-liberalization service regime. Hence, we have $\widetilde{K}_F = \Delta\Pi_F(E, t_1)$ in this case.

Alternatively, suppose the tariff reduction worsens world welfare at $K_F = K_F^0$. In this case, $K_F < \Delta\Pi_F(E, t_1)$ is necessary but may not be sufficient for a welfare-improving tariff reduction. If $\partial(WW^{NR})/\partial t \leq 0$ holds, $K_F < \Delta\Pi_F(E, t_1)$ becomes a sufficient condition and so $\widetilde{K}_F = \Delta\Pi_F(E, t_1)$ holds. If $\partial(WW^{NR})/\partial t > 0$ holds, on the other hand, we need to derive K_F' such that $WW^{OR}\big|_{t=t_1} - WW^{NR}\big|_{t=t_0} = 0$ holds at $K_F = K_F'$. Naturally, we have $WW^{OR}\big|_{t=t_1} > WW^{NR}\big|_{t=t_0}$ for all $K_F < K_F'$. Furthermore if $t_0 \geq t_D$ and $K_F < \Delta\Pi_F(N, t_0)$ hold or $t_0 < t_D$ and $K_F < \Delta\Pi_F(E, t_0)$ hold, the pre-liberalization regime is also the OR case so that the tariff reduction necessarily increases world welfare given that $K_F < \Delta\Pi_F(E, t_1)$ holds.

In summary, when the tariff reduction worsens world welfare at $K_F = K_F^0$, it is transformed to be welfare-improving (a) for all $K_F < \widetilde{K}_F = \max[K_F', \Delta\Pi_F(E, t_1), \Delta\Pi_F(N, t_0)]$ when $t_0 \geq t_D$ holds, and (b) for all $K_F < \widetilde{K}_F = \max[K_F', \Delta\Pi_F(E, t_1), \Delta\Pi_F(E, t_0)]$ when $t_0 < t_D$ holds. As long as K_D is small enough to satisfy $K_D < \Delta\Pi_F(E, t)$ for all t, we can always find a unique level of $\widetilde{K}_F$ in $K_F \in (K_D, K_F^0]$. ∎

The equilibrium repairs in the presence of ISOs

In the monopoly-ISO case, the ISO's maximization problem at Stage 3 coincides with that of firm D in the RR case. Hence, the first-order condition is given by (A1). Suppose $\lambda > 0$. This implies $\widehat{R}_F = (1-q)\,x_F$ and $r = V_F\,(x_D, x_F)$ at stage 3 where r is the service price set by the ISO. At stage 2, by the consumer's utility maximization as to x_D and x_F, the inverse demand functions are given by $p_D = V_D(x_D, x_F)$ and $p_F = V_F(x_D, x_F) - (1-q)\,r = qV_F\,(x_D, x_F)$. Each firm's maximization problems are respectively given by $\max_{x_D} \Pi_D = \{V_D(x_D, x_F) - c - (1-q)\,m_L\}x_D$ and $\max_{x_F} \Pi_F = \{qV_F(x_D, x_F) - (c+t)\}x_F$. By the first-order conditions, the optimal sales of the two firms, (x_D^{ISO}, x_F^{ISO}), must satisfy

$$V_D(x_D^{ISO}, x_F^{ISO}) + V_{DD}(x_D^{ISO}, x_F^{ISO})x_D^{ISO} = c + (1-q)\,m_L,$$

$$V_F(x_D^{ISO}, x_F^{ISO}) + V_{FF}(x_D^{ISO}, x_F^{ISO})x_F^{ISO} = \frac{(c+t)}{q}. \tag{A11}$$

By the above equations and $c \geq m_H$, $\lambda = V_F(x_D^{ISO}, x_F^{ISO}) + V_{FF}(x_D^{ISO}, x_F^{ISO})x_F^{ISO} - m_H = (c+t)/q - m_H > 0$ holds. Therefore, (x_D^{ISO}, x_F^{ISO}) and $R_F^{ISO} = (1-q)\,x_F^{ISO}$ actually constitute an equilibrium.

Suppose $\lambda = 0$. This means $R_F < (1-q)\,x_F$ and $V_F(x_D, qx_F + R_F) + V_{FF}(x_D, qx_F + R_F)R_F = m_H$ hold. Since we have assumed that $V_{FF}(d_D, d_F) < 0$ and $2V_{FF}(d_D, d_F) + (\partial V_{FF}(d_D, d_F)/\partial d_F)d_F < 0$ hold, $2V_{FF}(d_D, d_F) + (\partial V_{FF}(d_D, d_F)/\partial d_F)D < 0$ holds for any $D \in (0, d_F]$. With this property, by equation (A5), and $c \geq m_H$, we have

$$\begin{aligned} V_F(x_D, qx_F + R_F) + V_{FF}(x_D, qx_F + R_F)R_F &> V_F(x_D, x_F) + (1-q)\,V_{FF}(x_D, x_F)x_F \\ &> V_F(x_D, x_F) + V_{FF}(x_D, x_F)x_F = \frac{c+t}{q} > m_H. \end{aligned}$$

This inequality contradicts $V_F(x_D, qx_F + R_F) + V_{FF}(x_D, qx_F + R_F)R_F = m_H$. Hence, $\lambda = 0$ cannot hold in equilibrium.

Proof of Proposition 6

Since $\partial\,(\Pi_{ISO})\,/\partial a\partial t = -(1-q)\,b^2/\{q\left(4-b^2\right)(2+b)\} < 0$ holds, we have $\partial\,(\Pi_{ISO})\,/\partial t < \partial\,(\Pi_{ISO})\,/\partial t|_{a=\underline{a}} = -2\,(1-q)\,(c+t-m_H q)/\{q^2\left(4-b^2\right)\} < 0$. When $\Pi_{ISO}|_{t=0} > K_D$ is satisfied, there exists a unique cut-off level of t, denoted by t_{ISO}, such that $\Pi_{ISO} > K_D$ holds for $t \in [0, t_{ISO})$, $\Pi_{ISO} = K_D$ holds at $t = t_D$, and $\Pi_{ISO} < K_D$ holds for $t \in (t_{ISO}, \bar{t})$. Because $\Pi_D^{ISO} = \Pi_D^{NR}$ holds, possible entry of ISOs does not affect $\Delta\Pi_D$ and so the level of t_D. Given that $\Delta\Pi_F \leq K_F$ and $\Pi_{ISO}|_{t=0} > K_D$ hold, the equilibrium of the enter game becomes (i) the NR equilibrium if $\max[t_{ISO}, t_D] < t$ holds, because $\max[\Pi_{ISO}, \Delta\Pi_D] \leq K_D$ holds, (ii) the RR equilibrium if $t_{ISO} \leq t < t_D$ holds, because $\Pi_{ISO} \leq K_D < \Delta\Pi_D$ holds, (iii) the ISO equilibrium if $t_D \leq t < t_{ISO}$ holds because $\Delta\Pi_D \leq K_D < \Pi_{ISO}$ holds, and (iv) either the ISO equilibrium or the RR equilibrium if $0 \leq t < \min[t_{ISO}, t_D]$ holds, because $\min[\Pi_{ISO}, \Delta\Pi_D] > K_D$ means that both firm D and ISOs have an incentive to enter the aftermarket for good F, and at most a single firm or a single ISO enters in equilibrium due to the price competition in the market. ■

The repurchase of good F

Let x'_F and x''_F respectively denote the amount of good F that is originally purchased and that of good F that is repurchased. Likewise, let p'_F and p''_F respectively denote the original price of good F and the repurchase price of good F.

Suppose firm F cannot differentiate between the price of good F that is originally purchased and that of good F that is repurchased: $p''_F = p'_F$. This case corresponds to the situation in which firm F cannot re-export good F immediately after consumers find the broken units. In stage 3, each consumer maximizes $V(x_D, qx'_F + qx''_F) - p'_F x''_F$ with respect to x''_F. The demand for the repurchase of good F is determined by $p'_F = qV_F(x_D, qx'_F + qx''_F)$. In stage 2, the consumer maximizes $V(x_D, qx'_F + q\widetilde{x}''_F) + Z$ with respect to x_D and x'_F, subject to $p_D x_D + p'_F x'_F \leq I - p'_F x''_F$.

The demand for good D and that for good F are respectively given by $p_D = V_D(x_D, qx'_F + qx''_F)$ and $p'_F = qV_F(x_D, qx'_F + qx''_F)$. Given the demand functions, firm F determines the supply of good F, $x_F = x'_F + x''_F$. The maximization problems of the two firms in stage 2 are written as

$$\max_{x_D} \Pi_D = [p_D - \{c + (1-q)\, m_L\}]x_D = \{V_D(x_D, q\,(x'_F + x''_F)) - c - (1-q)\, m_L\}x_D,$$
$$\max_{x_F} \Pi_F = \{p'_F - (c+t)\}\,(x'_F + x''_F) = \{qV_F(x_D, qx_F) - (c+t)\}x_F.$$

These maximization problems coincide with those in the NR subgame. Analytically, the repurchase of good F in this case and the extra-purchase of good F in the NR subgame are identical. Therefore, the equilibrium outcomes in the two cases becomes the same.

Alternatively, suppose firm F can set a different price for the repurchase of good F. In stage 3, each consumer maximizes $V(x_D, qx'_F + qx''_F)) - p''_F x''_F$ with respect to x''_F subject to $x''_F \le (1-q)x'_F$. We have two cases: (i) all broken units are repurchased if $qV_F(x_D, qx'_F + qx''_F) \ge p''_F$ holds at $x''_F = (1-q)\,x'_F$, which means that $V_F(x_D, q(2-q)x'_F) \ge p''_F$ holds, and (ii) only a fraction of the broken units is repurchased if $qV_F(x_D, qx'_F) \ge p''_F > qV_F(x_D, qx'_F + qx''_F)$ holds.

Firstly, let us consider the case where all broken units are repurchased. The demand for the repurchase is given by $x''_F = (1-q)\,x'_F$, which is inelastic in p''_F. In this case, the equilibrium price becomes $\widetilde{p}''_F = qV_F(x_D, q(2-q)x'_F)$. In Stage 2, the consumer anticipates $x''_F = (1-q)\,x'_F$ holds in stage 3 and she maximizes $V(x_D, q(2-q)x'_F) + Z$ with respect to x_D and x'_F, subject to $p_D x_D + p'_F x'_F \le I - (1-q)\widetilde{p}''_F x'_F$. The demand for good D and that for good F are respectively given by $p_D = V_D(x_D, q(2-q)x'_F)$ and $p'_F = qV_F(x_D, q(2-q)x'_F)$. Note that $p'_F = \widetilde{p}''_F$ holds in this case. Then, the maximization problems of the two firms in stage 2 are given by:

$$\max_{x_D} \Pi_D = [p_D - \{c + (1-q)\, m_L\}]x_D = \{V_D(x_D, q(2-q)x'_F) - c - (1-q)\, m_L\}x_D,$$
$$\max_{x'_F} \Pi_F = \{p'_F - (c+t)\}x'_F + \{p''_F - (c+t)\}(1-q)x'_F = \{qV_F(x_D, q(2-q)x'_F) - (c+t)\}(2-q)x'_F.$$

The first-order conditions become:

$$\begin{aligned} V_D(x_D, q(2-q)x'_F) + V_{DD}(x_D, q(2-q)x'_F)x_D &= c + (1-q)\, m_L, \\ q[V_F(x_D, q(2-q)x'_F) + q(2-q)V_{FF}(x_D, q(2-q)x'_F)x'_F] &= c + t. \end{aligned}$$

The equilibrium sales, $(\widetilde{x}_D, \widetilde{x}'_F)$, are obtained by solving these equations. By comparing the above first-order conditions with the first-order conditions in the NR subgame, we have $\widetilde{x}_D = x_D^{NR}$ and $(2-q)\widetilde{x}'_F = x_F^{NR}$. This means that the equilibrium prices satisfy $\widetilde{p}_D = p_D^{NR}$ and $\widetilde{p}'_F = \widetilde{p}''_F = p_F^{NR}$. The opportunity to repurchase good F reduces the amount of the initial sales of good F compared to the case without the repurchase, that is, $\widetilde{x}'_F < x_F^{NR}$. However, if the amount of the repurchase of good F is taken into account, the equilibrium total sales of firm F satisfy $\widetilde{x}'_F + (1-q)\widetilde{x}'_F = x_F^{NR}$.

Since both the equilibrium sales and the equilibrium prices of the two goods become identical across the two cases, the equilibrium firms' profits, the equilibrium consumer surplus, the equilibrium welfare in the presence of the repurchase coincide with those in the NR equilibrium.

Secondly, let us move on to the case where only a fraction of the broken units is replaced by the repurchased good. In this case, the inverse demand for the repurchase is given by $p''_F = qV_F(x_D, q(x'_F + x''_F))$. Since $V_{FF} < 0$ holds, the demand for the repurchase is decreasing in p''_F. Firm F's maximization problem is written by

$$\max_{x''_F} \{p''_F - (c+t)\}x''_F = \{qV_F(x_D, q(x'_F + x''_F)) - (c+t)\}x''_F,$$

and the first-order condition is given by

$$qV_F(x_D, q(x'_F + \widetilde{x}''_F)) + q^2 V_{FF}(x_D, q(x'_F + \widetilde{x}''_F))\widetilde{x}''_F = c + t. \tag{8}$$

In stage 2, the consumer maximizes $V(x_D, q(x'_F + \widetilde{x}''_F)) + Z$ with respect to x_D and x'_F, subject to $p_D x_D + p'_F x'_F \leq I - \widetilde{p}''_F \widetilde{x}''_F$. The inverse demand for good D and that for good F are respectively given by $p_D = V_D(x_D, q(x'_F + \widetilde{x}''_F))$ and $p'_F = qV_F(x_D, q(x'_F + \widetilde{x}''_F))$. Note that $p'_F = \widetilde{p}''_F$ holds. Given the demand functions, the maximization problems of the two firms at stage 2 are written as

$$\begin{aligned}
\max_{x_D} \Pi_D &= [p_D - \{c + (1-q)\, m_L\}]x_D \\
&= \{V_D(x_D, q(x'_F + \widetilde{x}''_F)) - c - (1-q)\, m_L\}x_D, \\
\max_{x'_F} \Pi_F &= \{p'_F - (c+t)\}x_F + \{\widetilde{p}''_F - (c+t)\}\widetilde{x}''_F \\
&= \{qV_F(x_D, q(x'_F + \widetilde{x}''_F)) - (c+t)\}(x'_F + \widetilde{x}''_F)
\end{aligned}$$

By differentiating Π_F with respect to x'_F and using (8), we have

$$\begin{aligned}
\frac{\partial \Pi_F}{\partial x'_F} &= (1 + \frac{\partial \widetilde{x}''_F}{\partial x'_F})\left[qV_F(x_D, q(x'_F + \widetilde{x}''_F)) + q^2 V_{FF}(x_D, q(x'_F + \widetilde{x}''_F))(x'_F + \widetilde{x}''_F) - (c+t)\right] \\
&= (1 + \frac{\partial \widetilde{x}''_F}{\partial x'_F})q^2 V_{FF}(x_D, q(x'_F + \widetilde{x}''_F))x'_F < 0.
\end{aligned}$$

The last inequality is due to the properties that $V_{FF} < 0$ and $\partial \widetilde{x}''_F / \partial x'_F > -1$ hold. This means that the initial sales of good F must satisfy $\widetilde{x}'_F = 0$, which contradicts the condition that $x''_F \leq (1-q)x'_F$ must hold. Therefore, this case cannot be the equilibrium outcome.

In sum, even if consumers have an option to replace the broken units of good F with the new units by repurchasing them from firm F who can re-sale the good with a different price in the aftermarket, the equilibrium sales of the two goods, the equilibrium prices of them, and other equilibrium outcomes coincide with those in the NR equilibrium.

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Tables and Figures

Table 1: The welfare effects of trade liberalization when K_F is high

	Imports	Consumers	Firm D	Firm F	World Welfare
Within the NR equilibrum	+	+	−	+	+ or −
The switch form the NR to the RR	−	−	no effect	−	−
Within the RR equilibrum	+	+	+ or −	+	+ or −

Table 2: The welfare effects of trade liberalization when K_F is low

	Imports	Consumers	Firm D	Firm F	World Welfare
Within the NR equilibrum	+	+	−	+	+ or −
The switch form the NR to the OR	+ or −	+	−	no effect	+
Within the OR equilibrum	+	+	−	+	+

Figure 1: The valuatoin effect and the market-contraction effect

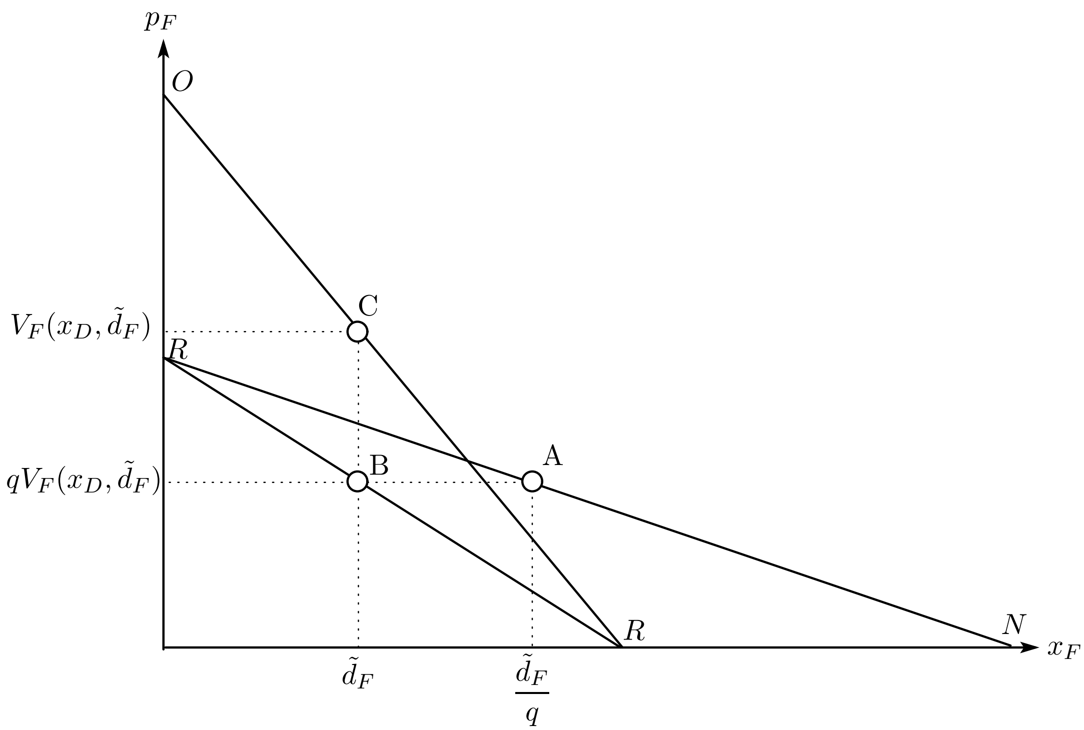

Figure 2: The comparision of the NR and the RR equilibrium

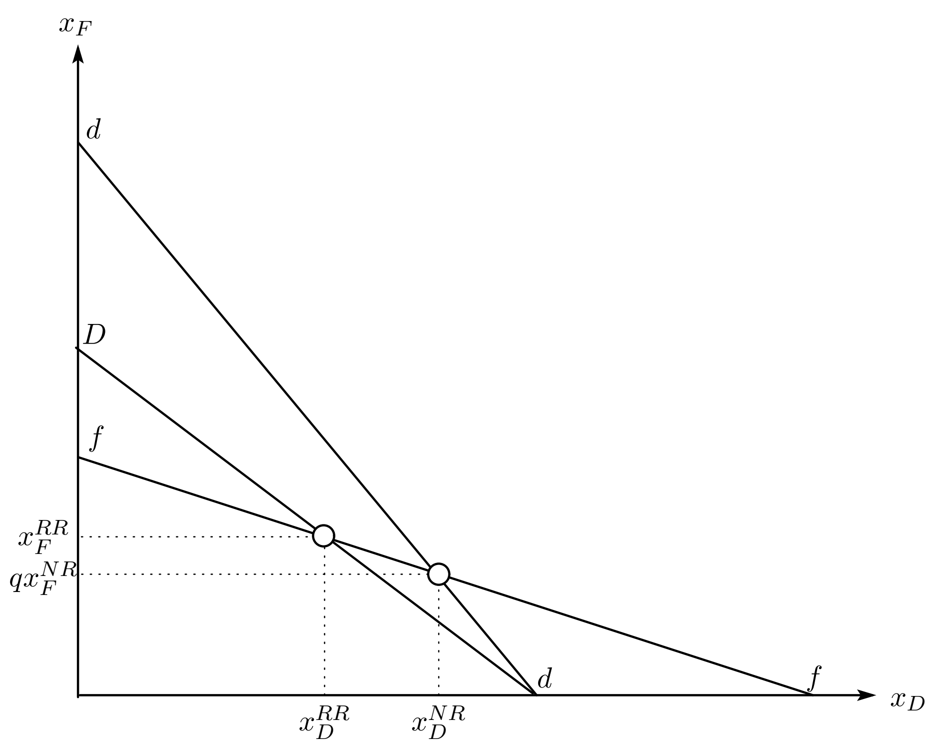

Figure 3: The comparison of the NR and the OR equilibrium

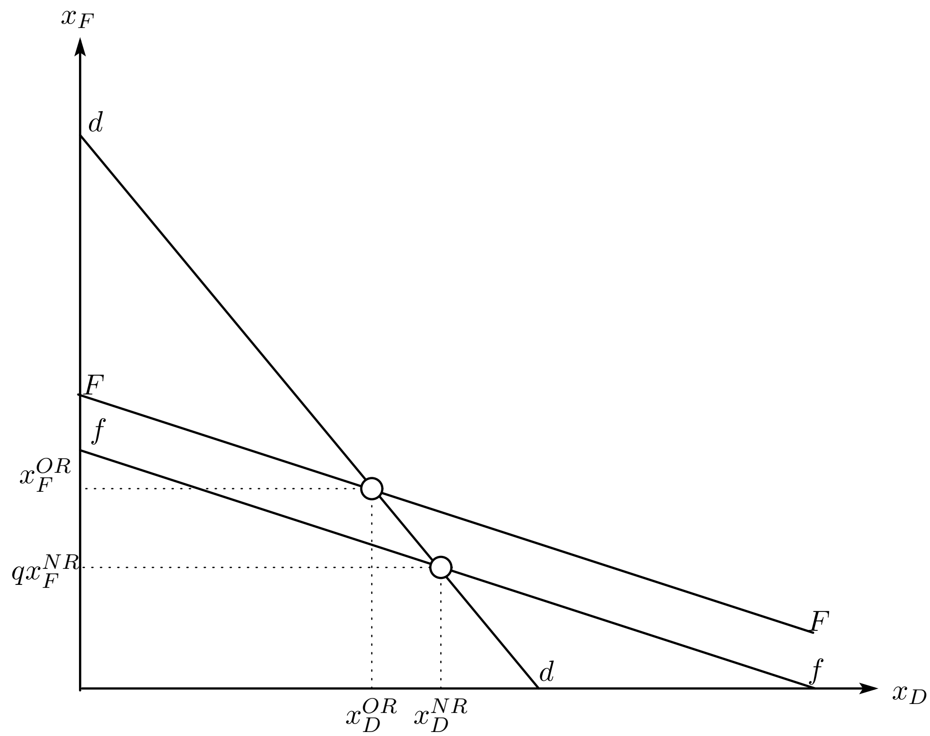

Figure 4: The equilibrium regimes