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Outsourcing decision-making in global remanufacturing supply chains: The impact of tax and tariff regulations

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A B S T R A C T

In contemporary international remanufacturing supply chains, whether an original equipment manufacturer (OEM) engages in remanufacturing operations or outsources to a third-party remanufacturer (TPR) is influenced by tax and tariff regulations. This study develops a two-stage game model for the decision-making of an OEM from an exporting country showing that the optimal remanufacturing model is significantly affected by the tax and tariff regulations of the importing country and more particularly, the difference between sales tax on remanufactured products and the unit product import tariffs on new products. The model selections for the OEM and the importing country align when this difference is close to zero. This paper is one of the few examining the impact of tax and tariff regulations on outsourcing decisions in remanufacturing contexts, which is largely neglected in the extant literature but has become increasingly important, especially with recent development trends of deglobalization (e.g., Brexit, the US–China trade war, and various sanctions). The significance of this study is threefold: the work makes novel theoretical contributions to the decision-making game model with tax and tariff constructs taken into consideration, has practical implementations for optimizing the strategic business deployment of OEMs, and has implications for consideration of policy and social welfare by policy makers of the destination country.

1. Introduction

Defined as the process of returning used, damaged, or discarded products to the quality standards of new products with an equivalent warranty (Ijomah, 2009; Lund, 1984), remanufacturing is a key strategy for sustainable production and a critical element of circular economy (Ijomah, Childe & Chris, 2004). Traditionally, remanufacturing supply chains have been concentrated in developed economies, but developing countries have become faster-growing markets in recent years due to their potential for competitive economic gains. The increasing involvement of multinational enterprises, liberalization in investment and trade policies, and lower transportation costs brought by technological development present strong incentives for original equipment manufacturers (OEMs) to operate remanufacturing supply chains internationally and engage in developing economies. A clear example of the recognition of such a fast-growing local market is how many multinational corporations (MNCs) are now actively outsourcing remanufacturing operations into Asia, which accounts for 25 percent of global consumption (Lu, Goh, Garg & De Souza, 2014). However, recent international economic and political frictions, such as the US–China trade war, Brexit, and trade sanctions, have significantly impacted the global economy and cross-border supply chains, including those of remanufacturing.

This research is particularly motivated by the impact of the recent US–China trade war on the cross-border remanufacturing industry. Following a series of trading and tariff skirmishes occurring since the 1990s, recent incidents such as the US–China trade war and Brexit are merely a fraction of the trend of deglobalization, which implies even greater uncertainties and risks caused by pro-

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tectionism in the form of trade barriers (Bello, 2004; Ramrattan & Szenberg, 2019; UNCTAD, 2020), which can ultimately lead to a long-lasting negative influence on international supply chains. In March 2018, the Office of the United States Trade Representative (USTR) imposed 25 percent punitive tariffs on more than 1,300 goods imported from China. In response, China imposed its own 25 percent tariffs on 545 categories of US products worth $34 bn. The high fluctuation of trade tariffs poses serious uncertainties and incurs large extra costs to exporting and in turn affects the costs of remanufactured products. Meanwhile, the Chinese government has been continuously enacting preferential tax regulations to attract foreign investment for the purpose of promoting the local remanufacturing industry and China's economy (European Union Chamber of Commerce in China, 2018). Facing increasing complexity and uncertainty in both global trade and capital flow, OEMs are found to be in a position to re-evaluate their costs and benefits and make careful decisions regarding their international supply chain strategy. More specifically, for those participating in remanufacturing, it has become a conundrum to choose between into investing in-house remanufacturing in destination countries and outsourcing to third-party remanufacturers (TPRs) in those local areas.

Thus, it has become important and necessary that MNCs' cooperate decision-makers, as well as other stakeholders, including policy makers, conduct thorough coinvestigations of taxation in such contexts to make well-informed strategic deployments. This is particularly important, as the coexistence of both economic and social sustainability can be achieved through global remanufacturing. However, research on the role of taxes and tariffs in cross-border remanufacturing has not kept pace. Despite the explicit consensus on the negative effects of taxes and tariffs from economic studies (Carbaugh, 2011; Samuelson & Nordhaus, 2005), in the realm of business decision-making, the literature and theory concerning tax regulations are largely missing, especially for those related to cross-border remanufacturing supply chains. While factors such as labour costs, material costs, lead time, and transportation costs are recognized and considered in the extant research and practical business decision-making, the impact of tax and tariff regulations on establishing and managing international supply chains has not received much attention (Shunko & Gavirneni, 2007). There are few recent exceptions; for example, Wang, Gao and Mukhopadhyay (2016) and Shunko, Do and Tsay (2014), Wang, Hubacek, Feng, Wei and Liang (2016) analysed offshore production decisions considering taxation; Nagurney, Besik and Dong (2019) applied a price network equilibrium model to a France-US dairy case and touched on consumer welfare. However, none of these attempts comes close to addressing the complex situation that cross-border remanufacturing often entails.

Hence, there is a pressing need to address the lack of understanding in the extant literature on the impact of tariffs and corporate taxes on remanufacturing models. As remanufacturing can have positive impacts on the economic, environmental, and societal pillars of sustainability, it is also of great significance, from a practical perspective, to examine the impact of international trade tariff and tax rate differentials on a firm's cross-border remanufacturing strategy. To address the above gaps, this research studies the cross-border remanufacturing decisions of OEMs in consideration of tax and tariff regulations, developing a model for cross-border remanufacturing supply chains with OEM production and cross-border remanufacturing. The paper revisits the different effects of remanufacturers' corporate taxes and import tariffs by comparing two types of cross-border remanufacturing models: OEM remanufacturing and TPR remanufacturing (a foreign OEM manufactures new products in its home country and then remanufactures them through either its in-house remanufacturing facilities or a TPR, both locally in the destination country). This work presents an analysis of and answers to the research question (with its two subquestions) stated below:

How do international trade tariff and tax rate differential policies affect OEMs' cross-border remanufacturing decisions and importing country's social welfare?

- How are OEMs' optimal price, sales volume, and total profits for new and remanufactured products affected by international trade tariffs and tax rate differentials?
- How is the importing country's social welfare affected under the two different remanufacturing models?

To the best of our knowledge, this is the first study to incorporate cooperate tax and tariff factors into decision-making concerning remanufacturing production planning. In exploring the two models of cross-border remanufacturing considering the real-world complexity of international trade where sales tax and import tariffs are levied on them, our findings make a meaningful contribution to the remanufacturing literature and practice. We not only analysed and compared the two possible revenues and pricing strategies for an OEM producing both new and remanufactured products but also assessed the social value created under the different models of remanufacturing. We find that cross-border and third-party remanufacturing are not always more costly than in-house remanufacturing by the OEM. Instead, under different tax rate ranges, either the OEM or TPR can achieve economic and social benefits in the host/destination country. Our findings have important and timely implications for OEM executives considering investing in cross-border remanufacturing and for governments evaluating the impact of tariffs on the remanufacturing industry and on social welfare.

The remainder of this paper is organized as follows. The next section presents a literature review with an emphasis on the key factors influencing a business's decision regarding cross-border remanufacturing. Section Three presents the assumptions and notations used, followed by the models this study proposes. Section Four analyses the models and presents the numerical results. The last section concludes the paper by highlighting managerial insights and proposing directions for future research. Full mathematical proofs are provided as appendices.

2. Literature review

2.1. Decision-making for remanufacturing

Remanufacturing has attracted considerable attention from academia as well as other stakeholders, including industry decision-makers and policy makers, for its potential benefits. Economically, as a natural low-cost alternative to all-new manufacturing, remanufacturing creates potential for higher profits, which has been witnessed across industries including automotive parts, machine tools, and consumer electronics (Atasu, Guide & Van Wassenhove, 2010; Zhu & Tian, 2016). It is also often associated with environmental and social benefits, such as decreased pollution and solid waste (Zhou, Wang, Bai & Wu, 2014), reduced carbon emissions, and increased employment opportunities (Diallo, Venkatadri, Khatab & Bhakthavatchalam, 2017; Steinhilper et al., 2011). Therefore, legislation and government policies have been increasingly inclined towards green production through means such as remanufacturing. For example, the Waste Electrical and Electronic Equipment (WEEE) directive of the European Union requires all OEMs to take responsibility for the entire product lifecycle, especially for handling the collection and recycling of end-of-life (EOL) products (Akyildirim, 2015; Cao et al., 2016; Fleckinger & Glachant, 2010; Ma, Zhao & Ke, 2013). For OEMs, amongst other factors, a major decision to make concerns the strategic deployment of either remanufacturing in-house or outsourcing to a TPR based on cost-revenue analysis (Kumar & Ramachandran, 2016).

The present work is based on the stream of literature on remanufacturing production decisions. Remanufacturing is often a sensible means for companies to achieve better economic and social benefits. However, OEMs may find it difficult to plan, analyse, implement, and consolidate complex remanufacturing business due to a high level of uncertainty (Bulmus, Zhu & Teunter, 2014; Goodall, Rosamond & Harding, 2014). Concerns such as customer acceptance of remanufactured products (Abdulrahman, Subramanian, Liu & Shu, 2015), limited capability in reverse logistics, a loss of intellectual property (Hartwell & Marco, 2016), and brand erosion (Lund, 1985; Seitz, 2007) complicate an OEM's selection of a remanufacturing model. Using a game theoretic framework for collection and remanufacturing, various collection strategies considering different channel structures have been examined (Atasu, Özdemir & Van Wassenhove, 2012; Savaskan, Bhattacharya & Van Wassenhove, 2004). For a single-manufacturer, single-retailer supply chain structure, it was found that the reverse channel with retailer's collection is optimal (Savaskan et al., 2004). Savaskan and Van Wassenhove (2006) further extend this to a multiple retailer setting. In the same vein, He, Wang, Yang, He and Jiang (2019) show customer perceptions of the inconvenience to different channels and investigate the channel structure of a competitive collection to achieve optimal recovery efficiency. As one of most important aspects of a firm's market segmentation strategy in the remanufacturing context, the effect of salesforce incentives on the profitability of remanufacturing has been considered (Kovach, Atasu & Banerjee, 2018). Meanwhile, the economic and social efficiencies of various policy and regulations instruments have been investigated in a number of studies, such as those on carbon tax policies (Meng, Yao, Nie, Zhao & Li, 2018), carbon emission cap-and-trade policies (Liu, Holmbom, Segerstedt & Chen, 2015), and take-back legislation (Zhou, Zheng & Huang, 2017). The policy theory behind reducing emissions is based on internalizing externalities, having a direct influence on a firm's financial and budgeting management (Chen & Tseng, 2011).

Many studies on remanufacturing production decisions are conducted from the cost minimum or revenue maximization perspective. If an OEM intends to carry out remanufacturing by itself, such investment becomes a function of committed funds, exchange rates, inflation, and other future uncertainties. Therefore, it is important that corporates carefully compare and assess viability at all levels of the remanufacturing process, from strategic planning to the operational stage, to make rational and well-informed decisions. From a cost perspective, since new and remanufactured products may share material costs, it is important to analyse both to optimize costs. The majority of costs incurred in remanufacturing arise from the additional resources required to return a product to its original performance capabilities. Such costs include expenses related to direct production, quality assurance, and the establishment of a reverse logistics network necessary to acquire used products (i.e., cores) (Matsumoto, 2010). Various studies have identified how different factors of each process may influence a firm's remanufacturing profits and production costs. For example, Sundin and Lindahl (2008) find that product design can have a significant impact on the cost of remanufacturing processes. This result is confirmed by Jun, Cusin, Kiritsis and Xirouchakis (2007), who discovered that the difference between the condition of returned used products and the required final quality level of remanufacturing has a significant effect on the overall cost. Researchers have also investigated how lot-sizing and inventory control issues affect the planning of remanufacturing production (Schulz, 2011; Teunter, Laan & Vlachos, 2004). If an OEM needs to export new products to the host country, trade barriers set by the importing country, such as tariffs or quotas, will affect whether the firm directly invests in the country because the barriers pose a cost increment. In fact, taxation is often recognized as one of the most important factors affecting the success of a firm conducting cross-border trade.

2.2. Taxation as a major cost of remanufacturing

The design and management of a global supply chain considering various types of taxation (e.g., tariffs, value added taxes, and income taxes) have been studied in the operations management literature. Zhen (2014) adopts a cross entropy-based algorithm to study an integrated optimization of outsourcing and production decisions in the context of the global supply chain and China's export-orientated tax policies. Similarly, Xiao, Hsu and Hu (2015) employ a news vendor model to study the optimal global production decision under the effects of tax cross-crediting. However, these studies fail to consider the global remanufacturing contexts where more complex supply chain processes occur.

OEMs are widely motivated to engage in remanufacturing operations at an international scale (Ferguson & Toktay, 2006; Martin, Guide & Craighead, 2010). Given the remarkable increase in the volume of goods returned in Asia, many MNCs have started or are considering operating remanufacturing activities in local regions. Under such a cross-border remanufacturing operation strategy, new products will first be exported to destination countries for sale, after which the EOL products from these products will be remanufactured. There are two means for an OEM to realize remanufacturing: applying and managing the remanufacturing operations itself or outsourcing to a TPR. Setting up localized in-house remanufacturing facilities means that the OEM needs to make overseas investments, which undoubtably is a major strategic decision. Therefore, in addition to the common factors determining an OEM's decision regarding remanufacturing (e.g., volume fluctuation of returned core components and customers' reception of remanufactured products), it must also consider externalities arising from foreign direct investment (FDI) in the host country, such as taxation (Zhou, Wang & McCalley, 2011). Concerning barriers and uncertainties, some prefer the alternative strategy and outsource their remanufacturing to a TPR.

Empirically, various factors, such as costs, market size, culture, and technology, have been considered in FDI studies (Barkema, Bell & Pennings, 1996; Chung & Alcácer, 2002; Tong & Walter, 1980), and local corporate taxes are recognized as a key factor shaping an OEM's corporate decisions on committing FDI (Zhou et al., 2011). As Webber (2011) highlights, tax payment is one of the most significant expenses for many businesses; hence, the management of global supply chains should appropriately take the impacts of taxation into consideration (Hsu & Zhu, 2011). Some developing countries may reduce corporation tax rates to attract foreign investment and stimulate their local economies (Blöchliger & Campos, 2011). Another contributing factor is the existence of tariffs and the uncertainty of other international barriers that jeopardize cross-border trade (Carbaugh, 2011; Samuelson & Nordhaus, 2005), resulting in higher risks and reduced incentives for many OEMs to remanufacture by themselves in their home countries.

Furthermore, tax payments not only affect the cost of remanufacturing but also have social implications for local communities, as they are a source for funding public goods (e.g., education, public health care, and public transport) (Freedman, 2003; Slemrod, 2004). The mutual dependence of corporations and society implies that both business decisions and social policies must follow the principle of shared value (Porter & Kramer, 2006). However, to the best of the authors' knowledge, there is no study examining FDI in the remanufacturing context or investigating remanufacturing with specific consideration of tax factors.

2.3. Summary

Numerous studies carried out in a domestic context have confirmed that remanufacturing can be profitable for OEMs (Guide, Harrison & Van Wassenhove, 2003; Hammond, Andrews, Mott & Woodrow, 1998), but most research asserts that OEMs should remanufacture by themselves and avoid third-party remanufacturing (Debo, Toktay & Van Wassenhove, 2005; Ferguson & Toktay, 2006; Ferrer & Swaminathan, 2010), as the entry of TPRs into the market could hurt OEMs, and the remanufactured goods can invade and compete with new products (Matsumoto, 2010). On the other hand, some have observed that with government intervention, TPR remanufacturing could benefit OEMs. Webster and Mitra (2007) find that an OEM is better off competing with TPRs than operating as a monopolist under government interventions, including extended producer responsibility for the takeback and disposal of EOL products. Many studies have been conducted to identify the key attributes that impact remanufacturing viability for remanufacturing investment decisions. Some focus on cost–benefit analyses or optimization issues to support their feasibility assessments. However, these studies are typically based on simple models of remanufacturing operations, ignoring the basic constraints on remanufacturing supplies, and fail to reflect the real complexity at play in practice. We contribute to this emerging stream of literature by investigating the profitability of remanufacturing under fundamental supply-loop constraints such as various tax regulations of the importing country and market conditions for remanufactured products. We also explore how these constraints interact with each other and with the cost structure of a production system within remanufacturing. The results of this study shed light on the impact of international tariffs on OEMs' decision to implement remanufacturing operations, which has not yet been investigated in the previous remanufacturing literature.

3. Models

3.1. Assumptions and notations

This paper assumes that a cross-border remanufacturing supply chain consists of an OEM from the exporting country and a remanufacturer locally based in the destination country that is either the OEM itself or a TPR. In the first period, the OEM manufactures a new product in its home country, incurring unit cost c_n (c_n covers all costs for a new product, including manufacturing and cross-border transportation costs), and then exports to the destination country. The importing country charges unit product tariff t_n according to its bilateral international trade agreement. The new product is sold at price p_n^i to customers in the destination market. In the second period, the OEM either conducts remanufacturing itself with unit cost c_{Or} or authorizes a TPR to remanufacture with unit cost c_{Rr} (c_{Or} or c_{Rr} covers all costs for remanufacturing the product, including recycling and production costs) in the host/importing country, where the corporate sales tax rates charged by the local government are differentiated for foreign investors and local companies. The OEM charges licence fee h for authorizing the TPR to remanufacture. Following this pattern, the OEM and TPR maximize their profits by choosing optimal prices (p_n and p_r) and quantities of new and remanufactured products (q_n and q_r) simultaneously. The two-period production decision frameworks under the corporate sales tax and international trade tariff policy are provided in Figs. 1 and 2.

On the demand side, it is assumed that the potential market size is a, and each consumer buys at most one unit of either new or remanufactured products, whichever offers the most utility as long as the net utility is nonnegative. The lower valuation of a remanufactured product is empirically proven by Guide and Li's (2010) previous study. In other words, consumers' willingness to pay for the remanufactured product is discounted to a fraction. We derive the demand functions from consumers' utility functions (see Appendix A).

Given the quantities of new and remanufactured products, q_n and q_r, the market-clearing prices for the new and remanufactured products are as follows:

$$p_n = a - q_n - \rho q_r \tag{1}$$

$$p_r = \rho(a - q_n - q_r) \tag{2}$$

These linear inverse demand functions are originally derived from Ferrer and Swaminathan's (2006) research and have been widely adopted in the literature on closed-loop supply chain management (Ferguson & Toktay, 2006; Wu & Zhou, 2019; Zhou, Xiong, Li, Xiong & Beck, 2013). Following common assumptions adopted in the literature on closed-loop supply chain management (Atasu, Sarvary & Van Wassenhove, 2008; Subramanian, Ferguson & Toktay, 2013; Wu & Zhou, 2019), this model assumes that consumers' willingness to pay for new product θ is uniformly distributed over $[0,\ a]$. Consistent with the findings of previous studies (Debo et al., 2005), primary consumers will discount the willingness to pay for the remanufactured product as fraction ρ ($0 \le \rho \le 1$); thus, consumers' willingness to pay for the remanufactured product is $\rho\theta$.

Similar to Debo et al. (2005) and Ferrer and Swaminathan (2010), we assume that the remanufacturing cost subsumes the cost of all remanufacturing-related activities. Referring to the consensus in the relevant literature that remanufacturing is typically a natural low-cost alternative to traditional manufacturing, it is assumed that the cost of a remanufactured product is accepted as less than that of a new product (Atasu et al., 2008; Zou, Wang, Deng & Chen, 2016). It is assumed that all players are risk neutral and profit seeking and have common knowledge of demand and cost information. Additionally, it is assumed that $0 < c_{Rr} < c_{Or} < c_n$. In practice, the remanufacturing sector is largely dominated by TPRs in many industries (Örsdemir, Kemahlıoğlu-Ziya & Parlaktürk, 2014). It is rare for an OEM to resort to remanufacturing. In fact, according to a database of over 2000 remanufacturing firms, OEMs constitute only 6% (Hauser & Lund, 2008). The remanufacturing process is susceptible to disruption in that EOL products are collected from consumers, and thus the timing, quantity, and quality of returns are highly uncertain Ferguson, Guide, Koca and Souza (2009); Reimann (2016); Wei, Tang and Liu (2015). The primary business of TPRs is to remanufacture used products of major OEMs. In general, manufacturing is a global sector, while remanufacturing is a local industry. Small local firms naturally seize remanufacturing opportunities more easily since they are located closer to both the supply of used products and final demands. In addition, TPRs can remanufacture used products from multiple brands, enjoying the advantage of a scaled economy. TPRs that carry out remanufacturing may enjoy better expertise in forecasting and managing remanufacturing costs than competing OEMs. We posit that TPRs have lower remanufacturing costs because of economies of scale (Savaskan et al., 2004). Although in the model, we limit our attention to a situation of constant unit remanufacturing costs for TPRs and OEMs, this assumption reflects the current practice in the reality and denotes that chain members have incentives to undertake remanufacturing activities and make efforts to increase the supply of used products from the market (Huang & Wang, 2017).

To examine the impacts of TPRs without the distraction of the initial and terminal time period effect, consistent with the remanufacturing literature (Ovchinnikov, 2011; Subramanian et al., 2013), the model is developed under a steady state period, which implies that all players make the same decisions in every period after a

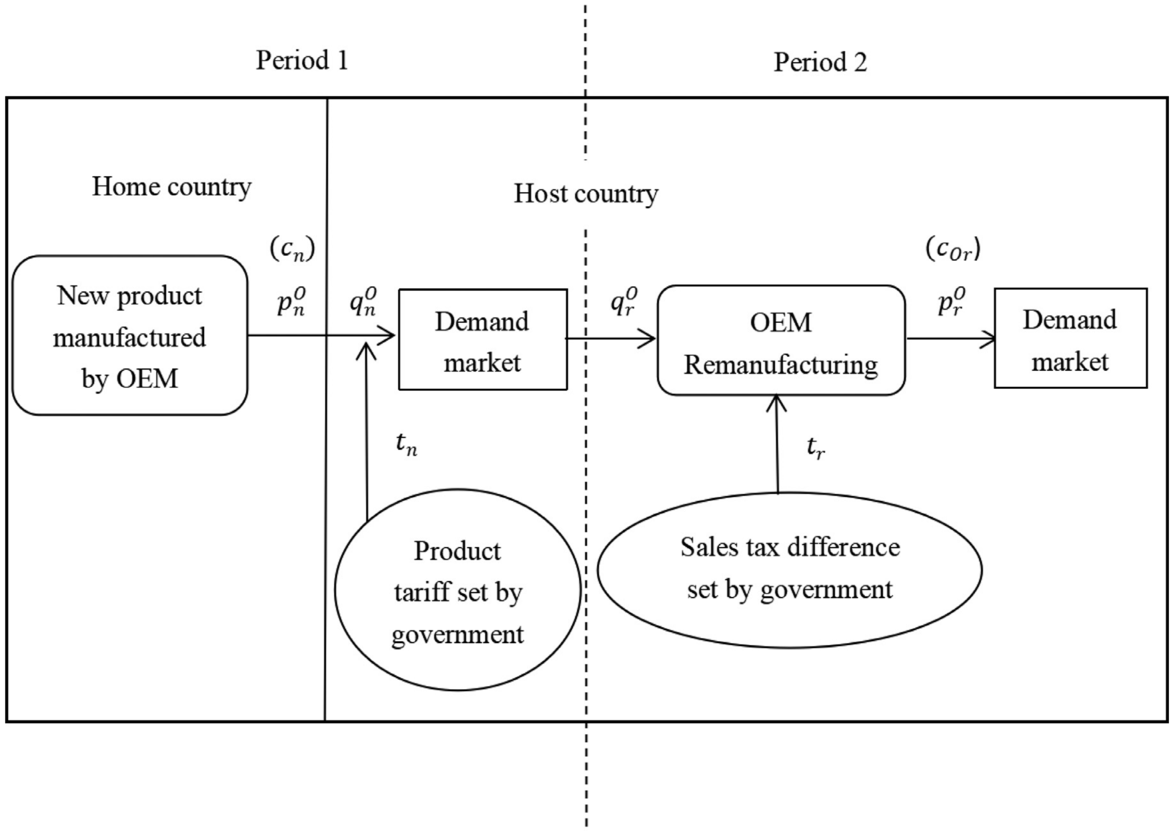

Fig. 1. Structure of the OEM-remanufacturing model (source: authors).

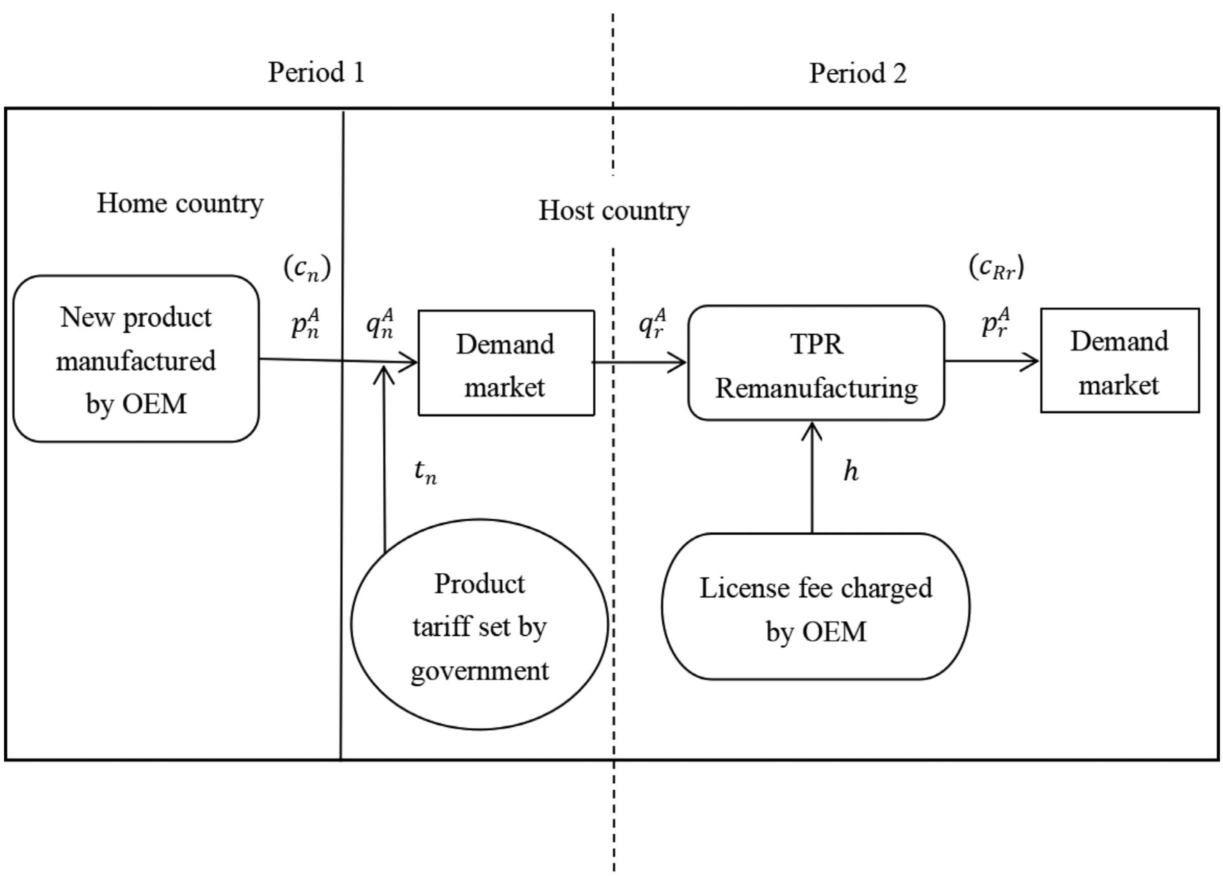

Fig. 2. Structure of the TPR remanufacturing model (source: authors).

Table 1
Variable symbols and descriptions (source: authors).

Symbol	Definition
i	$i \in \{O, A\}$ refers to the OEM-remanufacturing model or TPR- remanufacturing model
p_n^i	The selling price of a new product set by the OEM
P_r^i	The selling price of a remanufactured product set by the OEM or TPR
q_n^i	The sales volume of the new product
q_r^i	The sales volume of the remanufactured product
c_n	The unit cost of the new product
c_{Or}	The unit cost of the remanufactured product produced by the OEM
c_{Rr}	The unit cost of the remanufactured product produced by the TPR
t_n	The unit product import tariff set by the government in the importing country
t_r	The difference in sales tax between foreign investment and local production
h	The unit licence fee set by the OEM
a	The total size of the importing country's consumer market
θ	The consumers' willingness to pay for the new product
ρ	The consumers' acceptance of the remanufactured product
π_O^i	The profit of the OEM
π_R^i	The profit of the TPR
CS_{in}	The consumer surplus of new products in the importing country
CS_{ir}	The consumer surplus of remanufactured products in the importing country
CS_i	The total consumer surplus of the importing country
G_i	The government taxation of the importing country
w_i	The social welfare of the importing country

ramp up in the first period in an infinite horizon setting. Consequently, it is assumed that $q_r \leq q_n$, where all used products are available for remanufacturing, and the quantity of remanufactured products in the current period is restricted by the quantity of new products in the previous period, which equals the new product quantity in the current period.

Additionally, the government of the host country can influence the OEM's global remanufacturing decisions as its tax policy shifts, which includes unit product quantitative tariff t_n and the difference in the sales tax between foreign investment and local production t_r. It is assumed that $t_n > 0$, but t_r may be negative depending on the domestic government's willingness to attract foreign investment. When the government wants to attract foreign investment and offers tax preference to the OEM, $t_r < 0$. When the government wants to protect local remanufacturing companies, $t_r > 0$.

This paper also offers insights for the importing country by presenting analyses of its social welfare including consumer surplus, government taxation, and domestic companies' profits. ($w_i = CS_i + G_i + \pi_R^i$). Consumer surplus ($CS_i$, $CS_i = CS_{in} + CS_{ir}$) can be computed as the area under the demand curve above the market price (Jena, Ghadge & Sarmah, 2017; Li & Zuo, 2017). Referring to the literature, consumer surplus can be calculated by $CS_{in} = \int_0^{q_n^{i*}} p_n \partial q_n - p_n^{i*} q_n^{i*}$ and $CS_{ir} = \int_0^{q_r^{i*}} p_r \partial q_r - p_r^{i*} q_r^{i*}$, where $p_n = a - q_n - \rho q_r$ and $p_r = \rho(a - q_n - q_r)$ are assumed.

Subject to tax policy, the optimal strategy of a cross-border remanufacturing supply chain should consider the following aspects or 'trade-offs': (1) Is an ORM's in-house remanufacturing or TPR remanufacturing more profitable? (2) Which model provides better social welfare to the destination country?

The symbols and definitions of variables included in this model are summarized in Table 1.

3.2. Production decision model with a two-period horizon

3.2.1. OEM-Remanufacturing strategy model

In the OEM-remanufacturing model, as a single oligopoly, a foreign OEM produces a new product in its home country and then exports it to the importing country and conducts remanufacturing itself. The OEM completely monopolizes the importing country's market, whose profit comes from sales of the new and remanufactured products. The OEM may independently choose the optimal price and quantity of the new and remanufactured products to maximize its own profit. All proofs are provided in Appendix B.

According to the assumptions, the demands can be expressed as follows:

$$q_n^O = \frac{(1-\rho)a - p_n + p_r}{1-\rho} \tag{3}$$

$$q_r^O = \frac{\rho p_n - p_r}{\rho(1-\rho)} \tag{4}$$

The OEM determines the optimal price and quantity responses to maximize its own profit as follows:

$$\underset{p_r^O, p_n^O}{Max} \pi_O^O = \left(p_n^O - c_n - t_n\right) q_n^O + \left(p_r^O - c_{Or} - t_r\right) q_r^O \tag{5}$$

This is also expressed as follows:

$$\underset{p_r^O, p_n^O}{Max} \pi_O^O = \left(p_n^O - c_n - t_n\right) \frac{(1-\rho)a - p_n^O + p_r^O}{1-\rho} + \left(p_r^O - c_{Or} - t_r\right) \frac{\rho p_n^O - p_r^O}{\rho(1-\rho)}$$

The profit function of π_O^O is concave in p_r^O and p_n^O, implying the existence of a unique optimal solution (see Appendix A).

Theorem 1. *In the OEM-remanufacturing model, the optimal price and sales volume of the new product and remanufactured product are as follows:*

$$p_n^{O*} = \frac{c_n + t_n + a}{2} \tag{6}$$

$$p_r^{O*} = \frac{c_{Or} + t_r + \rho a}{2} \tag{7}$$

$$q_n^{O*} = \frac{-c_n + c_{Or} - t_n + t_r + (1-\rho)a}{2(1-\rho)} \tag{8}$$

$$q_r^{O*} = \frac{\rho c_n - c_{Or} + \rho t_n - t_r}{2\rho(1-\rho)} \tag{9}$$

The OEM's optimal total profit function under this model is as follows:

$$\pi_O^{O*} = \left(p_n^{O*} - c_n - t_n\right) \frac{(1-\rho)a - p_n^{O*} + p_r^{O*}}{1-\rho}$$

$$+\left(p_r^{O*}-c_{Or}-t_r\right)\frac{\rho p_n^{O*}-p_r^{O*}}{\rho(1-\rho)}$$

After the solution is substituted, it can be expressed as follows:

$$\pi_O^{O*}=\frac{(-c_n-t_n+a)[-c_n+c_{Or}-t_n+t_r+(1-\rho)a]}{4(1-\rho)}+\frac{(c_{Or}+t_r-\rho a)(-\rho c_n+c_{Or}-\rho t_n+t_r)}{4\rho(1-\rho)} \tag{10}$$

$$s.t.\begin{cases} t_n\geq 0\\ p_n^{O*}\geq 0(t_n\geq -a-c_n)\\ p_r^{O*}\geq 0(t_r\geq -c_{Or}-\rho a\ )\\ q_n^{O*}\geq 0(t_r\geq t_n+c_n-c_{Or}-(1-\rho)a)\\ q_r^{O*}\geq 0(t_r\leq \rho t_n+\rho c_n-c_{Or})\\ p_n^{O*}-c_n-t_n\geq 0(t_n\leq -c_n+a)\\ p_r^{O*}-c_{Or}-t_r\geq 0(t_r\leq \rho a-c_{Or})\\ p_n^{O*}\geq p_r^{O*}(t_r\leq t_n+c_n-c_{Or}+(1-\rho)a)\\ q_r^{O*}\ \leq\ q_n^{O*}\left(t_r\geq \frac{2\rho c_n-(1+\rho)c_{Or}+2\rho t_n-\rho(1-\rho)a}{1+\rho}\right)\end{cases} \tag{11}$$

The constraint condition can be simplified to

$$s.t.\begin{cases} t_n\geq 0\\ t_r\geq -c_{Or}-\rho a\left(p_r^{O*}\geq 0\ \right)\\ t_r\geq t_n+c_n-c_{Or}-(1-\rho)a\left(q_n^{O*}\geq 0\right)\\ t_r\leq \rho t_n+\rho c_n-c_{Or}\left(q_r^{O*}\geq 0\right)\\ t_n\leq -c_n+a\left(p_n^{O*}-c_n-t_n\geq 0\right)\end{cases} \tag{12}$$

Finally, the social welfare of the importing country is calculated as previously represented in the assumption:

$$CS_O=CS_{On}+CS_{Or}=\frac{\left[(1-\rho)a+p_r^{O*}-p_n^{O*}\right]q_n^{O*}}{2}+\frac{\left[\rho p_n^{O*}-p_r^{O*}\right]q_r^{O*}}{2}=\frac{\rho\ k1^2+\ k2^2}{8\rho(1-\rho)} \tag{13}$$

$$G_O=t_nq_n^{O*}+t_rq_r^{O*}=\frac{\rho t_n\ k1-t_r\ k2}{2\rho(1-\rho)} \tag{14}$$

$$w_O=CS_O+\ G_O+0=\frac{4\rho t_n\ k1-4t_r\ k2+\rho\ k1^2+\ k2^2}{8\rho(1-\rho)} \tag{15}$$

where $k1=\ c_{Or}-c_n-t_n+t_r+(1-\rho)a$ and $k2=c_{Or}+t_r-\rho c_n-\rho t_n$.

Propositions 1 and 2 are derived directly from Theorem 1.

Proposition 1. *Under the OEM-remanufacturing model, the optimal selling price of new product p_n^{O*} has a positive relationship with import unit tariff t_n. With the increase in the unit tariff, the OEM needs to increase the optimal selling price of the new product. In contrast, the optimal selling price of remanufactured product p_r^{O*} has a positive relationship with t_r and no relationship with t_n. The increase in the unit difference of sales tax adds an extra cost to the remanufactured product, so the optimal selling price of the remanufactured product needs to be raised.*

Proposition 2. *Under the OEM-remanufacturing model, the optimal sales volume of new product q_n^{O*} and the optimal sales volume of remanufactured product q_r^{O*} are affected by correlation coefficient $\frac{1}{2(1-\rho)}$. $q_n^{O*}$is negatively affected by unit tariff $t_n$but positively related to t_r, while the opposite is true for q_r^{O*}.*

Remanufacturing involves a typical multiple-period problem. With an increase in the unit tariff, demand cannibalization between new and remanufactured products leads to a reduction in the sales of new products when the sales volume for remanufactured products increases. In addition, the more consumers are willing to pay for the remanufactured product, the greater the impact of the unit tariff on the optimal sales volume of the new and remanufactured products becomes.

The profit of the OEM decreases with an increase in the unit tariff. The OEM loses more, and the importing government earns more with the higher tariff. This reflects the income transfer effect of the tariff. The profit of the OEM decreases with the increase in the unit difference of sales tax, the total cost of the OEM increases, and the profit space decreases with the increase in the unit difference of sales tax (see Appendix B).

3.2.2. TPR-Remanufacturing strategy model

Under the TPR-remanufacturing model, the TPR obtains technical authorization from the OEM to remanufacture. The OEM can gain income from technical authorization, while the TPR has a comparative cost advantage as discussed above.

The OEM and TPR determine the optimal price and quantity responses to maximize their own profits as follows:

$$\underset{p_n^A,h}{Max}\pi_O^A=\left(p_n^A-c_n-t_n\right)q_n^A+hq_r^A \tag{16}$$

$$\underset{p_r^A}{Max}\pi_R^A=\left(p_r^A-c_{Rr}-h\right)q_r^A \tag{17}$$

The profit function of π_R^A is concave in p_r^A, and the profit function of π_O^A is concave in p_n^A and h, implying the existence of a unique optimal solution. Please see Appendix A for more details.

Theorem 2. *In the TPR-remanufacturing model, the optimal sales prices and optimal sales volumes of the new product and remanufactured product and the optimal patent unit licence fee are, respectively:*

$$p_n^{A*}=\frac{c_n+t_n+a}{2} \tag{18}$$

$$p_r^{A*}=\frac{\rho c_n+c_{Rr}+\rho t_n+2\rho a}{4} \tag{19}$$

$$q_n^{A*}=\frac{-(2-\rho)c_n+c_{Rr}-(2-\rho)t_n+(2-2\rho)a}{4(1-\rho)} \tag{20}$$

$$q_r^{A*}=\frac{\rho c_n-c_{Rr}+\rho t_n}{4\rho(1-\rho)} \tag{21}$$

$$h^*=\frac{-c_{Rr}+\rho a}{2} \tag{22}$$

Proposition 3. *In the TPR-remanufacturing model, the optimal selling price of new product p_n^{A*} and the optimal selling price of remanufactured product p_r^{A*} are linear increasing functions of unit tariff t_n. The former increases faster than the latter. $\frac{\rho}{4}$ is the correlation coefficient of the latter, and its absolute value increases with the increase in consumer acceptance of remanufactured product ρ.*

With an increase in unit tariffs, the optimal selling price of the new product rises, which reflects the price effect of the tariff. The impact of the unit tariff on the optimal sales volume of the new and remanufactured products increases with increasing consumer acceptance of remanufactured products. However, unlike Proposition 1, according to the optimal selling price of the remanufactured product is not related to unit tariffs under the OEM-remanufacturing model, the optimal selling price of the remanufactured product rises with the increase in unit tariffs under the TPR-remanufacturing model.

Proposition 4. *Under the TPR remanufacturing model,*

- The optimal sales volume of new product q_n^{A*} is negatively affected by t_n with correlation coefficient $\frac{-(2-\rho)}{4(1-\rho)}$ but positively affected by ρ.

- The optimal sales volume of remanufactured product q_r^{A*} is positively related to t_n with correlation coefficients $\frac{1}{4(1-\rho)}$ and ρ.

With an increase in unit tariffs, the selling price of the new product increases such that the demand for the new product decreases and the demand for the remanufactured product increases, reflecting the trade effect and production effect of the tariff, respectively. Here, remanufactured products result in a cannibalization effect on new products. The impact of unit tariffs on the optimal sales volume of the remanufactured product increases as consumer acceptance of the remanufactured product increases.

The optimal profit expressions for the OEM and TPR are as follows:

$$\pi_O^{A*} = \left(p_n^{A*} - c_n - t_n\right) q_n^{A*} + h^* q_r^{A*}$$

$$\pi_R^{A*} = \left(p_r^{A*} - c_{Rr} - h^*\right) q_r^{A*}$$

After substitution, the specific expressions of the optimal profits of the OEM and TPR are as follows:

$$\pi_O^{A*} = \frac{(a - c_n - t_n)[(\rho-2)c_n + c_{Rr} + (\rho-2)t_n + (2-2\rho)a]}{8(1-\rho)} - \frac{(c_{Rr} - \rho a)(\rho c_n - c_{Rr} + \rho t_n)}{8\rho(1-\rho)} \tag{23}$$

$$\pi_R^{A*} = \frac{(\rho c_n - c_{Rr} + \rho t_n)^2}{16\rho(1-\rho)} \tag{24}$$

$$s.t.\begin{cases} t_n \geq 0 \\ p_n^{A*} \geq 0 (t_n \geq -c_n - a) \\ p_r^{A*} \geq 0\left(t_n \geq \frac{-\rho c_n - c_{Rr} - 2\rho a}{\rho}\right) \\ q_n^{A*} \geq 0\left(t_n \leq \frac{-(2-\rho)c_n + c_{Rr} + 2(1-\rho)a}{2-\rho}\right) \\ q_r^{A*} \geq 0\left(t_n \geq \frac{c_{Rr} - \rho c_n}{\rho}\right) \\ h^* \geq 0(\rho a - c_{Rr} > 0) \\ p_n^{A*} - c_n - t_n \geq 0 (t_n \leq a - c_n) \\ p_r^{A*} - c_{Rr} - h^* \geq 0\left(t_n \geq \frac{c_{Rr} - \rho c_n}{\rho}\right) \\ p_n^{A*} \geq p_r^{A*}\left(t_n \geq \frac{c_{Rr} - (2-\rho)c_n - 2(1-\rho)a}{2-\rho}\right) \\ q_r^{A*} \ \leq \ q_n^{A*}\left(t_n \leq \frac{-\rho(3-\rho)c_n + (1+\rho)c_{Rr} + 2\rho(1-\rho)a}{\rho(3-\rho)}\right) \end{cases} \tag{25}$$

The constraints can be simplified to

$$s.t.\begin{cases} t_n \geq 0 \\ t_n \leq \frac{-(2-\rho)c_n + c_{Rr} + 2(1-\rho)a}{2-\rho}\left(q_n^{A*} \geq 0\right) \\ t_n \geq \frac{c_{Rr} - \rho c_n}{\rho}\left(q_r^{A*} \geq 0, \ p_r^{A*} - c_{Rr} - h^* \geq 0\right) \\ \rho a - c_{Rr} > 0 (h^* \geq 0) \\ t_n \leq a - c_n\left(p_n^{A*} - c_n - t_n \geq 0\right) \end{cases} \tag{26}$$

With an increase in the unit tariff, the profit of the OEM decreases, and the profit of the TPR increases. The exporter and consumers jointly bear the loss caused by the tariff, which reflects the income transfer effect of the tariff (see Appendix B).

Then, the social welfare of the importing country is calculated as previously represented by the following assumption:

$$CS_A = CS_{An} + CS_{Ar} = \frac{\left[(1-\rho)a + p_r^{A*} - p_n^{A*}\right]q_n^{A*}}{2} + \frac{\left[\rho p_n^{A*} - p_r^{A*}\right]q_r^{A*}}{2} = \frac{k3^2 + \rho\ k4^2}{32\rho(1-\rho)} \tag{27}$$

$$G_A = t_n q_n^{A*} = \frac{t_n\ k4}{4(1-\rho)} \tag{28}$$

$$w_A = CS_A + \ G_A + \pi_R^{A*} = \frac{3\ k3^2 + \rho\ k4^2 + 8\rho t_n\ k4}{32\rho(1-\rho)} \tag{29}$$

where $k3 = \rho c_n - c_{Rr} + \rho t_n$ and $k4 = 2a + c_{Rr} - 2c_n - 2t_n - 2\rho a + \rho c_n + \rho t_n$.

To consider the decisions of the OEM and the government of the importing country, a comparative analysis is performed for the two models.

$$s.t.\begin{cases} t_n \geq 0 \\ t_r \geq -c_{Or} - \rho a \ p_r^{O*} \geq 0 \\ t_r \geq t_n + c_n - c_{Or} - (1-\rho)a\left(q_n^{O*} \geq 0\right) \\ t_r \leq \rho t_n + \rho c_n - c_{Or}\left(q_r^{O*} \geq 0\right) \\ t_n \leq \frac{-(2-\rho)c_n + c_{Rr} + (2-2\rho)a}{2-\rho}\left(q_n^{A*} \geq 0\right) \\ t_n \geq \frac{c_{Rr} - \rho c_n}{\rho}\left(q_r^{A*} \geq 0, \ p_r^{A*} - c_{Rr} - h^* \geq 0\right) \\ \rho a - c_{Rr} \geq 0 (h^* \geq 0) \\ t_n \leq -c_n + a\left(p_n^{O*} - c_n - t_n \geq 0, \ p_n^{A*} - c_n - t_n \geq 0\right) \end{cases} \tag{30}$$

To ensure that the two models are valid and comparable, constraint condition (30) is taken into consideration when the analysis is carried out.

3.3. Comparing the OEM and TPR models: price and quantity

We compare the optimal selling prices of the new product under the two strategy models to obtain the effects of t_n and t_r on the difference between them.

$$\Delta p_n = p_n^{A*} - p_n^{O*} = 0 \tag{31}$$

Proposition 5. *The difference in the optimal selling price of the new product between the two models is not associated with t_n and t_r. The optimal selling prices of the new product under the two strategy models are equal.*

This differs from the finding of some previous studies that assert the optimal selling price of new products must be lower when a TPR is authorized to remanufacture. In this study, the two selling prices can be equal; in other words, authorizing third-party manufacturing does not necessarily affect the optimal selling price of the new product.

Similarly, we compare the optimal selling prices of the remanufactured product under two strategy models to obtain the effects of t_n and t_r on the difference between them.

$$\Delta p_r = p_r^{O*} - p_r^{A*} = \frac{2t_r + 2c_{Or} - \rho c_n - c_{Rr} - \rho t_n}{4} \tag{32}$$

Proposition 6. *There exists $c' = \frac{\rho c_n + c_{Rr} - 2c_{Or}}{2}$, for which when $t_r - \frac{\rho t_n}{2} < c'$, the OEM carries out the remanufacturing itself and sells the remanufactured product at a lower price than the TPR. When $t_r - \frac{\rho t_n}{2} \geq c'$, the OEM chooses to authorize the TPR to remanufacture, and the optimal selling price of the remanufactured product produced by the TPR is lower.*

When the unit difference in sales tax set by the importing country is low, the OEM can produce the remanufactured product at a relatively low cost and thus sell it at a relatively low price. When the unit difference in sales tax set by the importing country is relatively large, the OEM prefers authorizing third-party remanufacturing, and the TPR can sell the remanufactured product at a relatively low price.

With the effect on prices analysed, we next consider another important element: quantity. We compare the optimal volumes of the new product and the remanufactured product under two strategy models to obtain the effects of t_n and t_r on the difference between them.

$$\Delta q_n = q_n^{O*} - q_n^{A*} = \frac{-\rho t_n + 2t_r - \rho c_n + 2c_{Or} - c_{Rr}}{4(1-\rho)} \tag{33}$$

$$\Delta q_r = q_r^{O*} - q_r^{A*} = \frac{\rho t_n - 2t_r + \rho c_n - 2c_{Or} + c_{Rr}}{4\rho(1-\rho)} \tag{34}$$

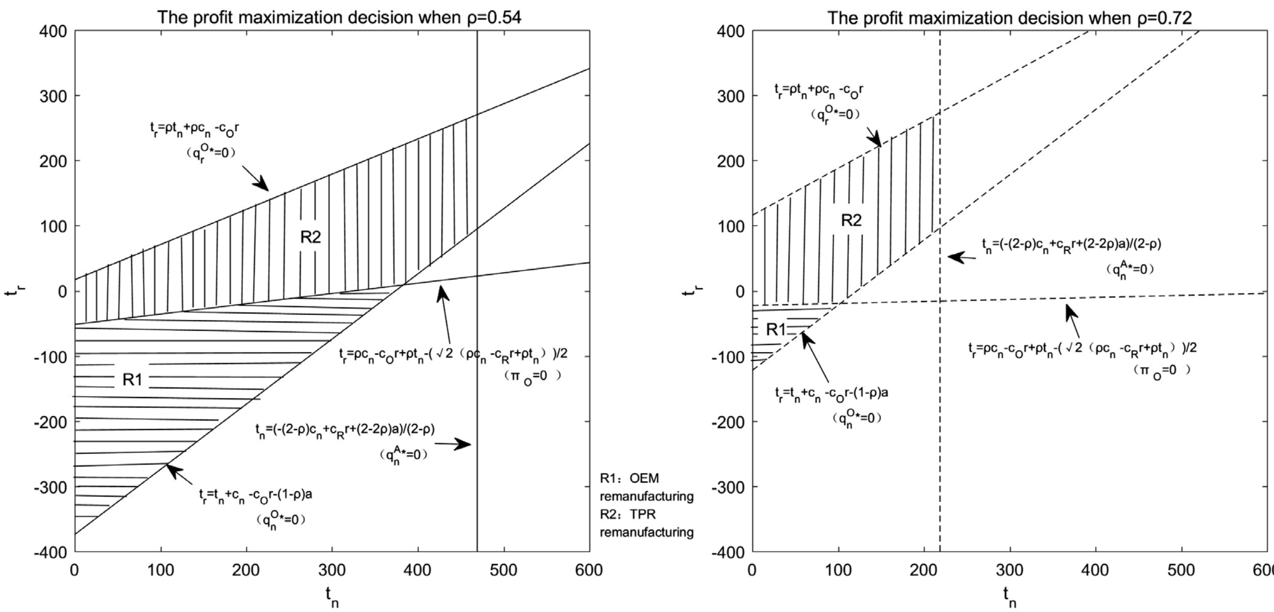

Fig. 3. Profit maximization decision-making of the OEM (source: authors).

Proposition 7. *The difference in the volume of the new product is negatively correlated with t_n and positively correlated with t_r. For the volume of the new product, t_n has less of an influence on OEM remanufacturing than on TPR remanufacturing, while t_r has a greater influence on OEM remanufacturing than on TPR remanufacturing. In contrast, for the volume of the remanufactured product, t_n has a greater influence on OEM remanufacturing than on TPR remanufacturing, and t_r has less of an influence on OEM remanufacturing than on TPR remanufacturing.*

With an increase in t_n and a decrease in t_r, the volume of the new product gradually increases, and the volume of the remanufactured product gradually decreases under the TPR-remanufacturing model than under the OEM-remanufacturing model. Thus, the cannibalization effect that remanufactured products have on new products is greater under the TPR-remanufacturing model with an increase in t_n and a decrease in t_r.

Proposition 8. *There exists $c' = \frac{\rho c_n + c_{Rr} - 2c_{Or}}{2}$ such that*

- When $t_r - \frac{\rho t_n}{2} < c'$, $q_n^{O*} < q_n^{A*}$ and $q_r^{O*} > q_r^{A*}$;
- When $t_r - \frac{\rho t_n}{2} > c'$, $q_n^{O*} > q_n^{A*}$ and $q_r^{O*} < q_r^{A*}$; and
- When $t_r - \frac{\rho t_n}{2} = c'$, the volumes of the new and remanufactured products under the two strategy models are equal.

Proposition 8 proves that the OEM carries out the remanufacturing itself when $t_r - \frac{\rho t_n}{2} < c'$, and the OEM chooses to authorize the TPR to remanufacture when $t_r - \frac{\rho t_n}{2} > c'$. Therefore, the cannibalization effect that the remanufactured product has on the new product is greater when the TPR carries out remanufacturing.

When the unit difference in sales tax set by the importing country is low, it is a better option to pursue the OEM-remanufacturing model, as it offers a cost advantage over the TPR-remanufacturing model, and the OEM will benefit from increasing the volume of the remanufactured product and decreasing the volume of the new product and vice versa.

3.4. Comparing the OEM and TPR models: Profit and social welfare

Profit and social welfare are important to decision making. First, we compare the optimal profits of the OEM under the two strategy models. The OEM's remanufacturing decision is determined by its profit maximization.

$$\Delta\pi_O = \pi_O^{O*} - \pi_O^{A*} = \frac{k5}{8\rho(1-\rho)} \tag{35}$$

where $k5 = 2c_{Or}{}^2 - 4\rho c_{Or}c_n - 4\rho c_{Or}t_n + 4c_{Or}t_r - c_{Rr}{}^2 + 2\rho c_{Rr}c_n + 2\rho c_{Rr}t_n + \rho^2 c_n{}^2 + 2\rho^2 c_n t_n - 4\rho c_n t_r + \rho^2 t_n{}^2 - 4\rho t_n t_r + 2t_r{}^2$.

Proposition 9. *There exists, $t_{r1} = \rho c_n - c_{Or} + \rho t_n - \frac{\sqrt{2}\ (\rho c_n - c_{Rr} + \rho t_n)}{2}$ such that*

When $t_r < t_{r1}$, $\pi_O^{O*} > \pi_O^{A*}$; and
When $t_r > t_{r1}$, $\pi_O^{O*} >< \pi_O^{A*}$.

Proposition 9 indicates that the OEM can make higher profits when carrying out in-house remanufacturing itself. When the unit difference in sales tax is greater than t_{r1}, the OEM's profit is higher when it authorizes the TPR to remanufacture. Here, $t_{r1} = \rho c_n - c_{Or} + \rho t_n - \frac{\sqrt{2}\ (\rho c_n - c_{Rr} + \rho t_n)}{2}$.

With an increase in the unit difference in sales tax, the difference in the optimal profits under these two strategy models decreases. An OEM's profitability and preferred remanufacturing model are affected by the different conditions of the unit tariff and the unit difference in sales tax. When the unit difference in sales tax is low, the OEM benefits from investing in and conducting in-house remanufacturing due to the lower cost. However, when the unit difference in sales tax is large, the OEM is better off authorizing third-party remanufacturing.

Similarly, we compare the optimal profits of the TPR under the two strategy models. The TPR only makes a profit under the TPR-remanufacturing model, and the TPR's maximum profit can be expressed as follows:

$$\Delta\pi_R = \pi_R^{A*} - 0 = \pi_R^{A*} = \frac{(\rho c_n - c_{Rr} + \rho t_n)^2}{16\rho(1-\rho)} \tag{36}$$

Proposition 10. *The optimal profit of the TPR is an increasing function of unit tariff t_n. If the price and demand in the market are optimal, the TPR can always obtain benefits, and its profit increases with the unit tariff.*

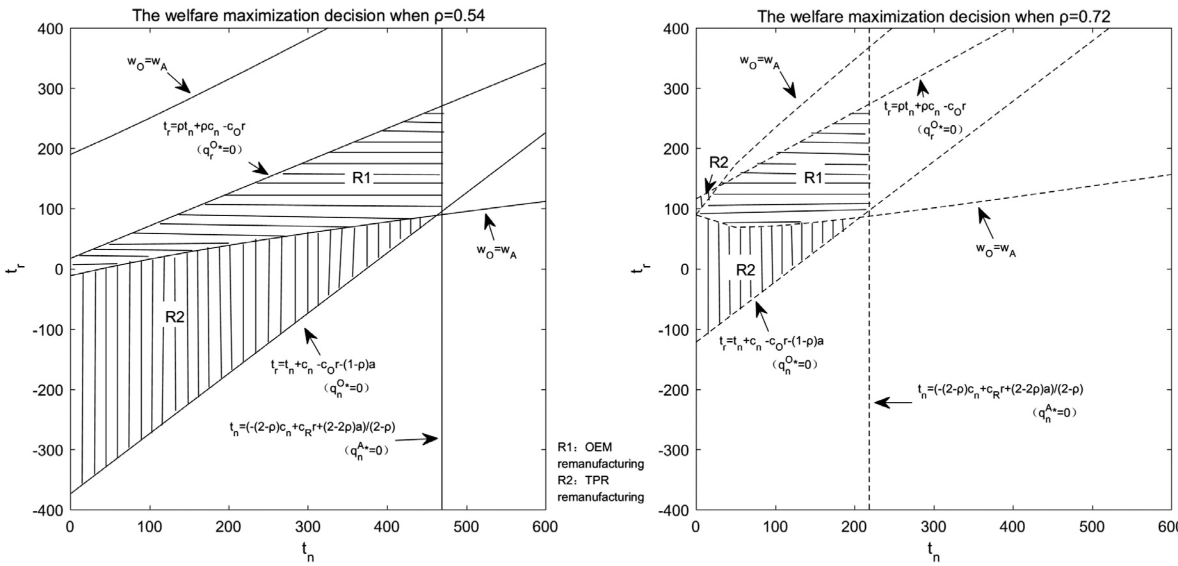

Fig. 4. Welfare maximization decision-making of the importing country (source: authors).

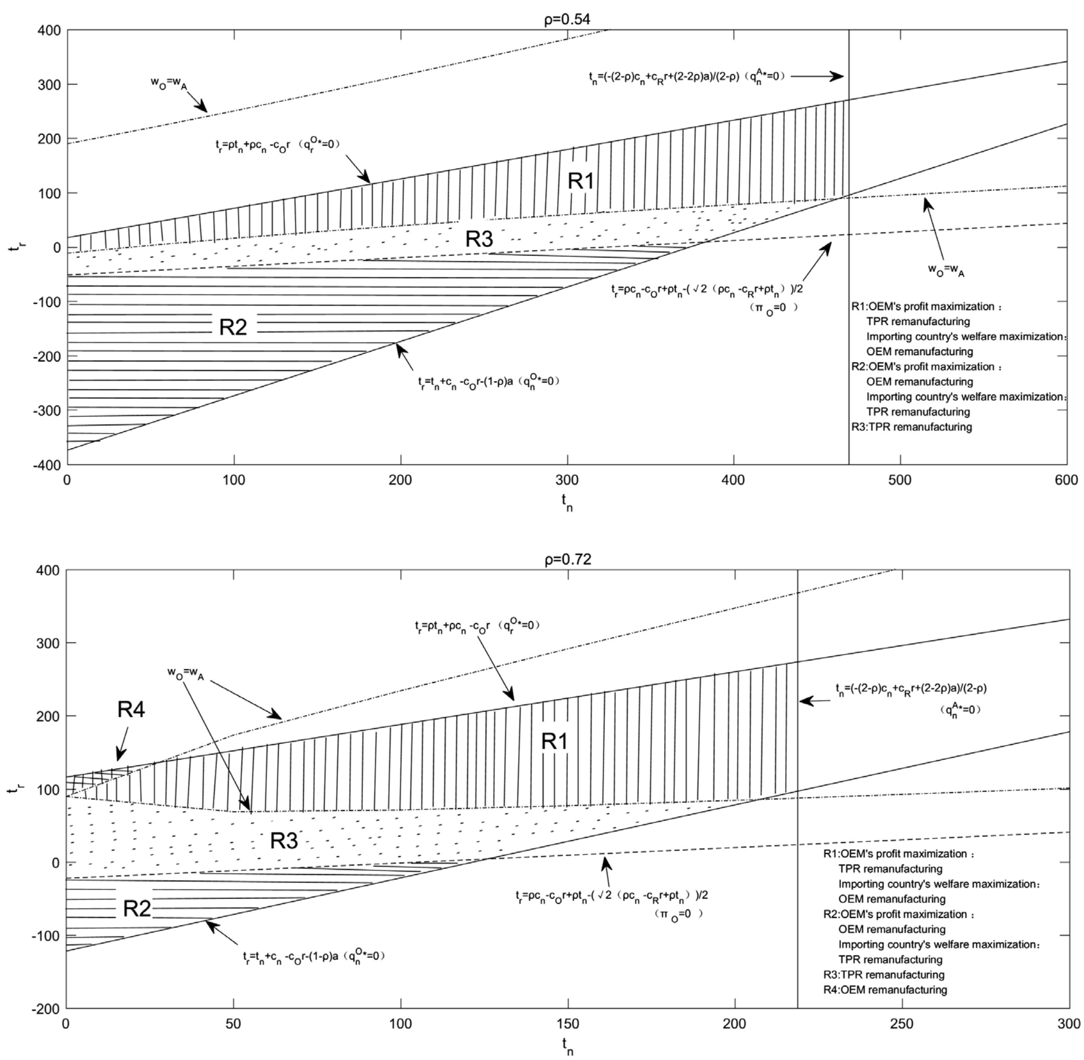

Fig. 5. Decision-making of the OEM and importing country (source: authors).

The greater the trade protection of the importing government is, the greater the losses the OEM sustains become and the more benefits the TPR obtains.

Next, we compare and analyse the social welfare of the importing country under the two remanufacturing models.

$$\Delta w = w_O - w_A = \frac{16\rho t_n\ k1 - 16 t_r\ k2 + 4\rho\ k1^2 + 4\ k2^2 - 3\ \ k3^2 - \rho\ k4^2 - 8\rho t_n\ k4}{32\rho(1-\rho)} \tag{37}$$

Proposition 11. *The social welfare difference of the importing country under the two strategy models is a concave function of the unit difference in sales tax t_r. With an increase in t_r, social welfare first increases and then decreases.*

When t_r is relatively low or high, the importing country achieves more welfare when the TPR is authorized to remanufacture. When t_r is moderate, the importing country can obtain more benefits when the OEM carries out remanufacturing.

4. Numerical analysis

Numerical examples are presented for comparative analysis. In this section, it is assumed that $c_n = 550$, $c_{Or} = 280$, $c_{Rr} = 200$, $a = 1400$, and the interval of ρ is [0.54, 0.72] (Guangfu & Wenxia, 2017; Huang & Wang, 2017).

4.1. Optimal profits of the OEM

Fig. 3 shows the effect of t_n and t_r on the difference in the optimal selling price of optimal profits of the OEM when $\rho = 0.54$ and $\rho = 0.72$. Reaching region R1 below line $t_r = \rho c_n - c_{Or} + \rho t_n - \frac{\sqrt{2}\ (\rho c_n - c_{Rr} + \rho t_n)}{2}$, the government of the importing country offers exporters tax incentives or a low sales tax, and the OEM prefers investing in-house remanufacturing to gain more profit. Region R2 above line $t_r = \rho c_n - c_{Or} + \rho t_n - \frac{\sqrt{2}\ (\rho c_n - c_{Rr} + \rho t_n)}{2}$ is the area where the government of the importing country levies a relatively high sales tax on the OEM, and the OEM prefers authorizing the TPR to maximize its own profit considering the rising cost.

4.2. Maximization of the importing Country's social welfare

Fig. 4 shows the effects of t_n and t_r on the social welfare difference of the importing country when $\rho = 0.54$ and $\rho = 0.72$. Reaching region R1 means that the remanufacturing model will provide improved welfare for the host country but is less optimal for the OEM (Fig. 3). In region R2, the TPR-remanufacturing model creates better welfare for the host country, although the OEM prefers to adopt remanufacturing in-house.

4.3. Maximization of the OEM's profit and the importing Country's social welfare

The OEM needs to consider both its own profit maximization and the importing country's social benefits to make decisions concerning investment in cross-border remanufacturing. Fig. 5 shows the decision region wherein we maximize the OEM's profit and the importing country's social welfare when $\rho = 0.54$ and $\rho = 0.72$. In region R1, to maximize its own profits, the OEM should choose to outsource remanufacturing to the TPR. However, in this region, the importing country's social welfare is greater when the OEM carries out remanufacturing. Thus, there is a strategic mismatch if the OEM and importing country both want to achieve maximized benefits.

In contrast, in region R2, to maximize its own profits, the OEM should choose to invest in cross-border in-house remanufacturing. However, in this region, the importing country's social welfare is greater when the OEM outsources remanufacturing to the TPR. In region R3, the maximum benefits for both the OEM and the importing country can be achieved when the OEM decides to outsource remanufacturing to the TPR. Similarly, in region R4, the maximum benefits for both the OEM and the importing country can be achieved when the OEM decides to invest in-house remanufacturing.

5. Conclusion

5.1. Contributions and implementation

Remanufacturing is a valid means to achieving a coexistence of social and economic benefits as well as to address increasingly urgent environmental issues. For OEMs not able to remanufacture recycled products in a profitable manner by themselves, outsourcing to TPRs is a viable alternative (Ferguson & Toktay, 2006). To assist decision-makers in reaching theory-supported and evidence-based advantageous strategies under recent developments in international relations, this paper serves as a practical tool for OEMs to choose between in-house remanufacturing and outsourcing to TPRs in local regions, with related economic and social implications examined. We hope the present research will contribute to addressing the negative impacts of deglobalization and protectionism, such as the US–China tariff war and other frictions in global economic activities, as well as the various unilateral incentivizing low-rate taxes levied by developing economies to attract foreign investment. As remanufacturing is becoming increasingly accepted and practised, the proposed model can be adopted by more cross-border businesses and countries to reach a decision on better operation models and tax issues.

As discussed, taxes and tariffs are significant elements of the cost of capital and thus critical for enterprise corporate decisions (Graham & Mills, 2008; Zhou et al., 2011). In addition to other influential factors (e.g., site setup costs, volume fluctuations of returned cores, labour costs, material costs, and logistics costs) that have already been well studied in the extant literature, our research emphasizes the two underrepresented elements, which often result in major expenses for businesses and can significantly affect an OEM's strategy of deploying cross-border remanufacturing supply chains. A two-stage game model is developed to illustrate the impact of tax and tariff policies on OEMs' profitability (optimal prices, sales volumes, and profits from new and remanufactured products) as well as on the social welfare of the importing country. By taking a meaningful further step towards understanding the impact of taxes and tariffs in global remanufacturing supply chains, our work highlights important factors that need to be brought to the attention of various stakeholders. First, it analytically indicates the trade-off involved in an OEM's global remanufacturing decision considering tax rate differentials. Second, under certain tax conditions, it is demonstrated that an OEM may achieve profit maximization but erode the importing country's social benefits. Third, considering economic and social benefits, this paper also provides guidelines for policy makers, especially those of developing economies, to consider when designing appropriate tax schemes for remanufacturers.

More specifically, for an OEM, the difference in sales tax levied on exporting firms' subsidiaries and domestic firms by the government of the importing country will cause the price and volume of a remanufactured product to differ between the two remanufacturing models, leading to a difference in profit. It is found that the remanufacturing model selected by an OEM is affected not only by the difference in sales tax but also by the unit product import tariff for new products. Our proposed selection boundary, $t_r = \rho c_n - c_{Or} + \rho t_n - \frac{\sqrt{2}\ (\rho c_n - c_{Rr} + \rho t_n)}{2}$, can therefore be applied by corporate decision makers. When the difference in sales tax is constant, the tax policy of the government of the host country concerning foreign investment is stable; the increase in the unit product import tariff for new products will reduce the profit of the OEM in both models; however, the decrease is more gradual in the TPR remanufacturing model than in the OEM remanufacturing model. Therefore, for better profitability, the OEM should adopt the TRP model if the import tariff is high enough when the difference in sales tax is constant. From the perspective of an importing country and tax/tariff policy makers, our results showcase how their selection of import tariffs and the difference in sales tax will affect social welfare differently. It is found that only in two regions can the importing country obtain more social welfare from remanufacturing (Fig. 4). From the above results, we recommend that the model selected for the OEM and importing country be aligned when the difference in sales tax is close to zero (R3 in Fig. 5). In other words, to achieve optimal welfare for all stakeholders, the destination country should treat foreign and local enterprises equally. Our results support the enaction of the Foreign Investment Law (Draft) by China in 2019, which reduces the difference in sales tax between foreign investment and local production. These findings not only echo the harsh critiques of taxes and tariffs diminishing social welfare from an economic perspective (see the work of Samuelson, Krugman, and Stolper) but also further develop the theory by incorporating taxation constructs into the decision-making mechanism, which is of practical significance for many OEMs in contemporary global remanufacturing supply chains and offers a valid and vivid demonstration of social welfare for legislators and policy makers.

5.2. Limitations and future research

This paper is not exempt from limitations. First, from the OEM's perspective, this work does not consider the production constraints of remanufactured products, i.e., as shown in some studies, the volume of the remanufactured product is restricted by the volume of the EOL product and the recovery rate. Second, the paper does not consider the retailer's role in the remanufacturing model, while in reality, retailer remanufacturing also exists as a possible alternative. Third, from policy and political perspectives, other possible types of trade barriers are not taken into consideration (e.g., quotas, subsidies, and carbon tariffs), nor are the political and economic uncertainties and risks related to international capital flow (i.e., FDI), which are beyond the focus of this research. Finally, the proposed model does not consider export policies (either supportive or restricting), which theoretically can affect an OEM's remanufacturing model selection, though in reality and in the contexts of this research, developed economies in general apply fewer export subsidies or restrictions, as well as fewer import barriers (see UNCTAD, 2020).

Several potential research directions can be developed building on the present work. First, it would be interesting to incorporate other government interventions into the proposed model. Second, it is important to understand the complete lifecycle of remanufactured product lines. Demand variability would add a new set of constraints to the current model and have different effects on the optimal policy. Third, as the volume fluctuation of returned cores is not considered in this model, relaxing this assumption to further investigate the robustness of the findings can be a promising direction for future research. Finally, the selection of a remanufacturing facility location covers issues of geographical location and proximity to the manufacturer's current supply chain links and production settings. An important extension of the setting considered in this paper may examine a scenario in which the OEM invests in setting up remanufacturing facilities based on or close to existing manufacturing plants.

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Supplementary materials

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