Trade Liberalization and Repair Services for Imports under International Oligopoly*

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Abstract

By an international oligopoly model, this paper examines the effects of trade liberalization in the presence of repair services. After consumers purchase goods, a certain faction of the units fails, and repairs are necessary to make the broken units useful. The market structure of the repair services for an imported product is endogenously determined. It is shown that, compared to the case without the repair services for imports, the provision of the repair services by the rival producer in the domestic country *hurts* consumers and the original producer of the good in the foreign country, and also reduces world welfare. By contrast, the provision of the repair services by the original producer benefits consumers and improves world welfare. When the fixed cost for FDI in repair services is high, trade liberalization in goods may lead to the entry of the rival producer into the repair services for imports, and thereby it may reduce the volume of imports, hurt consumers as well as the foreign firm, benefit the domestic firm, and worsen world welfare. The presence of independent service organizations (ISOs) may neither help consumers nor the foreign firm if the repair services are monopolized by a single ISO. The result suggests that promoting service FDI is important to guarantee the conventional effects of trade liberalization.

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1 Introduction

When consumers purchase durable goods such as automobiles, consumer electronics, furniture, bags, shoes, and even software, they usually take into account the durability of these products and the availability of the maintenance and repairs services. Firms also become the consumers of durable goods when they use machine tools, dies and molds, business software, computer systems, and network products in their production lines and operation systems. From the viewpoint of the producers of durable goods, providing maintenance and repair services is an important business activity to attract customers.[1]

The original producers of durable goods usually provide those services through their own service facilities. However, there is a case where consumers face difficulties to utilize the repair services provided by the original producers. This situation is typically observed for imported goods. To perform repair services effectively, proximity between service suppliers and consumers is a crucial element. This implies that producers in foreign countries have a disadvantage in performing repair services in the domestic country. To overcome the disadvantage, they need to establish the local affiliates of providing repair services by undertaking foreign direct investments (FDIs).[2] However, if the costs of establishing and managing the service facilities are very large, then foreign producers may refrain from undertaking FDI in repair services. For example, although it was found that some imported infrared heaters had a problem and they were subject to a product recall in Japan, some producers could not provide the repair services at all.[3] Even if the repair services have been provided in foreign countries, consumers may not utilize them if the cost of shipping goods back and forth between different countries is substantially high. For instance, the repairs of Japanese home appliances took six months to one year in China at the time when the Japanese firms had not established the local repair facilities.

Under the situation, the domestic producers, who are the competitors of the foreign producers in the product market, may provide the repair services for their competitors' products via their own service facilities. The repair services for competitors' products are provided "voluntarily" in the sense that they are conducted without the consent of the original producers. Although independent service organizations (ISOs) may also be able to provide the similar services, if the effective repairs require the specific knowledge about the details of products, the repair services

[1] In what follows, the maintenance and repair services, and other after-sales services that keep the quality of a product, are simply referred to as "repairs" or "repair services".

[2] For instance, Eschenbach and Hoekman (2005) 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.

[3] *The Nikkei (evening)*, May 18th, 2010, p.18.

provided ISOs cannot substitute for the repair services performed by the producers.

Providing the maintenance and repair services for the competitors' products has been a growing business practice. 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. Maruju Ironworks and Masuda Ironworks are providing the maintenance and repairs of machines, dies and molds produced by other companies. 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.

There are also the cases where a foreign firm who undertook an FDI in services provide the repair services for competitors' products. For example, Daikin Air Conditioning Technology Co., Ltd. in China, which is established as a foreign subsidiary of a Japanese air-conditioning company, Daikin Industry, Ltd., provides maintenance and repair services within China for competitors' products as well as its own products. GE Healthcare Japan Corporation, a joint venture of GE Company and Yokogawa Electric Corporation that sales medical analyzing devices in Japan, accepts the replacement of failed parts used in other company's analyzing devices.

Based on these real-world observations, the aim of this paper is to investigate: (i) who benefits from the provisions of maintenance and repair services for competitor's products, (ii) in what situation the domestic firms repair the broken units of competitor's products, and (iii) the effects of trade liberalization in goods when the market structure of the repair services for imported goods are endogenously determined. To our best knowledge, this is the first paper which addresses these research questions.[4]

1.1 Preview of the model and the results

Let us briefly preview the model and the main results of the paper. We construct an international duopoly model which comprises one domestic firm and one foreign firm. The two firms produce horizontally differentiated goods and compete in the domestic market. After consumers purchase the goods, a fraction of units of each good becomes broken immediately. The domestic firm already has established the service facilities and gives a full warranty to its product so that any broken units are subject to free repairs. If the foreign firm undertakes FDI in repair services and establishes the facilities for repairs in the domestic country, the same warranty is provided to the imported goods. Otherwise, the broken units of the imported goods can either remain scraps or be repaired by the domestic firm. If the domestic firm provides the repair services for imports,

[4]Section 1.3 briefly reviews the related papers.

consumers must pay the service fee to the domestic firm.

We assume the provision of repair services for imports incurs both a fixed set-up cost and a variable operation cost. The variable cost is relatively low if the foreign firm, who is the original producer, repairs the imported goods. This is because the original producer knows the technological details of the product. However, the fixed cost of the foreign firm to provide the service is relatively high because it needs to set up new facilities from scratch in the domestic country. If the rival producer provides the repair services for imports, the variable cost is relatively high which reflects the presumption that the original producer has better knowledge about its product than the non-original producer does. However, the fixed cost of starting the repair services for imports is lower if the domestic firm provides the services, because it already has the service facilities to repair its own good and the additional costs to expand the facilities and to learn the details about the rival's product would be lower than the costs of undertaking service FDI. As an extension, we also investigate the case where ISOs can provide the repair services for imports.

The first question is who benefits from repair services for imports. Seemingly, the repair services for imports benefit consumers and increase the foreign firm's operating profit, compared to the situation where the repair services are not provided. However, this presumption is correct only if the foreign firm, who is the original producer of the good, provides the repair services in the domestic country. If the repairs for imports are undertook by the rival producer who charges a fee for them, both consumers and the foreign firm become worse off compared to the no-repair case, ceteris paribus.

The reason why the repairs for imports by the domestic firm are detrimental to consumers is *not* because they directly hurt consumers. After they purchase the imported goods, consumers are willing to purchase the repair services only if the repairs increase their surplus. In fact, it is shown that the domestic firm sets the price of repairs so that consumers order the repairs of all broken units of the imported goods. The problem is that the repair services for imports by the domestic firm have a *collusive effect* which leads to an increase in the price of the good produced by the domestic firm. Specifically, because the domestic firm can earn additional profits from the repairs for the rival product and the repair market expands as the amount of imports increases, it reduces the sales of its own product to accommodate imports more, which results in an increase in the price of the domestic good. In other words, the domestic producer can use the repair services for imports as a commitment device to weaken the competition in the product market. Although consumers *ex ante* anticipate that utilizing the repairs services for imports provided by the domestic firm will eventually reduce their surplus, they cannot commit to leave the broken units of imported goods unrepaired since it is *ex post* optimal for the consumers to fix all of them given that they have already purchased the imported goods. Since the loss from the weakened competition in the product market outweighs the gains in the repair market of the imported goods, consumers become worse off.

Another important result is that the profit of the foreign firm is also decreased, despite the repair services for the imported goods provided by the domestic firm increases the attractiveness of its product and they also weaken the competition in the product market. This result is explained as follows. When repair services are not provided at all and so the broken units of the imported goods remains inconsumable, consumers anticipate in the product market that the actual amount of the imported goods they can consume will be smaller than the amount they purchase. On one hand, this anticipation reduces the consumers' valuations of the good and shrinks the market size for the imported goods. In other words, the repair services increase the market size of the imported goods. We call the effect the *valuation effect* of repairs. On the other hand, it makes the demand curve of the imported goods flatter because one-unit of the purchased good leads to less-than one unit of the actual consumption, and thereby the degree of the decrease in the marginal utility of consumption (i.e., the slope of the demand curve) is less than the case in the presence of the repair services. In other words, given their valuations and the price of the good, if consumers anticipate that a fraction of the purchased units are broken and remain useless in the future, consumers have an incentive to purchase the imported goods more than the amount they will purchase if the repair services are provided. We call the effect the *precautionary effect* of non-repairs.

If the repair services for the imported goods are provided, the presence of the valuation effect increases the rents that can be corrected in the imported-good sector but the absence of the precautionary effect reduces them. Since the former effect dominates the latter, the overall rents captured by the firms in the import market are increased by the repair services. The problem is that the rival producer, who provides the repair services on behalf of the original producer, sets the repair price so that it can capture all the gains the producers can earn from the positive valuation effect. Consequently, only the collusive effect and the absence of the precautionary effect matter for the foreign firm. Since the loss from the absence of the precautionary effect can outweigh the gains from the collusive effect, the repairs by the rival firm hurt the foreign firm. It is worth noting that the foreign firm cannot prevent the provision of the repair services by the rival firm since no contractual relations exist between the two firms.

By contrast, if the foreign firm provides the repair services by undertaking an FDI in services, it can now capture the positive valuation effect and its operation profit becomes larger with the repairs. In this case, the product market competition is intensified and consumers become better off with the repair services. It is also shown that even if the domestic service provider is an ISO rather than a producer of goods, its entry reduces the foreign firm's profits as long as it monopolizes the repair market, while it has *no effects* on consumers and the domestic firm. The repairs by ISOs help consumers and the foreign firm only if the repair markets are sufficiently competitive.

Given the effects described above, the next question is in what situation the domestic firm provides the repair services for the competitor's product. In our model, each firm's decisions to provide the repair services for imports are endogenously determined. Firms' choices depend on both degree of trade liberalization and that of liberalization in service FDI. In our model, trade liberalization in goods is represented by a reduction in tariff and liberalization in service FDI is represented by a reduction in the fixed cost of service FDI. Since larger imports achieved by a lower tariff increases the rents from providing the repair services for imports, the domestic firm becomes more eager to provide the repair services as trade liberalization proceeds. Hence, if the fixed cost of service FDI is large enough to prevent the foreign firm's service FDI, trade liberalization can change the equilibrium regime of the service provision from the non-repairs for imports to the domestic firm's repairs for them. The shift of the regime hurts consumers and the foreign producer, and reduces the amount of imports. Furthermore, if the effect outweighs the conventional effects of trade liberalization within each regime, the trade liberalization eventually reduces the amount of imports and hurt consumers, the foreign producer, and world welfare. This result is in sharp contrast to the conventional wisdom of the effects of trade liberalization. If the fixed cost of service FDI is sufficiently small so that trade liberalization leads to repair services by the foreign firm, trade liberalization increases the imports, benefits consumers and the foreign firm, and improves world welfare.

The above results support the recent efforts of liberalization in service sectors. For instance, 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. Our results suggest that the progress of trade liberalization may hurt consumers and foreign producers, and also worsen the world welfare, when the liberalization in the after-sales services has not been progressed. To secure the conventional benefits of trade liberalization, FDI in after-sales services should be also liberalized.

1.2 Related literature

There have been some theoretical analyses that incorporate service sectors into international trade models. They should include Djajić and Kierzkowski (1989), Markusen (1989), Markusen, Rutherford and Tarr (2005), Wong, Wu and Zhang (2006), Francois and Wooton (2008). None of them, however, investigates how the effects of trade policies in goods are connected to the liberalization in FDI in services. An exception is another paper of us, Ishikawa, Morita, and Mukunoki (2010) (henceforth, IMM), which considers post-production services such as distribution services in an international oligopoly model. IMM has shown that trade liberalization in goods may hurt consumers and world welfare if the post-production services are outsourced from the foreign firm to the domestic competitor in the form of a contract. IMM has also shown that FDI in post-production services must be liberalized to secure the welfare-improving trade liberalization. Although the policy implication suggested in that paper is similar to the current paper, the mechanisms are different. In IMM, the post-production services must be performed before the sales of the goods, and so the cost of providing services are passed on to the prices of goods. In this situation, we have shown that trade liberalization in goods increases the gains from service outsourcing and thereby raises the service fee that a foreign outsourcing firm pays to a domestic outsourced firm. Since the increase in the service fee is passed on to the goods price, the liberalization may reduce consumer surplus.

In the current paper, the shift of the equilibrium regime from no-repair services to repair services by the rival producer is the driving force of the detrimental effects of trade liberalization on consumers and world welfare. In contrast to IMM, the post-production services of this paper are performed *after* consumers purchase the goods, and so consumers have an option to refrain from purchasing the services. Even if the repair services by the rival firm eventually hurt consumers, however, they cannot undo the damage because it is ex post optimal for them to purchase the services. This time-inconsistency problem of repair services has not been considered in IMM and other papers. Furthermore, since repairs by the rival producer are conducted without consent of the original producer, trade liberalization can hurt the foreign firm, which cannot be the case in IMM.[5] Hence, the two papers should be regarded as compliments rather than substitutes.

[5]The service outsourcing in IMM(2010), which is necessary for welfare-reducing trade liberalzation, needs the agreement between the two firms. Hence, the foreign firm can stop the service outsourcing if trade liberalization under service outsourcing reduces the profits of the foreign firm. In other words, the profits of the foreign firm under

Since the focus of this paper is on maintenance and repair services, our model also relates to the literatures on the durable-goods theory. The papers which have considered the maintenance and repair markets include Mann (1992), Chen and Ross (1993,1998,1999), Ekzubga and Mills (2001), and Morita and Waldman (2004, 2010). However, none of them have considered the repair services provided by the rival producers, nor considered the effects of trade liberalization. Some papers have examined the effects of trade policy in the presence of durable goods in an international oligopoly model (Driskill and Horowitz, 1996; Goering and Pippenger, 2000). However, maintenance and repair services are not considered in these papers.

The remainder of the paper is organized as follows. In section 2, we explain the model. In section 3, the equilibrium in the product markets and the repair market are derived. In section 4, firms' entry decisions into the repair services for imports are examined. In section 5, the effects of a tariff reduction and its relation to liberalization in service FDI are discussed. In section 6, we introduce ISOs as potential entrants for repair services. In section 7, we summarize and conclude the paper. Proofs of lemmas and propositions are given in the appendix.

2 Model

The basic framework is based on Chen and Ross (1998), but we extend their domestic monopoly model to an international duopoly model with horizontal product differentiation. The domestic firm (firm D) produces good D in the domestic country and the foreign firm (firm F) produces good F in the foreign country.

After consumers purchase the goods, a unit of each good may fail because of imperfect quality control. We assume the probabilities that the purchased units work correctly are identical across the two goods, which are given by $q \in (0, 1)$. Therefore, the failure rate is $(1 - q)$. Consumers choose whether they order the repairs of the broken units. If a broken unit is repaired, it becomes consumable. For instance, let x and R respectively represent the amount of the good purchased by a consumer and of the good which is repaired after broken. We assume the unbroken unit and the repaired unit of the same good are perfect substitutes for consumers. Then, the final consumption of the good is given by $qx + R$ $(\leq x)$.

If the original producer of the good has established the local facilities for repair services, it provides a full warranty for its own product.[6] Naturally, consumers always order the repairs of

service outsourcing must be weakly larger than the those under non-outsoucing case, where trade liberalization always benefit the foreign firm.

[6]Under the full warranty assumption, the original producer would pass the variable costs of repairs on to the price of the good so that it can internalize any interactions between repair services and the sales of the good. Even

all broken units in this situation. If the repairs are not undertaken by the original producer, however, consumers must pay a repair price to fix each broken unit.

We consider the situation where firm D already has established the facilities to repair good D. However, the repair services for good F would not be provided unless firm F or firm D establishes the repair facilities for good F in the domestic country. If firm F establishes the service facilities, all broken units of good F are freely repaired by the full-warranty assumption. The establishment of service facilities by firm F requires FDI in services. If firm D establishes the repair facilities for good F, on the other hand, consumers must pay the repair price, r, per unit of the repairs.

We consider a three-stage game. At 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.

At stage 2, the two firms produce and supply the goods to the domestic market and the domestic consumers purchase them. We assume firms compete with each other a lá Cournot in the product market.[7] The sales of each good are given by x_i ($i \in \{D, F\}$). The utility of a representative consumer is given by $U(d_D, d_F, Z) = V(d_D, d_F) + Z$ where d_i ($\leq x_i$) is the amount of good i that works correctly out of x_i and Z is the consumption of a numeráire good. We define $V_i(d_D, d_F) := \partial V(d_D, d_F)/\partial d_i$ and $V_{ij}(d_D, d_F) := \partial^2 V(d_D, d_F)/\partial d_i \partial d_j$ ($i, j \in \{D, F\}$). We assume $V_i(d_D, d_F) > 0$ and $V_{ij}(d_D, d_F) < 0$ hold. 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.

On the supply side, 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.[8] The operating profits of firm D and those of firm F from the sales in the product

if we assume the orginal producer charges the fee for repairs, the basic results would remain unchanged.

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

[8]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.

market are given by $\pi_D^{sale} = (p_D - c)x_D$ and $\pi_F^{sale} = \{p_F - (c+t)\}x_F$, respectively, where p_i is the consumer price of good i. For simplicity, we focus on the case where consumers always purchase both good D and good F.

At stage 3, consumers may find some units of the purchased goods are broken and they choose whether they order the repairs of the broken units. Since the broken units of good D are subject to free repairs by firm D, consumers always choose to fix the broken units of good D. This means that $d_D = x_D$ always holds. With regard to good F, if firm F has established the repair facilities at stage 1, the broken units of good F are also subject to free repairs and we have $d_F = x_F$. In this case, even if firm D also provides the repair services for good F, consumers would never choose firm D to repair good F because firm D charges a positive repair price.[9]

If firm D chooses to establish the repair facilities for good F while firm F does not undertake service FDI, firm D sets the repair price, r, and consumers determine how much amount of broken units they order the repairs to firm D. 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 is given by m_L, and it is lower than the cost of repairing the rival's product, m_H. We assume $m_L < m_H \leq c$ holds so that the costs of repairs are no higher than the production cost. We also assume the producers' cost advantage is large enough to exclude the entries of ISOs.[10]

The net revenues, gross of the fixed cost, of firm D and those of firm F from the repair services are respectively given by $\pi_D^{repair} = -(1-q)\,m_L x_D + (r - m_H)R_F^D$ and $\pi_F^{repair} = -m_L R_F^F$ where R_F^i is the amount of good F that are repaired by firm i ($i \in \{D, F\}$). Note that the total amount of repairs, $R_F \equiv R_F^D + R_F^F$, must satisfy $R_F \leq (1-q)\,x_F$ and the total consumption of good F after repairs is given by $d_F = qx_F + R_F$ $(\leq x_F)$.

Each firm's total operating profits of each firm is defined as $\Pi_i = \pi_i^{sale} + \pi_i^{repair}$ ($i \in \{D, F\}$). To satisfy the second-order conditions of profit maximizations, $\partial^2 \Pi_i / \partial x_i \partial x_i < 0$ ($i \in \{D, F\}$) must hold.

3 Repair services and product market competition

We first analyze the repair market and the product market given firms' decisions made at stage 1. Suppose both firms chose to establish the repair facilities for good F. Then, firm F provides

[9] In fact, firm D has no incentives to set a non-positive price for repairs of good F. See Section 3 for details.

[10] 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, some new results are obtained. See Section 6 for details.

a full warranty for good F and firm D cannot attract consumers at stage 3 as long as the repair price is positive, $r > 0$. The existence of the cost of providing repair services means that firm D has no incentives to set a negative repair price, $r \leq 0$. Hence, even if firm D established the repair facilities for good F, only firm F provides the repair services in equilibrium if firm F undertook service FDI.

The strong position of firm F in the repair market means that we only need to analyze the following three cases: (i) **Rival's Repair (RR) case** where only firm D provides the repair services for good F, (ii) **Own Repair (OR) case** where only firm F provides repair services for good F, and (iii) **No Repair (NR) case** where no repair services are provided for good F. We use the backward induction to derive the sub-game perfect equilibrium.

3.1 The RR case

Firstly, let us consider the RR case. At stage 3, each consumer maximizes $V(x_D, qx_F + R_F) - rR_F$ with respect to R_F to determine the demands for repairs regarding good F. Given that the consumer has retained qx_F as the unbroken units of good F, if $V_F(x_D, qx_F) \geq r$ holds so that the marginal utility of consuming an additional unit of good F weakly exceeds the repair price, consumers will purchase the repair services to fix the broken units. Otherwise, consumers leave all broken units of good F unrepaired.

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. In this case, the demand for repairs is given by $R_F = (1-q)\, x_F$, which is inelastic in the service price. Alternatively, if both $V_F(x_D, qx_F) \geq r$ and $V_F(x_D, x_F) < r$ hold, only some fraction of the broken units are repaired. 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.

Given the demand for repairs, firm D chooses the supply of repair services. Specifically, firm D determines R_F so that it maximizes the profit from providing the repair services for good F.[11] Firm D's maximization problem is written by

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

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

[11] Because firm D monopolizes the repair market for good F, the equilibrium repair price and the equilibrium level of R_F should not be changed even if firm D chooses the service price to maximize the profit from the repair services.

At 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 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 the demand functions, the maximization problems of the two firms at stage 2 are written as

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

By using the envelope theorem, the first-order condition of the firm D's profit maximization is given by

$$V_D + V_{DD}x_D + V_{FD}\frac{\partial \widehat{R}_F}{\partial x_D}x_D + V_{FD}\widehat{R}_F = c + (1-q)\, m_L. \tag{2}$$

The right-hand side of (2) represents the *expected* marginal cost from selling good D. It is the sum of the production cost and the expected repair cost for good D. Regarding the left-hand side of (2), the first and the second terms represent the marginal revenue from the sales of good D. The third-term represents how a marginal increase in the sales of good D affects the revenue from the sales of good D through its effect on the equilibrium amount of repairs of good F. Because the sign of $\partial \widehat{R}_F / \partial x_D$ is ambiguous, we cannot determine the sign of the third term.[12] The last term represents the effects of an increase in x_D on the profits from providing the repair services for good F through its effect on the repair price. The last term is negative because $V_{FD} < 0$ implies that an increase in x_D decreases the equilibrium service price of repairs.

The first-order condition for firm F's profit maximization is given by

$$q\left[V_F + V_{FF}x_F\left(q + \frac{\partial \widehat{R}_F}{\partial x_F}\right)\right] = c + t \tag{3}$$

where the left-hand side represents the *expected* marginal revenue and the left-hand side represents the marginal cost from selling good F. Irrespective of the amount of $\widehat{R}_F$, the marginal revenue is discounted by $(1-q) \times 100$ percent. Even if it is anticipated that all broken units of good F are repaired at next stage, firm F cannot capture the whole revenues associated with the sales of x_F. This is because the repairs are undertaken by firm D, rather than by firm F. Specifically, firm D

[12] It is clear that $\partial \widetilde{R}_F / \partial x_D = 0$ if $\widetilde{R}_F = (1-q)\, x_F$ holds. Otherwise, by equation (A4) in the appendix, we have $\partial \widetilde{R}_F / \partial x_D = -\{V_{FD}(x_D, qx_F + R_F) + (\partial V_{FF}(x_D, qx_F + R_F)/\partial x_D)\, R_F\}/\{2V_{FF}(x_D, qx_F + R_F) + (\partial V_{FF}(x_D, qx_F + R_F)/\partial x_F)\, R_F\}$ in this case. If the the sub-utility function is given by a standard quadratic form as in Section 3.4, $\partial V_{FF}(x_D, qx_F + R_F)/\partial x_D = \partial V_{FF}(x_D, qx_F + R_F)/\partial x_F = 0$ and thereby $\partial \widetilde{R}_F / \partial x_D < 0$ holds.

manipulates the repair price at stage 3 so that it can capture the maximum revenue associated with the broken units of good D, $(1-q)x_F$. This means that firm F can only capture the profit associates with the unbroken units, qx_F. Hence, a fraction of firm F's profit is decreased in inverse proportional to q.

In face of the rival's repairs, firm F has an incentive to manipulate x_F to affect $\widehat{R}_F$, which is reflected in the term $V_{FF}x_F(\partial\widehat{R}_F/\partial x_F)$. If firm F anticipates that all broken units will be repaired at stage 3, $\widehat{R}_F = (1-q)\,x_F$ holds and so we have $\partial\widehat{R}_F/\partial x_F = (1-q) > 0$. This means that, ceteris paribus, firm F has an incentive to reduce the exports of good F if the rival firm repairs all broken units of good F. If some broken units will remain unrepaired, however, $\partial\widehat{R}_F/\partial x_F$ can be either positive or negative, meaning that it is ambiguous whether the rival's repairs of good F in stage 3 reduce firm F's exports in stage 2.[13]

The solution of (2) and (3) constitutes the equilibrium sales of each good, which are denoted by (x_D^{RR}, x_F^{RR}). 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 imports are provided by the rival producer in the domestic country, all broken units of the good are repaired in equilibrium.*

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

Intuitive explanation is as follows. 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 to consumers. The "quality" of repaired unit of good F is higher than that of the purchased unit of good F, in the sense that there is a risk that the purchased unit turns out to be a broken unit. 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. Besides that, because we have assumed that $m_H \leq c$ holds, $m_H \leq c+t$ 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. 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 the repairs of good F increases the attractiveness of good

[13]By equation (A4) in the appendix, we have $\partial\widetilde{R}_F/\partial x_F = -\{V_{FF}(x_D, qx_F + R_F) + (\partial V_{FF}(x_D, qx_F+R_F)/\partial x_F)\,R_F\}/\{2V_{FF}(x_D, qx_F + R_F) + (\partial V_{FF}(x_D, qx_F+R_F)/\partial x_F)\,R_F\}$. If the the sub-utility function is given by a standard quadratic form as in Section 3.4, $\partial\widetilde{R}_F/\partial x_F < 0$ always holds.

F in the product market and thereby decreases its profits from selling good D. However, we find that the former positive effect in the repair market always dominates the latter negative effect in the product market. Furthermore, even if firm F anticipates that the repairs of good F by the rival firm will reduce the marginal revenues from selling good F, it is not profitable for firm F to manipulate x_F so that it prevents the "full-repairs" by firm D. Consequently, all broken units of good F are repaired in the equilibrium of the RR case.

Since $\widehat{R}_F = (1-q)x_F$ always holds, the equilibrium repair price is given by $\widehat{r} = V_F(x_D, x_F)$. Then, the first-order conditions, (2) and (3, can be rewritten as

$$V_D(x_D, x_F) + V_{DD}(x_D, x_F)x_D + (1-q)V_{FD}(x_D, x_F)x_F = c + (1-q)\,m_L, \tag{4}$$

$$q\left[V_F(x_D, x_F) + V_{FF}(x_D, x_F)x_F\right] = c + t. \tag{5}$$

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 $r^{RR} = V_F(x_D^{RR}, x_F^{RR})$. By substituting them into the profits functions, the equilibrium operating profits of each firm in the RR case are given by $\Pi_D^{RR} = -V_{DD}(x_D^{RR}, x_F^{RR})\left(x_D^{RR}\right)^2 + \{r^{RR} - V_{FD}(x_D^{RR}, x_F^{RR})x_D^{RR} - m_H\}(1-q)x_F^{RR}$ and $\Pi_F^{RR} = -qV_{FF}(x_D^{RR}, x_F^{RR})\left(x_F^{RR}\right)^2$. The equilibrium consumer surplus is given by $CS^{RR} = V(x_D^{RR}, x_F^{RR}) - p_D^{RR}x_D^{RR} - \{p_F^{RR} + (1-q)r^{RR}\}x_F^{RR}$. The equilibrium world welfare is defined as $WW^{RR} = CS^{RR} + (\Pi_D^{RR} - K_D) + \Pi_F^{RR} + tx_F^{RR}$ where the last term is the tariff revenues.

3.2 The OR case

Suppose firm F undertook FDI in services to provide the repair services for good F by itself. Firm F gives a full-warranty to each buyer of good F. At stage 2, each consumer anticipates that all broken units of good F are freely repaired at stage 3. This means that $R_F = (1-q)\,x_F$ holds, and the consumer maximizes $V(x_D, x_F) + Z$ subject to $p_D x_D + p_F x_F \le I$ 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' optimization problems become:

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

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

The first-order conditions are given by

$$V_D(x_D, x_F) + V_{DD}(x_D, x_F)x_D = c + (1-q)\,m_L, \tag{6}$$

$$V_F(x_D, x_F) + V_{FF}(x_D, x_F)x_F = c + t + (1-q)\,m_L, \tag{7}$$

and the equilibrium sales 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 $p_F^{OR} = V_F(x_D^{OR}, x_F^{OR})$. By using them, the equilibrium profits of each firm and the equilibrium consumer surplus are represented as $\Pi_D^{OR} = -V_{DD}(x_D^{OR}, x_F^{OR})\left(x_D^{OR}\right)^2$, $\Pi_F^{OR} = -V_{FF}(x_D^{OR}, x_F^{OR})\left(x_F^{OR}\right)^2$, and $CS^{OR} = V(x_D^{OR}, x_F^{OR}) - p_D^{OR}x_D^{OR} - p_F^{OR}x_F^{OR}$. The equilibrium world welfare is given by $WW^{OR} = CS^{OR} + \Pi_D^{OR} + (\Pi_F^{OR} - K_F) + tx_F^{OR}$.

3.3 The NR case

Suppose neither firm D nor firm F established the repair facilities for good F in Stage 1. In this case, all broken units of good F become scraps, which means that $d_F = qx_F$ holds. In Stage 2, the representative consumer maximizes $V(x_D, qx_F) + Z$ subject to $p_Dx_D + p_Fx_F \leq I$. The first-order condition yields demands for each product, which is respectively given by $p_D = V_D(x_D, qx_F)$ and $p_F = qV_F(x_D, qx_F)$.

Given the inverse demand functions, firm D and firm F maximize

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

with respect to x_D and x_F respectively. The first-order conditions of profit maximizations are given by

$$V_D(x_D, qx_F) + V_{DD}(x_D, qx_F)x_D = c + (1-q)\,m_L, \tag{8}$$

$$q\left[V_F(x_D, qx_F) + qV_{FF}(x_D, qx_F)x_F\right] = c + t. \tag{9}$$

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 $p_F^{NR} = qV_F(x_D^{NR}, qx_F^{NR})$. The equilibrium profits of each firm, the equilibrium consumer surplus, and the equilibrium world welfare are respectively given by $\Pi_D^{NR} = -V_{DD}(x_D^{NR}, x_F^{NR})\left(x_D^{NR}\right)^2$, $\Pi_F^{NR} = -V_{FF}(x_D^{NR}, x_F^{NR})\left(qx_F^{NR}\right)^2$, $CS^{OR} = V(x_D^{NR}, qx_F^{NR}) - p_D^{NR}x_D^{NR} - p_F^{NR}x_F^{NR}$, and $WW^{NR} = CS^{NR} + \Pi_D^{NR} + \Pi_F^{NR} + tx_F^{NR}$.

3.4 Comparison

Here, we compare the three cases. To understand the effects of repair services, we first examine how the demands for good F are different among the three cases, holding x_D constant. In the OR case, good F is freely repaired by firm F and each consumer demands good F as if it will not be broken. Hence, the inverse demand for good F, which should be equal to the marginal utility from purchasing good F, is given by $p_F = V_F(x_D, x_F)$. The OR curve depicted in Figure 1 represents the demand curve for good F in the OR case.

[Figure 1 around here]

In the RR case, each consumer anticipates at the time of buying good F that she will fix all broken units of good F in Stage 3 by paying $\widehat{r} \times (1-q)\, x_F$. Then, the representative consumer's marginal utility from consuming good F should be equal to the sum of the price of good F and the expected unit-payment for repairs, $p_F + (1-q)\,\widehat{r} = V_F(x_D, x_F)$. Since firm D provides repair services so that $\widehat{r} = V_F(x_D, x_F)$ holds in stage 3, the inverse demand for good F is given by $p_F = V_F(x_D, x_F) - (1-q)\,\widehat{r} = qV_F(x_D, x_F)$ that is depicted as the RR curve in Figure 1. MR^{RR} is the marginal revenue curve derived from the RR curve. Holding x_D constant, the equilibrium sales of good F, $\widehat{x}_F$, are determined so that firm F's marginal revenue from selling good F is equal to its marginal cost, $c + t$ (see (5)). Then, the equilibrium price of good F is given by $\widehat{p}_F = qV_F(x_D, \widehat{x}_F)$ and each consumer pays $\widehat{p}_F \times \widehat{x}_F = qV_F(x_D, \widehat{x}_F)\widehat{x}_F$ to firm F and $(1-q)\,\widehat{r} \times \widehat{x}_F = (1-q)\,V_F(x_D, \widehat{x}_F)\widehat{x}_F$ to firm D, as is depicted in Figure 1.

In the NR case, each consumer anticipates that a fraction of good F becomes broken and remains unrepaired. Hence, the inverse demand for good F is derived from the expected marginal utility of buying good F: $p_F = \partial V(x_D, qx_F)/\partial x_F = qV_F(x_D, qx_F)$. The demand curve is depicted by the RN curve in Figure 2, while MR^{NR} is the marginal revenue curve based on the RN curve. If x_D is kept constant at the equilibrium level attained in the RR case, the equilibrium sales of good F, $\widetilde{x}_F$, must satisfy $q\widetilde{x}_F = \widehat{x}_F$ by (5) and (9), and the equilibrium price, $\widetilde{p}_F$, satisfies $\widetilde{p}_F = \widehat{p}_F$. Since $q\widetilde{x}_F = \widehat{x}_F$ means that $\widetilde{x}_F > \widehat{x}_F$ holds, holding x_D kept constant, the sales of good F and the profit of firm F is higher in the NR case than that in the RR case.

[Figure 2 around here]

This effect is explained as follows. In the NR case, the representative consumer anticipates that the amount of good F she can consume is smaller than the amount she purchases. Hence, a decrease in her marginal utility by an increase in x_F is smaller than the decrease in the presence of repair services. As a result, the slope of the demand curve is flatter in the NR case than those in the OR case and in the RR case. In other words, if the consumer is willing to consume a certain amount of good F, she must purchase larger amount of the good since some fraction of the purchased units will be broken. We call the effect the *precautionary effect*. The larger demand in the NR case due to the precautionary effect induces firm F to make relatively larger exports than it does in the RR case, ceteris paribus. It is worth noting, however, even though the precautionary effect increases the sales of good F, it does not affect the amount of good F that is eventually consumed as well as the amount of good D supplied by firm D. Hence, $q\widetilde{x}_F = \widehat{x}_F$ holds.[14]

Repair services have another effect that increases the attractiveness of good F which raises the consumer's willingness to pay for the good. We call it the *valuation effect*. However, the valuation effect does not work in favor of firm F as long as firm D provides the repair services for good F. This is because firm D manipulates the service price so that it can capture the additional rents associated with good F generated by the valuation effect. In other words, either in the RR case or in the NR case, firm F cannot capture any rents associate with the broken units, $(1-q)x_F$. As a result, holding x_D constant, the primary demands for good F are reduced and the exports of good F are decreased by the existence of the rival's repairs.

Bearing these effects in mind, now we compare the equilibrium outcomes by taking into account changes in firm D's incentives and the strategic interactions between the two firms. As we have mentioned, only the units of each good that work correctly are regarded as substitutes by consumers. Therefore, the product market competition in the NR case can be regarded as if the two firms compete in setting x_D and qx_F respectively. Then, firm D's reaction function, $x_D = R_D^{NR}(qx_F)$ is derived from (8) and it is depicted as *dd* line in Figure 3. Similarly, firm F's reaction function, $qx_F = R_F^{NR}(x_D)$ is derived from (9) and it is depicted as ff line in Figure 3. By (9), we can also derive the optimal sales of good F as a function of x_D, which is depicted in $f'f$ line in Figure 3. The equilibrium amounts of working units, (x_D^{NR}, qx_F^{NR}), are determined at the intersection of *dd* curve and ff curve, and then x_F^{NR} is obtained by $f'f$ curve.

[Figure 3 around here]

In the RR case, 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 has a less incentive to increase x_D. The effect, which we call the *collusive effect,* enhances the imports of good F. In Figure 3, the firm D's reaction function which is derived from (4), $x_D = R_D^{RR}(x_F)$, is depicted as *Dd* line. Due to the collusive effect, *Dd* line locates insides *dd* line. Because the amount of the working units of good F are the same between the RR case and the NR case if x_D is kept constant (i.e., $\widehat{x}_F = q\widetilde{x}_F$ holds), ff line also represents the firm F's reaction function in the RR case. The equilibrium sales of each good, (x_D^{RR}, x_F^{RR}), are determined at the intersection of *Dd* curve and ff curve. 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.

[14] Remember that the units of good F that work correctly, rather than the purchased units of good F, are the substitutes for good D.

In the OR case, firm F can capture the rents from the valuation effect. Although the marginal cost of supplying good F is also increased from $c+t$ to $c+t+(1-q)m_L$, we can easily confirm that the valuation effect always dominates the cost effect. The firm F's reaction function which is derived from (7), $x_F = R_D^{OR}(x_D)$, is depicted as FF line in Figure 4, whereas firm D's reaction function is given by dd curve. In equilibrium, firm F supplies good F so that it exceeds the equilibrium level of working units in the NR case: $x_F^{OR} > qx_F^{NR}$. This in turn implies that $x_D^{OR} < x_D^{NR}$ holds in equilibrium.

[Figure 4 around here]

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 case and the collusive effect in the RR case. Putting it all together, 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.[15]

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.*

This proposition implies that, irrespective of who repairs broken units of good F, the repair services always: (i) increase the equilibrium amount of good F that works correctly, (ii) decrease the equilibrium sales of good D, and (iii) decrease the equilibrium sales of good F.

Regarding the equilibrium profits, we have $\Pi_F^{NR} > \Pi_F^{RR}$ holding the tariff level. Although the collusive effects in the RR case works in favor of firm F, the rival's repairs eliminate the precautionary effect which exists in the NR case and decreases the sales of good F. Since the latter effect dominates the former effect, the regime change from the NR case to the RR case hurts firm F. By contrast, the precautionary effect does not matter for firm D since it is unrelated to the equilibrium amount of good F that works correctly. By contrast, the valuation effect and the collusive effect work in favor of firm D. Hence, we have $\Pi_D^{RR} > \Pi_D^{NR}$.

In the OR case, on the other hand, firm F can capture the rents associated with the valuation effect, and its positive effect on the profit always outweighs the negative effect on profit due to the absence of the precautionary effect. Besides that, the increase in the working 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 $\Pi_D^{NR} > \Pi_D^{OR}$.

[15] 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.

How the presence of the repair services affect consumers? Consumers prefer the OR equilibrium to the NR equilibrium because the working units of good F is larger and the degree of product market competition is more intense in the former case. In the RR case, although the repairs by the rival firm increases the working units of good F, the collusive effect associated with the rival's repairs weakens the product market competition and raises the equilibrium price of good D. Since the negative effect from the higher price of good D dominates the positive effect from the increased availability of good F, consumers prefer the NR case to the RR case. The following proposition summarizes the comparison of the operation profits and consumer surplus.

Proposition 2 *Given the tariff level,* $\Pi_F^{RR} < \Pi_F^{NR} < \Pi_F^{OR}$, $\Pi_D^{OR} < \Pi_D^{NR} < \Pi_D^{RR}$, *and* $CS^{RR} < CS^{NR} < CS^{OR}$ *hold.*

It is worth noting that even if consumers *ex ante* anticipate that the repairs of the imported goods by the rival producer would raise the price of good D in the product market and eventually become harmful for them, they cannot commit themselves to leave the broken units of imported goods being unrepaired after they purchase good F since repairing the broken units of good F is *ex post* optimal for consumers. Due to this time-inconsistency problem, consumers cannot avoid the negative effect of the repair services by the non-original producer on the intensity of the product market competition.

4 Entry into the repair services

Now we examine the firms' entry decisions at stage 1. Each firm simultaneously decides whether it provides the repair services for good F, given the choice of the rival firm. Each firm has two choices: entry into the repair services for good F denoted by E and non-entry into the repair market denoted by N.

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. Because firm D cannot earn any profits from the repair services if firm F chooses $\sigma_F = E$, its gains from the entry are given by

$$\Delta\Pi_D(N, t) = \Pi_D^{RR} - \Pi_D^{NR}, \quad \Delta\Pi_D(E, t) = 0. \tag{10}$$

Regarding firm F's gains, we have

$$\Delta\Pi_F(N, t) = \Pi_F^{OR} - \Pi_F^{NR}, \quad \Delta\Pi_F(E, t) = \Pi_F^{OR} - \Pi_F^{RR}. \tag{11}$$

Since $\Pi_F^{NR} > \Pi_F^{RR}$ holds given t, firm F's gains from the entry are larger when firm D also chooses the entry: $\Delta\Pi_F(E, t) > \Delta\Pi_F(N, t)$.

We next consider how the import tariff affects the gains from the entry. We have the following lemma.

Lemma 2 $\partial\{\Delta\Pi_D(N,t)\}/\partial t < 0$ *always holds. If* m_L *is large and* c *and* t *are small,* $\partial\{\Delta\Pi_F(\sigma_D,t)\}/\partial t \geq 0$ *(*$\sigma_D \in \{E,N\}$*) holds. Otherwise,* $\partial\{\Delta\Pi_F(\sigma_D,t)\}/\partial t < 0$ *holds.*

This lemma suggests that if firm F does not provide the repair services, firm D's gains from the entry become larger as trade liberalization proceeds. Intuitively, since a tariff reduction increases the domestic country's imports of good F and so does the amount of the broken units, it becomes more attractive for firm D to earn profits from repairing the rival's product.

The same effect applies to firm F, whereas there is an additional effect. In the RR case and the NR case, since firm F cannot capture the rents associated with the broken units, the demand curves as well as the marginal revenue curves are flatter than those in the OR case (see Figures 1 and 2). Hence, the degrees of the increase in x_F by the tariff reduction is larger in the RR case and the NR case than that in the OR case. Whether a tariff reduction enhances or undermines firm F's entry depends on which effect dominates. If the cost of providing repair 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.

Given the effects of the tariff on the gains from entry, we derive the possible equilibrium outcomes. Firstly, 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

$$\begin{cases} \Delta\Pi_D(N,t) > K_D & \text{for} \quad t \in [0, t_D) \\ \Delta\Pi_D(N,t) = K_D & \text{for} \quad t = t_D \\ \Delta\Pi_D(N,t) < K_D & \text{for} \quad t \in (t_D, \bar{t}) \end{cases} \tag{12}$$

holds, where $\bar{t}$ represents the prohibitive level of tariff that makes $x_F^{RR} = 0$. 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

$$\Delta\Pi_F = \begin{cases} \Delta\Pi_F(E,t) & \text{for} \quad t \in [0, t_D) \\ \Delta\Pi_F(N,t) & \text{for} \quad t \in [t_D, \bar{t}) \end{cases} . \tag{13}$$

We have the following proposition.

Proposition 3 *The equilibrium outcome of the entry game becomes: (i) the OR case if* $\Delta\Pi_F > K_F$ *holds, (ii) the RR case if both* $\Delta\Pi_F \leq K_F$ *and* $t < t_D$ *hold, and (iii) the NR case otherwise.*

Given K_D, Figure 5 depicts the possible equilibrium outcomes in the (t, K_F) space.[16] In equilibrium, no repair services are provided for good F when both t and K_F are high (the region 'NR' in the figure). When K_F is high while t is low, the repairs of good F are sorely provided by firm D in equilibrium (the region 'RR'). Otherwise, the repairs of good F are provided by the original producer in equilibrium (the region 'OR').

[Figure 5 around here]

5 Liberalization of goods trade and service FDI

Now we examine the effects of trade liberalization in goods represented by a decline in t. Firstly, we examine trade liberalization within each regime of the service market. We have the following proposition.

Proposition 4 *Given the structure of the repair market, (i) a tariff reduction always increases the imports of good F and benefits firm F and consumers, (ii) it may benefit firm D in the RR case while it always hurts firm D in the NR case and in the OR case, (iii) it may worsen world welfare in the NR case and in the RR case while it always improve it in the OR case.*

Within each regime, trade liberalization always benefits consumers and firm F. If firm D does not provide repair services for the rival's product, trade liberalization in goods hurts firm D. When firm D provides the repair services for imports, trade liberalization may increase its profits. This is because the trade liberalization has two effects on firm D's profits under the RR case. On one hand, it decreases the sales of good D, x_D^{RR}, and thereby lowers the profits from selling its own product. On the other hand, since trade liberalization increases the sales of good F, x_F^{RR}, it increases firm D's profits from providing the repair services for good F. Hence, whether trade liberalization benefits or hurts firm D depends on the relative magnitudes of these two effects.

Furthermore, trade liberalization may worsen world welfare in the NR case and in the RR case. In the NR case, the "quality" of good F is inferior to that of good D in the sense that a fraction of the good that is purchased is eventually broken and remains unrepaired. Since the increased consumption of good F substitutes for that of good D, the overall quality of goods is lowered by trade liberalization. The effect shrinks the consumers' gains as well as the profit gains of firm F by the trade liberalization, and the profit loss of firm D becomes relatively significant.

[16] We depict the case where c is small and m_L is large so that both $\Delta\Pi_F(E,t)$ and $\Delta\Pi_F(E,t)$ are inverse U-shaped curves.

Similarly, in the RR case, both goods are fully repaired in equilibrium but the higher cost of repairing the rival product, $m_H > m_L$, implies that the repairs of good F are more costly than those of good D in the RR case. Hence, the substitution effect of trade liberalization from good D to good F worsens the overall efficiency of the repair activities. Due to these effects, trade liberalization may worsen world welfare in the NR case and in the RR case.

In the OR case, on the other hand, both the qualities of the two goods and the costs of repairing them are identical. Under the circumstance, trade liberalization in goods always improves world welfare.

We have shown that trade liberalization is always beneficial for consumers and the foreign firm given the structure of the repair market. However, if we take into account of the changes in the market structure of the repair market, trade liberalization may even reduce imports and hurt consumers and the foreign firm. Let K_F^0 denote the initial level of the fixed costs for FDI in repair services. We have the following proposition.

Proposition 5 *If $K_F^0 > \min[\Delta\Pi_F(E,0), \Delta\Pi_F(E,t_D)]$ and $K_D < \Delta\Pi_D(N,0)$ hold, there exists a case where a tariff reduction from $t_0 \in (t_1, \bar{t})$ to $t_1 \in [0, t_D)$ changes the equilibrium regime from the NR case or the OR case to the RR case. Under the situation:*
(i) holding K_F fixed at $K_F = K_F^0$, then the tariff reduction from t_0 to t_1 may decrease the imports, consumer surplus, and the profits of firm F. It may increase the profit of firm D and worsen world welfare.
(ii) we can find a unique cut-off level of K_F, $\widetilde{K}_F$ $(\leq K_F^0)$, such that the tariff reduction from t_0 to t_1 always increases the imports, benefits consumers and firm F, and improves world welfare for all $K_F \in (K_D, \widetilde{K}_F)$.

To understand the first part of this proposition, let us suppose K_F^0 is high enough to satisfy $K_F^0 > \overline{K}_F := \arg\max_{K_F} \Delta\Pi_F$. Also, suppose K_D is low enough to satisfy $K_D < \Delta\Pi_D(N,0)$ so that t_D is positive. As is shown in Figure 3, the equilibrium outcome becomes the NR case for $t \in [t_D, \bar{t})$ and the RR case for $t \in [0, t_D)$. By Proposition 2, consumer surplus and the profits of firm F declines discontinuously at $t = t_D$ by changing the equilibrium regime from the NR case to the RR case. If the effect of the change in the regime outweighs the effects of trade liberalization within each regime, trade liberalization from $t_0 \in [t_D, \bar{t})$ to $t_1 \in [0, t_D)$ reduces imports, consumer surplus, and the profits of the foreign firm. Besides that, since $\Pi_D^{RR} - K_D = \Pi_D^{NR}$, $CS^{RR} < CS^{NR}$ and $x_F^{RR} < x_F^{NR}$, and $\Pi_F^{RR} < \Pi_F^{NR}$ hold at $t = t_D$, the change of the structure of the repair market from the NR case to the RR case also reduces world welfare.

Even if the initial tariff satisfies $t_1 < t_D$, the same results can be obtained when $\min[\Delta\Pi_F(E,0), \Delta\Pi_F(E,t_D)] < K_F^0 < \overline{K}_F$ holds. In this case, a tariff reduction from $t_0 \in [t_1, t_D)$ to $t_1 \in [0, t_0)$

can change the equilibrium regime from the OR case to the RR case. In fact, we can always find an example of a tariff reduction which leads to these paradoxical effects if $K_F > \min[\Delta\Pi_F(E,0), \Delta\Pi_F(E,t_D)]$ holds.

Because Proposition 4 tells that a tariff reduction within the RR case always increases the imports and benefits consumers and firm F, even if a tariff reduction changes the equilibrium regime to the RR case, it is less likely to hurt consumers and the foreign firm as t_1 approaches zero. Even if the tariff is completely eliminated, however, the tariff reduction may cause the detrimental effects on consumers and world welfare.[17]

The second part of Proposition 5 tells us that in order to avoid the paradoxical effects of trade liberalization in goods, the fixed cost for FDI in services, K_F, must be lowered. For instance, if it is reduced so that $K_F < \min[\Delta\Pi_F(E,0), \Delta\Pi_F(E,t_D)]$ holds, the RR case is no longer a possible equilibrium for all $t \in [0,\bar{t})$ and trade liberalization can only change the equilibrium regime from the NR case to the OR case. This situation corresponds to the case where K_F is set at $K_F = K_F^1$ in Figure 3, for example. By Propositions 2 and 4, trade liberalization that entails the regime shift from the NR case to the OR case always increases the imports, consumer surplus, and the profits of the foreign firm. Although trade liberalization that changes the regime into the OR case also increases world welfare gross of K_F, world welfare net of the fixed cost can be decreased. If K_F is sufficiently low, however, the welfare burden of the fixed cost become small enough so that trade liberalization always improves world welfare.[18]

The result suggests that promoting FDI in repair services is important to secure the welfare-improving trade liberalization which benefits consumers, the foreign firm, and the world as a whole.

6 Repair services by ISOs

Up to this point, we have assumed that either firm D or firm F can provide the repair services for good F. In this section, we analyze the equilibrium under which ISOs are also able to provide the repair services for imports. In Stage 1, many potential ISOs, firm F, and firm D simultaneously decide whether they provide the repair services for good F. Each ISO's unit cost of production is given by $m_H + \alpha$ where $0 \leq \alpha < c - m_H$ holds. Since the producing firms have better knowledge about the goods, the unit cost of each ISO for repairs is weakly higher than that of firm D, while it is lower than the production costs of the goods. If an ISO enters the repair market, it must

[17] The example of this case is provided in the proof of Proposition 5.

[18] If K_F is reduced further so that the equilibrium regimes before the tariff reduction also becomes the OR case, any tariff reductions always have the favorable effects as Proposition 4 suggests.

incur the same fixed cost, K_D, as that of firm D.[19]

If neither firm D nor firm F provides the repair services for good F and only a single ISO provides them, the ISO acts as a monopolist in the repair market. If firm F does not enter the repair market while more than two ISOs enter the repair market, ISOs, or ISOs and firm D, engage in the Bertrand competition. In this case, the equilibrium repair price becomes equal to the marginal costs of ISOs: $r = m_H + \alpha$.

We can confirm that, even if ISOs enter the repair market, all broken units of good F are repaired in equilibrium.

Lemma 3 *If an ISO enters the repair market, all broken units of the imported goods are repaired in equilibrium.*

Suppose a single ISO monopolizes the repair services for good F. The ISO's profit-maximization problem at stage 3 is similar to that of firm D in the RR case, whereas the marginal cost of repairs is $m_H + \alpha$ rather than m_H. Since $m_H + \alpha < c$ holds, however, it is optimal for the ISO to set $R_F = (1 - q)\, x_F$ so that $r = V_F(x_D, x_F)$ holds at stage 3. 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.

Next consider how the presence of ISOs affects the equilibrium of the product market. Because the price competition in repairs leads to the marginal-cost pricing for ISOs, as long as $K_D > 0$, it is not profitable for an ISO to enter the repair market if firm F or other ISOs choose to enter the repair market. This means that at most a single ISO enters the repair market in equilibrium in the presence of the fixed cost. Specifically, given that firm F does not undertake service FDI, if the operating profit of an ISO from monopolizing the repair market is higher than K_D while the gains in the operating profit of firm D from providing the same repair services by setting $r = m_H + \alpha$ is smaller than K_D, the "monopoly-ISO case" constitutes a Nash equilibrium of the Stage-1 game.

If $K_D = 0$, on the other hand, firm D and ISOs can enter the repair market freely. Given that firm F does not provide the repair services for its own good, they set $r = m_H + \alpha$ $(< V_F(x_D, x_F))$ and firm D monopolizes the repair market as long as $\alpha > 0$. In this case, although ISOs cannot provide repair services in equilibrium, firm D's service price becomes lower than the price it would charge in the absence of ISOs since the potential entry of competitive ISOs acts as a threat. We call the case as the "competitive-ISO case". If $\alpha = 0$, ISOs actually provide the repair services in equilibrium.

[19] As is the unit-cost of repairs, the fixed cost of entry for ISOs may be higher than K_D. Even in this case, the qualitative nature of our analysis would be unchanged.

6.1 Monopoly ISO

In the monopoly-ISO case where a single ISO monopolizes the repair services for good F, the equilibrium service price becomes $r = V_F(x_D, x_F)$ and so the inverse demand for good F is given by $p_F = qV_F(x_D, x_F)$. The equilibrium profits of the monopoly-ISO become $\pi_{MSO} = \{V_F(x_D, x_F) - (m_H + \alpha)\}(1-q)x_F$. At 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 $\Pi_F = [qV_F(x_D, x_F) - (c+t)]x_F$. By solving the first-order conditions, we obtain the equilibrium sales of the two goods under the monopoly-ISO case, which are denoted as x_D^{MSO} and x_F^{MSO}. The equilibrium consumer surplus and the producing firm's profits are respectively denoted by CS^{MSO}, Π_D^{MSO}, and Π_F^{MSO}.

In the monopoly-ISO case, firm F cannot capture the rents associates with the repairs and its maximization problem becomes the same as the RR case. As is discussed in Section 3.4, holding $x_D = x_D^{NR}$,firm F's optimal sales of good F denoted by x'_F becomes the same as the amount of the working units of good F in the NR case. Namely, $x'_F = qx_F^{NR}$ holds. Meanwhile, firm D also cannot capture any rents from the repair services for imports, so its maximization problem is the same as that in the OR case. Because of the absence of the collusive effect in this case, firm D's optimal sales of good D are also unchanged between the NR case and the monopoly-ISO case holding x'_F fixed at $x'_F = qx_F^{NR}$. As a result, the equilibrium sales are given by

$$x_D^{MSO} = x_D^{NR}, \quad x_F^{MSO} = qx_F^{NR}. \tag{14}$$

Since the equilibrium amount of working units remain unchanged for both goods, firm D's profits and consumer surplus in the monopoly-ISO case become the same as those in the NR case, which means that $\Pi_D^{MSO} = \Pi_D^{NR}$ and $CS^{MSO} = CS^{NR}$ hold.

With regard to the volume of imports, since $x_F^{MSO} = qx_F^{NR} < x_F^{NR}$ holds, the repairs by the monopoly-ISO reduces the volume of imports compared to the case in the absence of the repairs for good F. This is because, as in the RR case, there is no longer the precautionary effect and the valuation effect is wholly captured by the monopoly-ISO. As a result, $\Pi_F^{MSO} < \Pi_F^{NR}$ holds. Furthermore, $x_F^{NR} < x_F^{RR}$ means that $x_F^{MSO} < x_F^{RR}$ holds, and this in turn implies that $\Pi_F^{MSO} < \Pi_F^{RR}$ holds. Hence, if the repairs for imports are monopolized by either firm D or a single ISO, firm F prefers the repairs by the rival firm since they have the collusive effect in the product market which works in favor of both producing firms. The following proposition summarizes the comparison.

Proposition 6 *Given the tariff level, a change from the NR case to the monopoly-ISO case does not affect the profits of the domestic firm nor consumer surplus, while it reduces the volume of* *imports and the profits of the foreign firm. The equilibrium profits of the foreign firm under the monopoly-ISO case are lower than those under the RR case.*

The result suggests that as long as the repair market is monopolized, the repair services by an ISO hurt the original producer. The damage is larger, rather than smaller, than the case where the rival in the product market monopolizes the repair services. This is because the latter weakens the product market competition. If the fixed cost of the monopoly-ISO is high and so the net profits of providing the repair services is relatively small, the entry of a monopoly ISO also worsens world welfare.

The result suggests that as long as the repair market is monopolized, the repair services by a non-original producer hurt the original producer. The damage is larger, rather than smaller, than the case where the competitor in the product market provides the repair services since it weakens the product market competition. If the fixed cost of the monopoly-ISO is high and so the net profits of providing the repair services is relatively small, the entry of a monopoly ISO also worsens world welfare.

6.2 Competitive ISOs

Suppose $K_D = 0$ in which the presence of competitive ISOs limits the repair price firm D charges. In this case, the equilibrium repair price is reduced to the ISOs' marginal costs: $r = m_H + \alpha$. Then, the inverse demand for good F is given by $p_F = V_F(x_D, x_F) - (1-q)(m_H + \alpha)$. At stage 2, firm D sets x_D to maximize $\Pi_D = [V_D(x_D, x_F) - \{c + (1-q)m_L\}]x_D + \alpha(1-q)x_F$ and firm F sets x_F to maximize $\Pi_F = [V_F(x_D, x_F) - (c + (1-q)m_H + t)]x_F$. Note that firm D no longer affects the equilibrium service price set in the next stage by manipulating x_D. This means that even though firm D monopolizes the market, the collusive effect is absent in the product market.[20]

By solving the first-order conditions, we obtain the equilibrium sales of the producing firms under the competitive-ISO case as x_D^{CSO} and x_F^{CSO}. The equilibrium consumer surplus and the producing firms' profits are respectively given by CS^{CSO}, Π_D^{CSO}, and Π_F^{CSO}. We have the following proposition.

Proposition 7 *Given the tariff level, a change from the NR case to the competitive-ISO case increases the profit of the foreign firm and consumer surplus, while it may increase or decrease*

[20]This property depends on the nature of the competition in the product market. If firms D and F engage in Bertrand competition in the product market, firm D can increase the profit from the repair services by manipulating p_D to change x_F. In this case, the change from the NR-case to the competitive-ISO case may still decrease the profit of the foreign firm and consumer surplus if α is high enough.

the volume of imports and the profit of the domestic firm.

In the competitive-ISO case, each ISO cannot capture any rents from the repair services. The situation is interpreted as if firm F provides the repair services by itself with the higher unit-cost of repairs $(m_H + \alpha)$. Hence, as in the OR case, firm F can capture the valuation effect of repairs and the repairs increase the profits of firm F and consumer surplus, while it reduces the profits of firm D. Since the ranking between x_F^{CSO} and x_F^{NR} is ambiguous, the repair services by the competitive ISOs can either increase or decrease the volume of imports.

It is worth noting that although repair services in the presence of competitive ISOs have the same welfare effects as the repair services by the original producer do, promoting FDI in repair services is more favorable than promoting entries of ISOs from the viewpoint of world welfare because the unit cost of repairs of the original producer is smaller than those of ISOs.

7 Conclusion

Using a duopoly model with horizontal product differentiation, this paper examines the interaction between trade liberalization in good and the liberalization of FDI in services. Our focus is on the repair services for imports, which can be provided either by the original producer or by the rival producer in the domestic country.

When the fixed cost of FDI in repair services is sufficiently high, trade liberalization in goods enhances the domestic firm's entry into the repair services for imports, and the entry benefits the domestic firm since the domestic firm can capture, through charging the repair services, a certain fraction of the rents associated with the sales of the imported goods. Since the repaired units and the new units of the imported goods are substitutes, the repairs have an effect of reducing the amount of imports. Although the repairs consumers' willingness to pay for the imported goods, the rents associated with the increased consumers' valuations are captured by the domestic firm. Therefore, the repairs by the domestic firms hurt the foreign firm. Furthermore, the repairs induce the domestic firm to reduce the supply of her own product because the manipulation increases the profit from the repair market. As a result, the repair services increase the price of the domestic product and consumers become worse off compared to the case with no repairs.

However, if the foreign firm, who is the original producer of the imported goods, undertakes an FDI in repair services, the repair services encourage the competition in the product market, which benefit consumers and the foreign firm. Trade liberalization in goods, however, does not necessarily encourage the service FDI unless the fixed cost of the FDI is sufficiently low.

Furthermore, even if the repair services are provided by ISOs, it neither helps nor hurts consumers if a single ISO monopolizes the repair market. It still reduces the profit of the foreign firm and the loss is *bigger* than the case where the domestic firm provides the repair services. The entries of ISOs benefits consumers and the foreign firm only if the fixed cost of entry is eliminated so that many ISOs can enter the repair market.

These results suggest the importance of liberalization in service sectors, especially the liberalization of FDI in services. The liberalization not only reduces the cost of providing services, but also diminishes the possibility that trade liberalization in good leads to an anti-competitive behavior by the domestic firm in the product market. In other words, countries should promote FDIs in aftermarket services to guarantee welfare-improving trade liberalization which enhances the product market competition.

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

Appendix

Proof of Lemma 1

At stage 3, the firm D's maximization problem is to choose R_F 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

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

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

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

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

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),

$$V_F(x_D, q x_F + R_F) + V_{FF}(x_D, q x_F + R_F) R_F = m_H \quad \text{(A4)}$$

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

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

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

Proof of Proposition 1

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

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

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

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 (6) and (7), 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 $x_F^{NR} > 0$ holds as long as $x_D^{RR} > 0$ and $x_F^{RR} > 0$ hold.

By solving (6) and (7), and\ using (A5) and (A6), the equilibrium sales in the NR case are given by

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

$$x_F^{NR} = \frac{\{4-(2-q)\,b^2\}}{(4-b^2)\,q} x_F^{RR}. \tag{A10}$$

By (A9) and (A10), it is obvious that $x_D^{RR} < x_D^{NR}$ and $x_F^{RR} < x_F^{NR}$ hold. By (A5), (A6), (A9), and (A10), 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

Under the quadratic utility function, the operation profit of each firm in each case is calculated as follows:

$$\begin{cases} \Pi_D^{RR} = \left(x_D^{RR}\right)^2 + (1-q)\left[\left(x_F^{RR}\right)^2 + \left(\dfrac{c+t}{q} - m_H\right) x_F^{RR} + b x_D^{RR} x_F^{RR}\right] \\ \Pi_D^{OR} = \left(x_D^{OR}\right)^2 \\ \Pi_D^{NR} = \left(x_D^{NR}\right)^2 \end{cases}, \tag{A11}$$

$$\begin{cases} \Pi_F^{RR} = q\left(x_F^{RR}\right)^2 \\ \Pi_F^{OR} = \left(x_F^{OR}\right)^2 \\ \Pi_F^{NR} = \left(qx_F^{NR}\right)^2 \end{cases}. \tag{A12}$$

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) By (A11) and (A12), 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 $\Pi_F^{OR} - \Pi_F^{NR} = 4\,(1-q)\,(c+t-qm_L)\,[\{a(2-b)+bc\}q - q\,(1-q)\,(1-b)\,m_L - (q+1)\,(c+t)]/\{(4-b^2)^2 q^2\} > 4\,(1-q)^2\,(c+t-qm_L)^2/\{(4-b^2)^2 q^2\} > 0$ where the inequalities are due to $a > \underline{a}$. Hence, $\Pi_F^{RR} < \Pi_F^{NR} < \Pi_F^{OR}$ is satisfied.

(ii) By (A11) and (A12), we have

$$\Pi_D^{RR} - \Pi_D^{NR} = \frac{(1-q)\, B_1 x_F^{RR}}{(4-b^2)^2 \{4-(2-q)\, b^2\} q}$$

where $B_1 = a(2-b)\{4(1-b)(2+b)^2 + (3+2b)\, b^4 + \left(4-2b^2-b^3\right) b^2 q\} q + 2\{16-20b^2+5b^4+2(2-b^2)b^2q\}t + bq(1-q)\{16-4(1-q)\, b^2 - b^4\} m_L - \left(4-b^2\right)^2 \{4-(2-q)\, b^2\} q m_H + \{2\left(16-20b^2+5b^4\right) + (2+b)(8-2b^2-b^3)bq + 4b^3q^2\}c$. By using $a > \underline{a}$ and $c > m_H$, we can confirm that $B_1 > (2+b)\{4-(2-q)\, b^2\}\{(8-4b-2b^2+b^3q)c - (2+b)(2-b)^2 q m_H + 2\left(4-2b-b^2\right) t + b^3(1-q)\, q m_L\} > (2+b)\{4-(2-q)\, b^2\}\{2c\left(4-2b-b^2\right)((1-q)\, c + t) + b^3(1-q)\, q m_L\} > 0$. 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 $\Pi_D^{OR} < \Pi_D^{NR} < \Pi_D^{RR}$.

Regarding the consumer surplus, 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 $d_F^{NR} = q x_F^{NR}$ hold because the broken units of good F remain unrepaired. We have

$$CS^{RR} - CS^{NR} = -\frac{(1-q)\, b B_2 x_D^{RR}}{2\left(4-b^2\right)^2 \{4-(2-q)\, b^2\} q}$$

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 $B_3 = 2q(b+1)(2-b)^2 a - \{\left(4-3b^2\right)(1+q) + 2b^3q\}c - \left(4-3b^2\right)(1+q)\, t - (4-3b^2+2b^3)(1-q)\, q m_L$. 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 Lemma 2

(i) By (A11), $\partial\{\Delta\Pi_D(N,t)\}/\partial t = -2(1-q)\, B_4/[\left(4-b^2\right)^2 \{4-(2-q)\, b^2\}^2 q^2]$ where $B_4 = (2-b)\{8-2(2+b)\, b + (2-q)\, b^3\} b^2 q a + 4\{16-20b^2+5b^4+2b^2\left(2-b^2\right) q\}t - (4-b^2)^2\{2\left(2-b^2\right)+$

$b^2q\}qm_H+2b^3\{8-(3-q)\,b^2\}q\,(1-q)\,m_L+4\,(1+b)\left(2-b^2\right)b^2q+b^5\,(1+q)\,q\}c$. Since $\partial B_5/\partial a>0$ holds, $B_5>B_5|_{a=\underline{a}}=(2+b)\,\{4-b^2\,(2-q)\}[\left(8-4b-2b^2+b^3q\right)(c-m_H)+2\left(4-2b-b^2\right)\{t+(1-q)\,m_H\}+(1-q)\,qb^3m_L]>0$. Hence, $\partial\{\Delta\Pi_D(N,t)\}/\partial t<0$ is satisfied.

(ii) By (A12), we have $\partial^2\{\Delta\Pi_F(N,t)\}/\left(\partial a\partial t\right)=4\,(1-q)\,/\{q\,(2-b)\,(b+2)^2\}>0$ and $\partial^2\{\Delta\Pi_F(E,t)\}/\left(\partial a\partial t\right)=4\,(1-q)\,\{8-b^2\,(3-q)\}b^2/[(2-b)\,(2+b)^2\,\{4-b^2\,(2-q)\}^2]>0$. Besides that, we have $\partial\{\Delta\Pi_F(N,t)\}/\partial t|_{a=\underline{a}}=\partial\{(\Delta\Pi_F(E,t)\}/\partial t|_{a=\underline{a}}=-8\,(1-q)\,\{c+t-qm_L\}/\{q\left(4-b^2\right)^2\}<0$. 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 $\partial\{\Delta\Pi_F(N,t)\}/\partial t>0$ holds for $a>\widetilde{a}^N$, $\partial\{\Delta\Pi_F(N,t)\}/\partial t=0$ holds for $a=\widetilde{a}^N$, and $\partial\{\Delta\Pi_F(N,t)\}/\partial t<0$ holds for $a\in(\underline{a},\widetilde{a}^N)$. Similarly, we can derive $\widetilde{a}^E=[2\{\left(4-b^2\right)^2+b^2q(8-b^2\,(3-q))\}t+(2-b)\,\{2\,(2-b)\,(2+b)^2+b^2q(8-b^2\,(3-q))\}c-(2-b)\,\{16+8b-12b^2-2b^3+3b^4+b^2q(8-b^2\,(4-q))\}qm_L]/\{(2-b)\left(8-b^2\,(3-q)\right)b^2q\}$ such that $\partial\{\Delta\Pi_F(E,t)\}/\partial t>0$ holds for $a>\widetilde{a}^E$, $\partial\{\Delta\Pi_F(E,t)\}/\partial t=0$ holds for $a=\widetilde{a}^E$, and $\partial\{\Delta\Pi_F(E,t)\}/\partial t<0$ 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, $\partial\{\Delta\Pi_F(\sigma_D,t)\}/\partial t>0$ (resp. $\partial\{\Delta\Pi_F(\sigma_D,t)\}/\partial t<0$) is more likely to hold as c and t become smaller (resp. large) and m_L becomes larger (resp. small). ■

Proof of Proposition 3

(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 $t<\widehat{t}_D$ 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 $t\geq\widehat{t}_D$ 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. ■

Proof of Propostion 4

(i) By (A6), (A8), and (A10), 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) 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) 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 $x_F^{RR}|_{t=t_1}-x_F^{NR}|_{t=t_0}=-2.4294<0$, $CS^{RR}|_{t=t_1}-CS^{NR}|_{t=t_0}=-1.0574<0$, $(\Pi_D^{RR}|_{t=t_1}-K_D)-\Pi_D^{NR}|_{t=t_0}=0.31014>0$, $\Pi_F^{RR}|_{t=t_1}-\Pi_F^{NR}|_{t=t_0}=-2.6552<0$, 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 $x_F^{RR}|_{t=t_1}-x_F^{OR}|_{t=t_0}=-2.4294<0$, $CS^{RR}|_{t=t_1}-CS^{OR}|_{t=t_0}=-15.564<0$, $(\Pi_D^{RR}|_{t=t_1}-K_D)-\Pi_D^{OR}|_{t=t_0}=8.6968>0$, $\Pi_F^{RR}|_{t=t_1}-\left(\Pi_F^{OR}|_{t=t_0}-K_F\right)=-4.0286<0$, 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 $WW^{OR}\big|_{t=t_0} > WW^{NR}\big|_{t=t_0}$ 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 $K_F \in (K_D, K_F^0]$. ■

Proof of Lemma 3

(i) 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^{MSO}, x_F^{MSO}), must satisfy

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

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

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

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.

(ii) In the competitive-ISO case, the service price must be equal to each ISO's marginal cost for repairs, $r = m_H$. Let $\mu = V_F(x_D, x_F) - m_H$. If $\mu \geq 0$ holds, the consumer repairs all broken units of imported products at Stage 3. If $\mu < 0$ holds, on the other hand, the service price is high so that the consumer does not repair all broken units.

Suppose $\mu = V_F(x_D, x_F) - m_H \geq 0$ holds. In this case, $R_F = (1-q)\,x_F$ holds. By the consumer's utility maximization at Stage 2, the inverse demand functions are given by $p_D = V_D(x_D, x_F)$, $p_F = V_F(x_D, x_F) - (1-q)\,m_H$. 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 $\max_{x_F} \Pi_F = \{V_F(x_D, x_F) - (c+t) - (1-q)\,m_H\}x_F$. By the first-order conditions, the optimal sales of the two firms, (x_D^{CSO}, x_F^{CSO}), must satisfy

$$\begin{aligned} V_D(x_D^{CSO}, x_F^{CSO}) + V_{DD}(x_D^{CSO}, x_F^{CSO})x_D^{CSO} &= c + (1-q)\,m_L, \\ V_F(x_D^{CSO}, x_F^{CSO}) + V_{FF}(x_D^{CSO}, x_F^{CSO})x_F^{CSO} &= c + t + (1-q)\,m_H. \end{aligned} \tag{A12}$$

By using (A12), $c \geq m_H$, and $V_{FF} < 0$, we have $\mu = V_F(x_D^{CSO}, x_F^{CSO}) - m_H = c + t - qm_H - V_{FF}(x_D^{CSO}, x_F^{CSO})x_F^{CSO} > 0$. Therefore, (x_D^{MSO}, x_F^{MSO}) and $R_F^{CSO} = (1-q)\,x_F^{CSO}$ actually constitute an equilibrium.

Suppose $\mu = V_F(x_D, x_F) - m_H < 0$ holds. By the consumer's utility maximization at Stage 3, the amount of repair $\widehat{R}_F$ is determined such that $V_F(x_D, qx_F + \widehat{R}_F) = m$ holds. By this condition, we have $\partial \widehat{R}_F/\partial x_F = -q < 0$. At stage 2, the inverse demands for the two goods can be obtained as $p_D = V_D(x_D, qx_F + \widehat{R}_F)$ and $p_F = qV_F\left(x_D, qx_F + \widehat{R}_F\right)$. The first-order condition of the firm F's profit maximization is given by

$$qV_F\left(x_D, qx_F + \widehat{R}_F\right) + \left[q + \frac{\partial \widehat{R}_F}{\partial x_F}\right] qV_{FF}\left(x_D, qx_F + \widehat{R}_F\right)x_F = c + t.$$

By using $\partial \widehat{R}_F/\partial x_F = -q$ and $V_F(x_D, qx_F + \widehat{R}_F) = m_H$, it is rewritten as

$$qm_H = c + t,$$

which cannot be hold since $c \geq m_H$. Hence, $\mu < 0$ cannot hold in equilibrium.

In summary, either in the monopoly-ISO case or the competitive-ISO case, consumers repairs all broken units of the imported product in equilibrium. ■

Proof of Proposition 7

In the competitive-ISO case, the first-order conditions of the profit maximizations at Stage 2 are given by $V_D(x_D, x_F) + V_{DD}(x_D, x_F)x_D = c + (1-q)\, m_L$ and $V_F(x_D, x_F) + V_{FF}(x_D, x_F)x_D = c+t+(1-q)\, m_L$. By solving these equations under the quadratic utility function, the equilibrium sales are represented as

$$x_D^{CSO} = \frac{(2-b)\,(a-c) - (1-q)\,(2m_L - bm_H) + bt}{(4-b^2)} \tag{A13}$$

$$x_F^{CSO} = \frac{(2-b)\,(a-c) - (1-q)\,(2m_H - bm_L) - 2t}{(4-b^2)}. \tag{A14}$$

The equilibrium profits and consumer surplus are respectively given by $\Pi_D^{CSO} = \left(x_D^{CSO}\right)^2$, $\Pi_F^{CSO} = \left(x_F^{CSO}\right)^2$, and $CS^{CSO} = \{(x_D^{CSO})^2 + (x_F^{CSO})^2\}/2 + b(x_D^{CSO})(x_F^{CSO})$.

Since we have $x_D^{CSO} - x_D^{NR} = -b\,(1-q)\,(c+t-qm_H)/\{q(4-b^2)\} < 0$ and $x_F^{CSO} - qx_F^{NR} = 2\,(1-q)\,(c+t-qm_H)/\{q(4-b^2)\} > 0$, $\Pi_D^{CSO} - \Pi_D^{NR} = \left(x_D^{CSO}\right)^2 - \left(x_D^{NR}\right)^2 < 0$ and $\Pi_F^{CSO} - \Pi_F^{NR} = \left(x_F^{CSO}\right)^2 - \left(qx_F^{NR}\right)^2 > 0$ hold. Besides that, we have $\partial(CS^{CSO} - CS^{NR})/\partial a = (1+b)\,(1-q)\,(c+t-qm_H)\,/\{q\,(2+b)^2\} > 0$ and

$$\begin{aligned} CS^{CSO} - CS^{NR} &> CS^{CSO} - CS^{NR}\big|_{a=\underline{a}} \\ &= \frac{(1-q)\,(c+t-qm_H)}{2q^2\,(4-b^2)^2} \left[\begin{array}{c} \left(4+4b-b^2\right)(1-q)\,(c+t-qm_H) \\ +2\,(2+b)\,bq\{(1-q)\,(m_H - m_L) + t\} \end{array} \right] > 0. \end{aligned}$$

Hence, we have $\Pi_D^{CSO} < \Pi_D^{NR}$, $\Pi_F^{CSO} > \Pi_F^{NR}$, and $CS^{CSO} > CS^{NR}$. ■

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Figures

Figure 1: The determination of x_F in the RR case given $x_D = \widehat{x}_D$

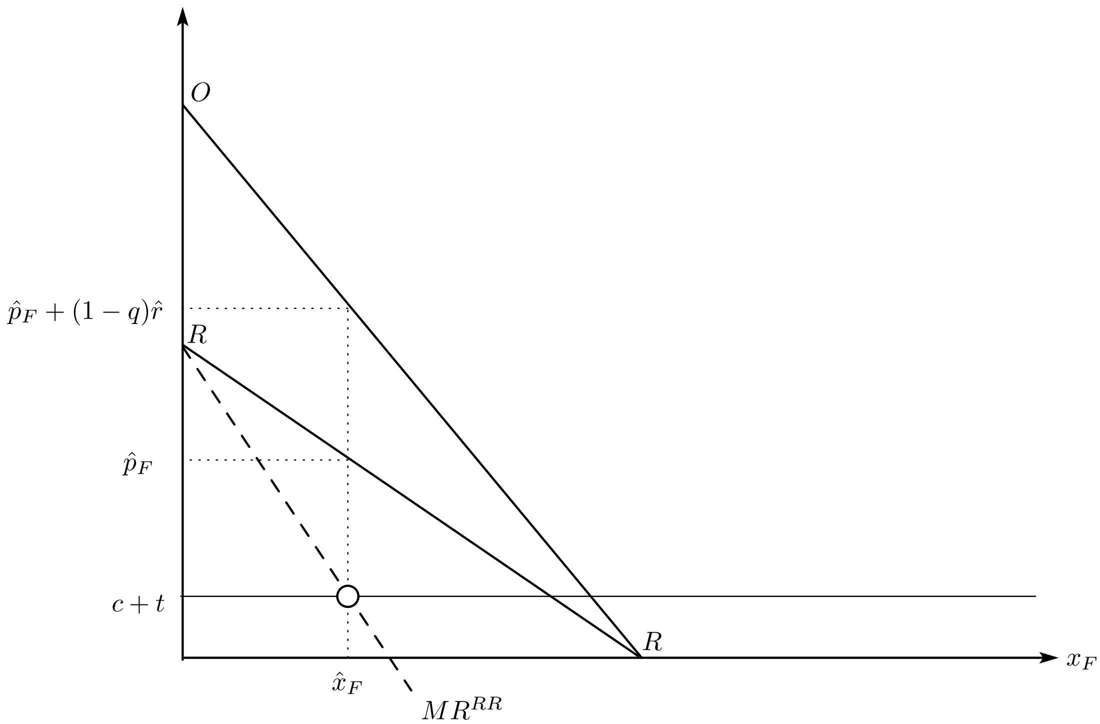

Figure 2: The determination of x_F in the NR case given $x_D = \widehat{x}_D$

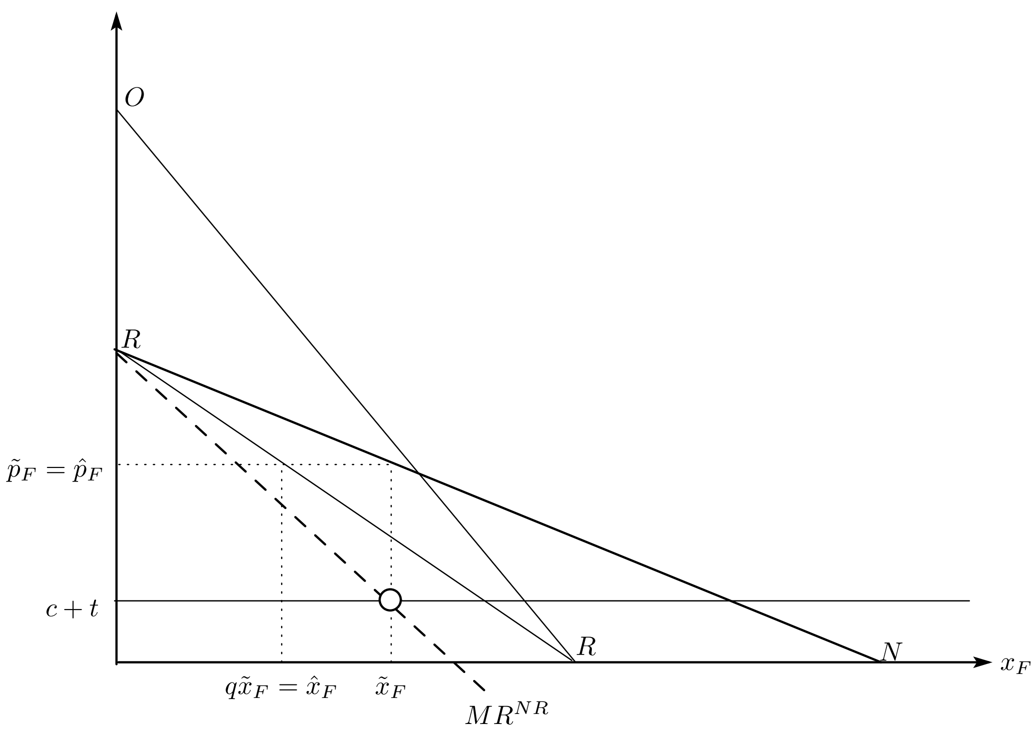

Figure 3: The comparision of the NR case and the RR case

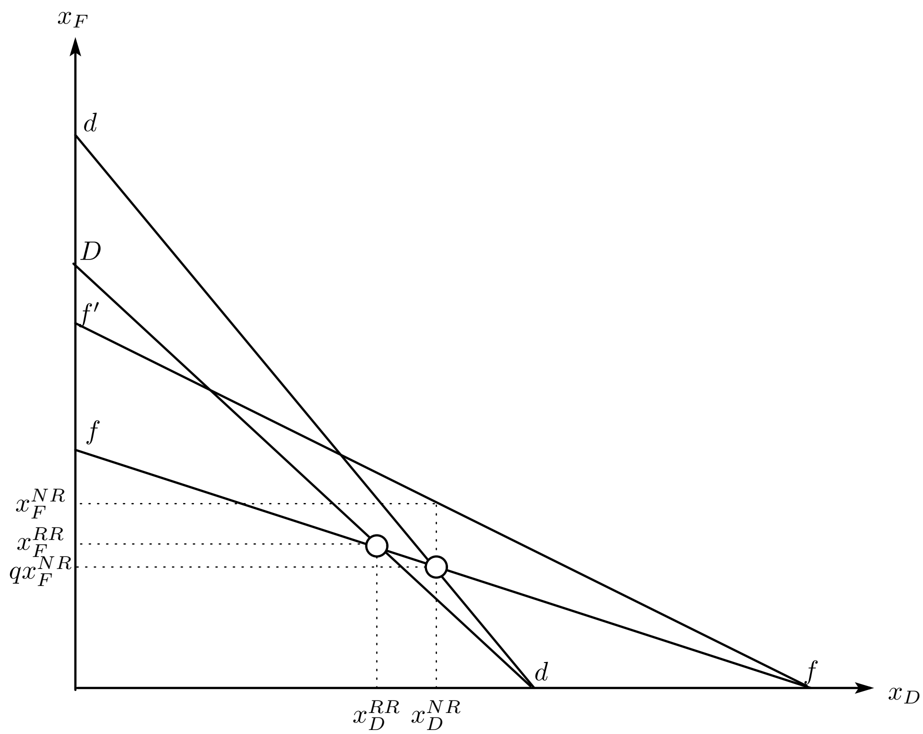

Figure 4: The comparison of the NR case and the OR case

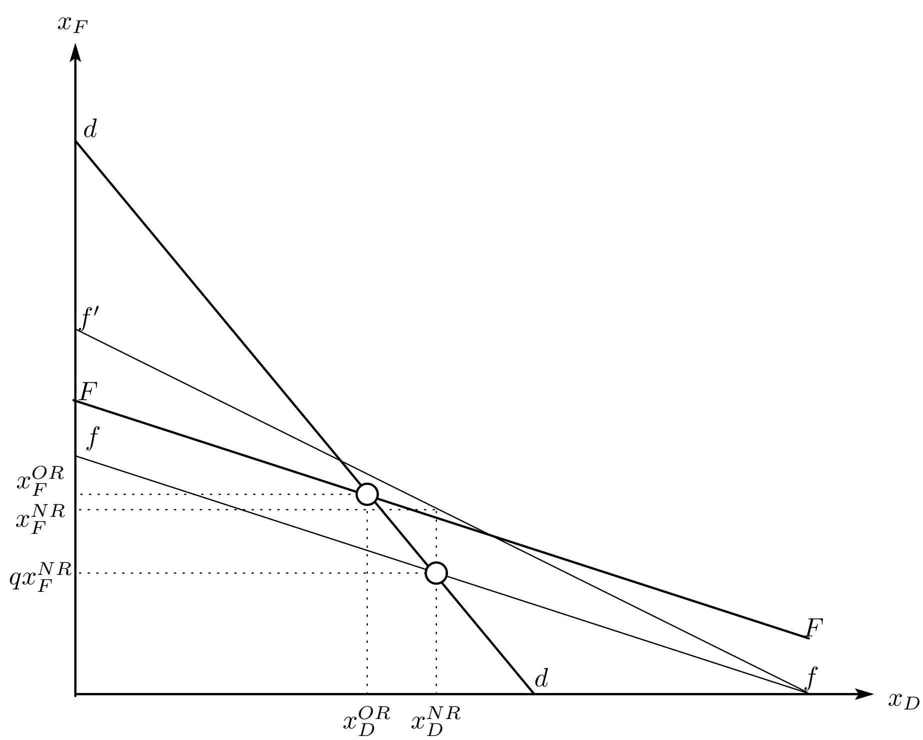

Figure 5: The equilibrium regimes of repair services