Front. Eng. Manag. 2024, 11(1): 1–15
https://doi.org/10.1007/s42524-023-0251-7

REVIEW ARTICLE

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Pricing and production strategies in remanufacturing from the perspectives of supply chain: Review and future directions

Abstract Remanufacturing is widely recognized as beneficial to the environment and a circular economy. However, remanufacturing is more complex than traditional manufacturing due to the effects of government policy, uncertainty of consumer preferences, competition and cooperation among firms, and so on. These factors motivate academics to optimize remanufacturing outcomes, especially for product pricing and production. This study reviews the published literature on pricing and production strategies in remanufacturing from four perspectives of supply chain, namely, government policy, consumer characteristics, relationships among firms, and supply chain structures. Review results can benefit scholars/practitioners in the future by highlighting the challenges and opportunities in remanufacturing strategies.

Keywords remanufacturing, reverse and closed-loop supply chain, circular economy

1 Introduction

Remanufacturing is the process in which used or end-of-life products are restored to like-new conditions and re-entered into the distribution system as "new products" (Wei and Zhao, 2015). Given the increase in environmental consciousness, governments in many countries launched policies to encourage firms to engage in remanufacturing activities (Bi et al., 2017; Yan et al., 2017). For example, China has proposed to vigorously develop the remanufacturing industry. Specifically, high-end, intelligent and in-service remanufacturing is to be implemented to accelerate the sustainable and healthy industry development. In the US, the total annual sales of the remanufacturing industry is approximately 53 billion dollars in 1997 (Atasu et al., 2008), and 2.4 billion dollars are loaned for three electric vehicle factories to support remanufacturing (Gong et al., 2013). On Oct. 7, 2015, former US President Barack Obama signed *S. 565, The Federal Vehicle Repair Cost Savings Act of 2015*, which required federal agencies to encourage the use of remanufactured parts in federal vehicle repairs because of lower cost. With the government support and economic benefit, more and more firms began to participate in remanufacturing activities. Apple integrates remanufacturing into its business (Ovchinnikov et al., 2014) and Dell has a separate website where refurbished computers and accessories are sold (Ovchinnikov, 2011). Meanwhile, Hewlett-Packard, Sony, Huawei and Lenovo have used recycled components instead of new raw materials in production, partially for reasons of cost savings by 30%–50% (Toffel, 2004). Therefore, remanufacturing not only offers firms unique opportunities to improve their profits, but also helps firms to serve social responsibility.

As an effective way to contribute to sustainability, remanufacturing has been booming in various countries, but still presents research challenges (Govindan et al., 2019). In the remanufacturing industry, proper pricing and production strategies can not only improve a firm's profit, but also promote social utility. Thus, such strategies in this context have gradually become hot research topics. Numerous scholars have studied pricing and production strategies in the remanufacturing activities from various perspectives of supply chain, which can be generally divided into four perspectives: Governments, consumers,

Received Jan. 6, 2022; revised Sep. 12, 2022; accepted Nov. 14, 2022

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This work was supported by the National Natural Science Foundation of China (Grant Nos. 71871076, 71521001, 71690235, and 72001064).

other members in the supply chain, and the entire supply chain. From the perspective of the governments, the effects of policies on pricing and production strategies in remanufacturing activities are the most studied. From the perspective of consumers, environmental preference and concern for the quality of remanufactured products are the main topics. From the perspective of other members in the reverse supply chain (RSC) and closed-loop supply chain (CLSC), selecting suitable sales and recycling channels, as well as creating the optimal pricing and production strategies, is essential when members have vertical or horizontal competition and cooperation. From the perspective of the entire supply chain, the structures must be carefully considered due to the potential effect of change in the above three perspectives. This study begins at the end of the supply chain, that is, from the consumers' perspective, and ends at the overall structure of the supply chain. The aim is to summarize the pricing and production strategies of remanufacturing from four perspectives of the supply chain and seek new research directions. The research status, methods, and key findings of existing literature are reviewed from the local to the entire supply chain.

First, this study reviews the published literature on pricing and production strategies in remanufacturing from three aspects: Research status, research methods, and new directions. Second, the structures of supply chain (the fourth perspective) are examined and probable research scenarios are proposed. Finally, the findings are summarized. By reviewing previous literature, this study discusses the research status, refreshes the information, and proposes significant insights for devising better pricing and production strategies in remanufacturing activities.

The rest of this paper is organized as follows. Section 2 describes the review methodology. In Section 3, we review the papers from four perspectives and propose research directions. Section 4 presents the conclusions.

2 Review methodology

The review methodology of published literature can be described in three stages that are introduced by Sitcharangsie et al. (2019). Specifically, the problems to be answered are formulated. Then, the criteria for the inclusion and exclusion of papers are examined, including temporal scope, publication language, database source of papers, and index of journal selection. Finally, this study presents the reasons why the related literature is divided into four perspectives of the supply chain.

2.1 Problem formulation

One of the significances of reviewing existing literature in a certain field is to know the research status, methods, and future directions to explore. With the same purposes, the present study seeks to answer the following questions by reviewing existing literature on pricing and production strategies in remanufacturing from four perspectives of the supply chain:

(i) What is the current development in remanufacturing from four perspectives of the supply chain?

(ii) What are the research methods used in the published literature?

(iii) What are the existing supply chain structures in remanufacturing?

(iv) What are the probable research directions in remanufacturing?

2.2 Criteria for inclusion and exclusion of papers

This section shows the selection criteria of papers for the review, including the temporal scope, publication language, database source, and index of journal selection.

2.2.1 Temporal scope and publication language

The literature written in English and published from January 2010 to December 2021 are included in this study.

2.2.2 Paper search and selection

First, papers on pricing in remanufacturing are collected from a few well-known databases, including Web of Science, ScienceDirect, Scopus, Derwent Innovation Index, Information Service in Physics, Electro-Technology, Computer and Control, Korean Journal Database, MEDLINE, Russian Science Citation Index, and SciELO Citation Index. Second, the following keywords are used to search papers: "remanufacturing", "remanufactured" or "remanufacture", "pricing" or "price", "used products", "recycling" or "recycle", "collecting" or "collect", and "supply chain". Then, papers written on journals listed in the first two quarters (Q1 and Q2) are filtered by using SCImago Journal Rank (SJR), an alternative method to check the quality of papers due to its large collection of journals (Falagas et al., 2008). Suitable papers have been recommended from Q1 journals, which includes the top 25% of cited journals (Bornmann and Marx, 2014; Bornmann and Williams, 2017). Therefore, the quality of collected papers is guaranteed. Figure 1 shows the annual distributions of the papers.

2.3 Classification of the papers

The first perspective of this review is government policies applied in remanufacturing activities. In the last few years, governments have launched a series of policies to promote the development of remanufacturing, causing

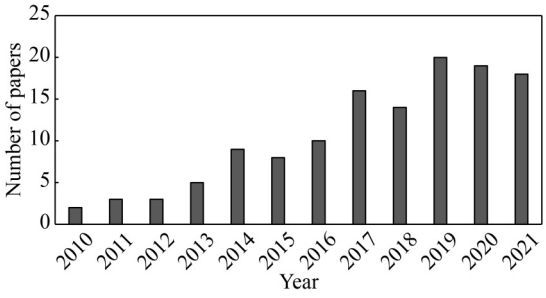

Fig. 1 Paper distribution from 2010 to 2021.

concerns among a growing number of scholars. Therefore, research has focused on studying the effects of government policies on pricing and production strategies in remanufacturing to provide effective advice for policy improvement.

The second perspective is consumer characteristics, which should be considered when the decision-makers (e.g., manufacturers, retailers, and third parties) devise pricing strategies. The reason is that remanufacturing activities occur in the RSC or CLSC, in which consumers are the beginning. Specifically, consumers' environmental preferences and opinions on the quality of remanufactured products are the focus of numerous papers. Hence, this is the second perspective of the review.

Apart from consumer characteristics, other members in the RSC or CLSC (e.g., manufacturers, retailers, and third parties) must consider more issues when devising pricing and production strategies to maximize their profits. The selection of sales or recycling channels comprises one of the most discussed aspects in literature, because these factors not only change the supply chain structure but also affect the relationships among members in the RSC or CLSC. Specifically, multiple sales or recycling channels can lead to competition and cooperation among supply chain members in the vertical direction, as considered in several papers. Moreover, such relationships also happen in the horizontal direction because more and more firms become involved in remanufacturing. Given these two aspects, the relationships among members in the RSC or CLSC are worth coordinating. Through the foregoing discussion, we can conclude that considering issues mainly including channel selection, competition, and cooperation among members is the third perspective of the review following the government and consumer.

Whichever of the perspectives mentioned above can more or less lead to the change of RSC or CLSC structure and affect the relationships among members in the supply chain. Thus, we finally summarize the supply chain structures that have been discussed and propose new structures that are worth exploring in the future.

On this basis, this study reviews the existing literature from four perspectives. Figure 2 shows the total framework and Table 1 shows the statistics of reviewed papers in each perspective:

(i) Effects of government policies on pricing and production strategies;

(ii) Pricing and production strategies considering consumers' environmental preference and opinions on product quality;

(iii) Channel selection, competition, and cooperation among supply chain members;

(iv) Supply chain structure.

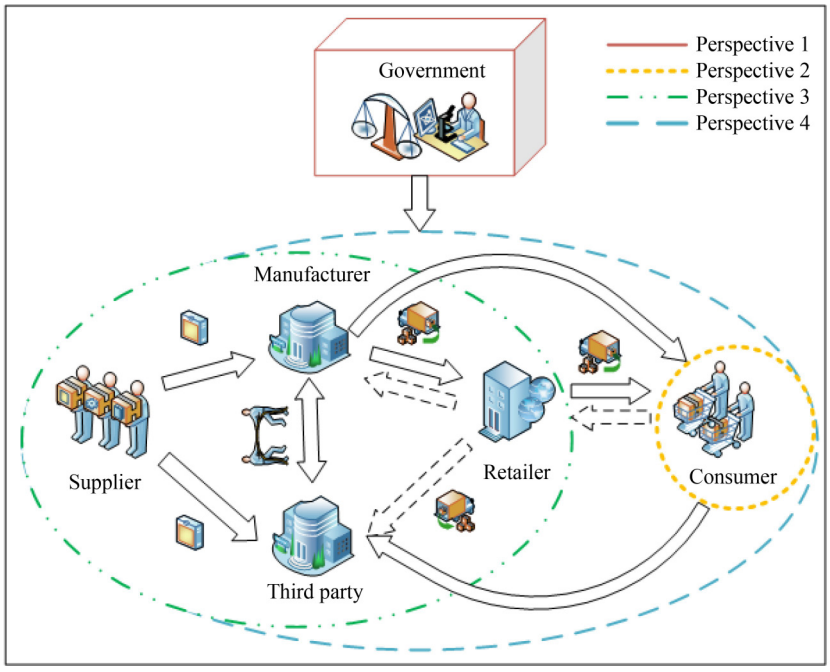

Fig. 2 Four perspectives of the review.

Table 1 Statistics of reviewed papers

Review perspective	Subsection	Number of papers
Governments	Governments' policy	25
Consumers	Consumers' preferences	20
	Product quality	16
Members except for governments and consumers in the supply chain	Channel selection	33
	Competition and cooperation	31

3 Review results and discussions

In this section, four major perspectives that affect pricing and production strategies in remanufacturing are discussed. Research methods are summarized and probable directions are proposed separately in each perspective.

3.1 Effects of governments' policies on pricing and production strategies

Environmental pollution has become a threat to human survival and health, and is increasingly arousing the concerns of global citizens (Yang et al., 2018). Global warming, sewage discharge, and other phenomena affect the stable and circular development of society. Worldwide, governments have launched policies, especially various direct subsidies (e.g., investment tax credits and cash grants) and indirect subsidies (e.g., carbon tax and carbon emission capacity regulations) to mitigate environmental pressures (Kök et al., 2018; Cao et al., 2020a; 2020b; 2020c; Wang et al., 2021; Cheng et al., 2022). The carbon tax is launched mainly for manufacturers and aims to reduce environmental pollution by limiting carbon emissions. For example, firms in the US do not receive subsidies or tax credits for remanufacturing but rather pay emission taxes (Yenipazarli, 2016), while various other parties such as suppliers, retailers, consumers, and third parties receive direct subsidies. In other words, the government subsidy can be given to any member of the supply chain. Therefore, the first problem is to determine who can better promote social development with government subsidies.

Scholars have studied the effects of subsidies given to different parties on the pricing and profits of firms in remanufacturing activities. Literature has focused on a single recipient of subsidies, typically the (re)manufacturer or consumer (Li et al., 2014; Wang et al., 2020b; Feng et al., 2021) because the former is the origin of the remanufacturing while the latter is the source of product recycling and the end point of remanufactured products. However, a growing number of scholars have realized the diversity of government subsidy parties in the past several years, and papers have emerged in large numbers with regard to subsidy allocation. As shown in Table 2, the parties of subsidy allocation are diverse, and two or more members of the supply chain may gain such government subsidies. Most of the reviewed papers pay attention to how the government allocates subsidies to members engaging in remanufacturing activities for maximizing profit, which promotes the development of the remanufacturing industry and rationalizes the allocation of subsidies to a certain extent. Indeed, the government has a great moderating role in economic development. However, we cannot ignore the internal coordination among members in the supply chain, that is, making contracts or other methods to allocate subsidies especially when the cooperative awareness among members in the supply chain is gradually increasing. The autonomous subsidy allocation when cooperators have different powers for decisions presents an interesting research direction. In addition, when the majority of firms devise pricing and production strategies, the ultimate goal is to maximize their profits, which is also reflected in various models. However, compared with the manufacturer's total profit maximization model, one paper found that the social welfare maximization model is superior in terms of product recycling and profit sources (Shu et al., 2018a) and thus may be a meaningful model for further research. We can also further consider how the optimality of these two types of models changes depending on the magnitude of the risk. Several scholars have built a game-theoretic model to discuss the impacts of government subsidy on manufacturing and remanufacturing quantities, consumer surplus, original equipment manufacturer and independent remanufacturer profit, social surplus, and environment for each choice of the original equipment manufacturer and the independent remanufacturer (Qiao and Su, 2021b). Zhang et al. (2021) investigated the effects of government fund policy on consumers, the environment, and society using numerical analysis. Their findings show that without a government fund policy, the manufacturer remanufacturing mode is better for CLSC members.

One aspect of the literature review is to waive core assumptions and propose research findings (Torraco, 2005). To clearly show the similarities and differences among the reviewed papers, Table 2 summarizes 17 papers that examined government subsidies in remanufacturing between 2010 and 2020. Each study is characterized by "key assumption", "factors besides policies", "goal", "decisions besides pricing" and "objects of subsidy or carbon tax".

3.2 Pricing and production strategies considering consumers' environmental preferences and opinions on product quality

Despite its great economic and environmental potential, remanufacturing also brings a series of difficulties (Habibi et al., 2017). The main challenge is that consumers have lower acceptance of remanufactured

Table 2 Summary of papers on government subsidy

Reference	Key assumption	Factors besides policies	Goal	Decisions besides pricing	Objects of subsidy or carbon tax
Miao et al. (2018)	Monopolist	/	*	Production decisions	1
Han et al. (2017)	Monopolist	/	*	Production decisions	3
Hong et al. (2020)	Monopolist	Consumers are environmentally conscious	*	Production decisions	1 or 2
Wang et al. (2019b)	Symmetric information	/	*	Allocation of government subsidies	1 and 2
Zhou and Yuen (2020)	Symmetric information	Government budget constraint	*	/	3 and 4
Li et al. (2014)	Symmetric information	Carbon emission	*	Carbon emission quantities	5
Shu et al. (2018a)	Remanufactured and new materials are the same	/	* and **	Recycling rate	1
Chen et al. (2020)	Remanufactured and new products are the same	Uncertainty returns	* and ***	Production decisions	1
Li et al. (2019b)	Remanufactured and new products are the same	The retailers fairness concern psychology	*	Recycling amount	6
Yenipazarli (2016)	Product life is one period	WTP	*	Production decisions	1
Cao et al. (2020b)	Each replacement consumer owns one used product with the same value	WTP	*	Consumer surplus	3
He et al. (2019a)	All firms are rational, risk-neutral	Sales channels, WTP	* and **	Channel optimization	3
Wang et al. (2020b)	E-platform is not the leader	Remanufacturer's altruistic preference	*	Profit of e-platform	1
Zhao et al. (2018)	Consumers' environmental preference	WTP	*	Subsidy-sharing percentage	1 and 3
Choi (2017)	/	Branding effect	*	Brand investment decisions	1
Wang et al. (2018)	Not all acquisitions can be remanufactured	Donation quantity of remanufactured products	*	Production decisions	1
Wan and Hong (2019)	All collected products are remanufactured	/	*	Transfer price paid to the retailer	1 or 6

Notes: WTP: willingness to pay; * profit maximization; ** social welfare maximization; *** governments minimal expected subsidy expenditures; 1 manufacturer or remanufacturer; 2 retailer; 3 consumer; 4 third-party remanufacturer; 5 supplier; 6 recyclers.

products, which limits the demand and hinders the realization of the full potential value from remanufacturing activities (Galbreth et al., 2013; Abbey et al., 2015b; Wang and Hazen, 2016). Consumers have uncertain valuations for remanufactured products, which leads to consumer post-purchase regrets (Yang et al., 2021). Giri et al. (2018) showed that the model considering demand dependent on greening level provided better results than the model considering demand dependent on selling price. Hence, firms proposing remanufacturing strategies need to consider how consumers may react to the addition of remanufactured products in their offerings, especially in terms of consumers' environmental preferences.

In recent years, scholars have increasingly focused on how to effectively quantify consumers' environmental preferences to establish more realistic research models for a firm's optimal pricing strategy in remanufacturing activities. To our knowledge, consumers' willingness to pay (WTP) is a measurement metric that is used frequently for consumers' environmental preferences. Numerous papers show that consumers' WTP for new and remanufactured products are θ and $\alpha\theta$, respectively. α is a discount factor in consumers' evaluation of remanufactured products (Frota Neto et al., 2016; Long et al., 2019; Wen et al., 2020; Zhang et al., 2021), while θ is distributed uniformly between 0 and 1 when the market is normalized (Ovchinnikov, 2011; Li et al., 2017). An increasing θ has three main effects on making decisions, namely, increases in: i) demand for remanufactured products (Zhang and He, 2019); ii) price of remanufactured products (Xu and Wang, 2018; Huang and Wang, 2019); and iii) recycling rate.

So far, the discount factor for remanufactured products is always assumed as a constant due to its tractability. However, empirical research challenges this assumption. Abbey et al. (2019) found that consumers have significantly different discount factors for remanufactured products. To answer whether the constant or variability has a significant effect on the results, Kleber et al. (2018) considered a model in the CLSC and found remarkable consistency between the results of the constant and variable discount factor models. As a result, the discount factor of consumers' WTP for remanufactured products can be reasonably applied to remanufacturing decisions.

A few other innovative measurement metrics are proposed for consumers' environmental preferences. Abbey et al. (2015a) proposed a construct where a firm's decisions are guided by estimating the proportion of

consumers who may switch from new to remanufactured products for a given price difference. Zhao et al. (2018) used the price elasticity of demand (PED) for remanufactured products as a metric to differentiate consumers' environmental preferences, in which non-green consumers have higher price elasticity than green consumers. Their findings show that remanufacturers can increase the selling price of remanufactured products if consumers are more environmentally friendly. In addition, Chen et al. (2019a) operationalized consumers' environmental preferences as a consumer word-of-mouth. Table 3 lists these innovative opinions on consumers' environmental preferences, although the quantitative expressions are also worth referring to. On this basis, new scenarios can be sought to study the influence of consumers' environmental preferences on pricing and production strategies.

The reason why consumers have lower acceptance of remanufactured product is its quality (Mitra, 2016b; Feng et al., 2020; Ma et al., 2020), which can mainly be described as product functionality and cosmetic defects (Abbey et al., 2017). To mitigate consumers' concerns and increase the high flow of remanufactured products, firms have taken several measures, such as money-back guarantee, false warranty claims, and end-of-life returns (Chen et al., 2019b; Assarzadegan and Rasti-Barzoki, 2020; Liu et al., 2020; Confente et al., 2021). Qiao and Su (2021c) examined the optimal prices and quality of new and remanufactured products and especially discussed the quality adjustment of the original equipment manufacturer in a new market segment that consists of the indifferent and the new-product only segments. The optimal online return policy for remanufactured products was also explored (Cao et al., 2020c). Moreover, (re)-manufacturers and retailers cooperate together and develop revenue-sharing contracts to ensure greater consumer flow (Xiao et al., 2011). From the view of the (re)manufacturer, the quality of acquisition is as important as that of remanufactured products. The reason is that the acquisition quality affects the recovery rate, which further affects the level of inventory and production decisions and thereby the pricing and profit (El Saadany and Jaber, 2010; Cai et al., 2014). Table 4 shows a few papers considering the quality of returned products for decision making and the methods used. We can see that returned products are generally the same type. When considering the quality of returned products, either all the old products or only parts of them can be recycled, and thus the quantity of returned products is uncertain. Precisely for this uncertainty, members of the supply chain take pricing strategies more seriously. In the future, to find ways to reduce uncertainty, improve the consumers' trust and build trust in relationships among (re)manufacturers, retailers, and consumers is significant. Figure 3 shows several topics on which scholars may focus in the future.

3.3 Channel selection, competition, and cooperation among supply chain members

In current practice, given various uncertainties such as the complexity of the source of used products, the variability of the quality of returned products, and the level of consumers' participation, manufacturers face difficulties in recycling enough used products through a single channel to achieve economies of scale in remanufacturing (Wan and Hong, 2019). To overcome this obstacle, many firms such as Apple, IBM, and Hewlett-Packard explore multiple sales or recycling channels to attract consumers and seize market share (Chiang et al., 2003; Mukhopadhyay et al.,

Table 3 Measurement metrics and expressive methods of consumers' environmental preference

Reference	Measurement metric	Expressive method
Zhao et al. (2018)	Price elasticity of demand	Consumers are ordered by the levels of their environmental preferences; non-green consumers have stronger substitution preference towards remanufactured products, that is, higher price elasticity than green consumers
Chen et al. (2019a)	Word-of-mouth	The total of consumers' environmental preferences is the function of the fluctuation ratio of consumers' environmental preferences with the word-of-mouth effect
Abbey et al. (2015a)	Switch ratio	Proportion of consumers who may switch from the new to the remanufactured product for a given price difference

Table 4 Papers on product quality

Reference	Product type	Method	Quantity of returned products to be remanufactured	Quantity of returned products
Cai et al. (2014)	/	Heuristic algorithm is developed based on Particle Swarm Optimization	All	All
El Saadany and Jaber (2010)	A single product	Extended economic production quality model	All	Part, the lowest quality level
Shu et al. (2018b)	/	Stackelberg game	Part	All
Xiong et al. (2014)	Automotive engine	A continuous-time Markov decision process	All	Part, basic condition requirements
Bulmus et al. (2014b)	/	Nonlinear programming	All	*N* types of returned products

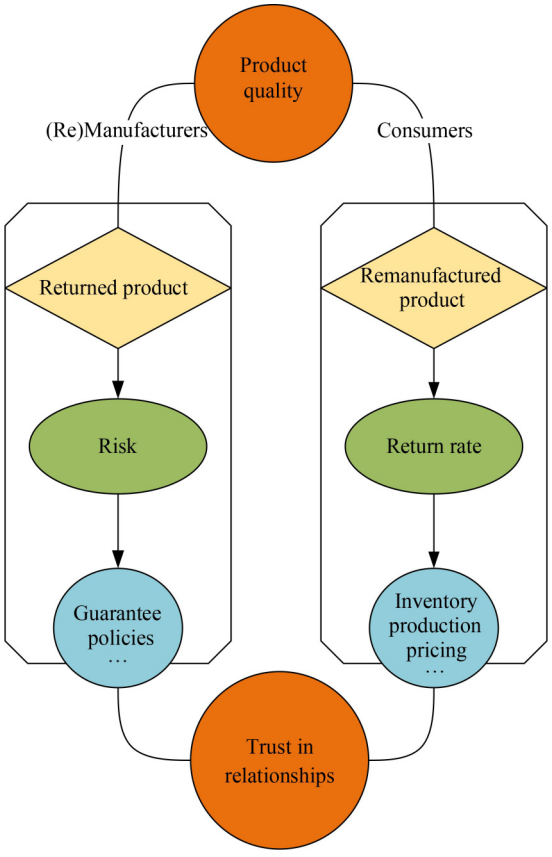

Fig. 3 Summary of ideas and possible research direction.

2008, Qiao and Su, 2021a; 2021c). Firms can combine traditional and online channels to sell or recycle products, which is called dual sales or recycling channels (Chen et al., 2021; Liu et al., 2021; Wen et al., 2021; Zheng et al., 2021). The selling or the recycling price can also be decided jointly (external centralized channel) or separately (external decentralized channel) with other supply chain members (e.g., retailers, recyclers, and third parties). The two separate main sales channels are: i) Manufacturers directly selling new or remanufactured products to consumers (Gan et al., 2017; Xiao et al., 2020); and ii) Manufacturers inducing retailers or third-party to sell new or remanufactured products to consumers (Huang et al., 2013; Maiti and Giri, 2015; Wei et al., 2019; Taheri-Moghadam et al., 2021). For recycling, the main channels are: i) Manufacturers directly recycle used products from the market (He, 2015); ii) Retailers engage in recycling; or iii) Third parties recycle used products (Li et al., 2019a; He et al., 2019b). Two or more channels can be combined to satisfy the requirements of members in the supply chain.

However, selling or recycling products through multiple channels presents several challenges, such as sales or recycling share allocations, channel conflict, and members' competition. Different channel selections affect the pricing and production strategies of supply chain members. As such, which one is better for a firm? How should a firm choose the sales or recycling channel? Many papers have drawn two conclusions on the selection of channels:

(i) A centralized pricing model can achieve profit maximization (Liu et al., 2020).

(ii) The retailer-led decentralized scenario is more acceptable (Gu and Gao, 2012; Xiao et al., 2014; Yoo et al., 2015; Zhang et al., 2019).

Although many previous papers assume that the manufacturer is the channel leader, the above statements show that this might not be true in several conditions, for the retailer to recycle used products is reasonable, and is consistent with several works (Gao et al., 2016; Giri et al., 2017; Wang et al., 2020a). Wu and Zhou (2017) have also found a prisoner's dilemma in which the Pareto optimal solution is for both manufacturers and retailers to use the manufacturer-managed collection, but the retailer-managed collection is a dominant strategy. In particular, when retailers engage in remanufacturing activities, manufacturers become product suppliers who focus on new product development and production (Yi et al., 2016). The complex relationship of members in the supply chain then moves down, in which case, we may consider the relationships between real raw material suppliers and manufacturers or even downstream members of the supply chain. When a supplier is a leader in the game, the optimal pricing or other decisions may differ. The study of the coordination mechanism between suppliers and manufacturers or the mechanism by which suppliers and manufacturers make centralized decisions is then meaningful, especially when suppliers have more power than other members in the supply chain. Future research can pay more attention to firms' pricing and production strategies when suppliers engage in recycling activities. Suppliers are the providers of raw materials, and thus may better recycle, disassemble, and clean old products.

Furthermore, a firm's internal structure also affects the choice of channels, and thereby the firm's pricing and other strategies. A centralized firm (coordinate manufacturing and remanufacturing divisions) chooses direct rather than indirect selling to avoid double marginalization. However, a decentralized firm (separate manufacturing and remanufacturing divisions) can find indirect selling more appealing because it can increase firm profit, supply chain profit, total demand, and even the profit of the manufacturing division more than direct selling (Shi et al., 2020). Moreover, not only new and remanufactured products can be sold through single- or multi-channels (i.e., different providers) but also services, such as sales effort (e.g., advertisement and product information) (Jena et al., 2017) or after-sales service (e.g., maintenance and warranty repair agreements) (Wu, 2012; Alqahtani and Gupta, 2017; Li et al., 2019c; Tang et al., 2020). Service is an "intangible product", which is different from new or remanufactured products and affects firms' pricing

decisions and consumers' choices. Therefore, how to choose suppliers and the degree of after-sales service need investigation when firms make pricing and production strategies.

As mentioned above, multi-channels can lead to external channel competition (i.e., sales or recycling competition among supply chain members). For sales channels, the main competition mode is between third-party sales platforms and retailers when manufacturers choose more than one sales channels. For recycling channels, a few competition modes can occur. An independent third-party enterprise that recycles and carries out remanufacturing activities may be independently profitable and result in external competition with the manufacturer who also engages in remanufacturing (Ho et al., 2018). The competition also occurs when two or more members participate in recycling activities, such as retailers and third parties, retailers and manufacturers, or retailers and retailers. For example, Shekarian et al. (2021) studied the impact of carbon emissions and remanufacturing on the dual channels of forward and reverse logistics with a collection competition. Feng et al. (2022) developed a game model of multi-level competitive recycling and remanufacturing supply chain with two manufacturers and multiple recyclers. Hosseini-Motlagh et al. (2020) investigated a CLSC that includes one (re)manufacturer investing in remanufacturing and energy-saving efforts, two retailers competing in selling items, and two collectors competing in collecting used items. Moreover, competition happens between two supply chains when the members of the separate supply chain cooperate with each other. The competitive strategies among supply chain members are mainly price and production quantity (Bulmus et al., 2014a; Zhao et al., 2017; Wang et al., 2019a), different product competition (Jena et al., 2019), service (Zhao et al., 2013; Xu et al., 2017; Hosseini-Motlagh et al., 2020), interchangeability design of product parts (Wu, 2013), and investment (Xu et al., 2022). Given that multi-channels can lead to different modes of competition that affect pricing decisions, it has attracted much attention and research. However, literature on the competition between suppliers and other members of the supply chain remains scarce. As for suppliers who provide raw materials, they occupy the production technology and supply channels, and thus may better recycle used components and then make them "as-old-as-new" and finally sell them to manufacturers. If a supplier engages in recycling activity, many scenarios can be examined. For instance, a competition model between recycling suppliers and other recyclers or ordinary suppliers can be constructed, and the impact of consumers' environmental preference for suppliers' recycling channel and other channels on pricing and production strategies can be examined.

In addition to external channel competition, product competition (i.e., new and remanufactured products) may occur between manufacturers and remanufacturers when the former produces remanufactured products. One reason why manufacturers engage in remanufacturing activities is the opportunity to gain profits (i.e., sales driven) (Wu and Wu, 2016). Another reason is to deter independent operating remanufacturers by strategically recycling used product, thereby decreasing its availability and acquisition to rival independent operating remanufacturers (i.e., recycling driven) (Debo et al., 2005). This may lead to cannibalization in the same market if a manufacturer produces remanufactured products (Wu, 2015; Wu et al., 2020). However, proponents of remanufacturing state that this process may not necessarily lead to cannibalization for all product categories (Guide Jr and Li, 2010), and even so, the combined profitability, sales volume, and market share of manufacturers for new and remanufactured products tend to increase over new product sales (Huang et al., 2014). Therefore, firms must rationally decide whether to remanufacture and implement pricing strategies according to their conditions.

With the development of society, an increasing number of firms collaborate on certain issues to improve their performance in terms of cost, delivery, or consumer satisfaction, even those with a competitive relationship (Zhou et al., 2021). This relationship is termed co-opetition (Jena and Sarmah, 2016). Literature discusses two common cooperative mechanisms: i) Competitive contracts such as two-tariff contracts (Hong et al., 2015; 2016; Taleizadeh et al., 2018), revenue and the expense sharing contracts (Xie et al., 2018), and complete or partial compensation contracts (He, 2015); and ii) Technology authorization (Huang and Wang, 2017; 2018; Zhao et al., 2019). Competition and cooperation mechanisms have advantages and disadvantages. Chen and Chang (2012) showed that the competitive strategy can generate higher profit than the cooperative strategy under such conditions of a low level of product substitutability and/or low remanufacturing cost incurred by the independent remanufacturers. However, Jena and Sarmah (2014) observed that the total channel profit of the co-operative system is higher than that of the non-co-operative systems. When market size increases, the global co-operative system can make more profits compared with the co-operative and non-co-operative channels. Firms can choose a better system according to their situation. Most of the above articles on competition and cooperation involve two members in the supply chain, while few papers study the modes of cooperation among three or more members, especially when considering suppliers. Literature mainly regard factors affecting pricing and production strategies as fixed parameters in the models, but actually, many factors are random, such as product supply, consumer demand, price, and cost. In addition, the relationship between price and demand is not necessarily linear. We can shift the focus to random and uncertain risk exploration such that the model can be more consistent with reality.

The above review shows that the three perspectives may overlap with each other but cannot contain all factors affecting decisions. Taking a certain fixed perspective as the main line and considering other important factors at the same time is a relatively good study method, which can help us find new research scenarios. Game theory is most frequently used for pricing when considering two or more decision factors, especially the Stackelberg game, Cournot model, and Nash equilibrium. Several optimization methods are used to answer firms' optimal pricing problems, such as Karush–Kuhn–Tucker (KKT), the Jacobian matrix, and the Hessian matrix. Few papers use nonlinear optimization models to solve pricing problems. To make the model more realistic, dynamic pricing is also indispensable in remanufacturing. Whether from the perspective of the government, society, or firm, optimization theory is necessary and can be increasingly used in future research.

3.4 Structures of the supply chain

Government participation, consumers' environmental preferences, product quality, channel selection, and competition or cooperation among supply chain members can all be reflected through the supply chain structures and in turn change the supply chain structures. To intuitively reflect the research scenario of the supply chain, we hereby exhibit the supply chain structures from few to more members participated in the supply chain in Fig. 4. Figure 5 presents the structures of the supply chain based on different selection channels of product types. Different products are sold to consumers through single channels.

When manufacturers sell new and remanufactured products directly to consumers, no external competition but cannibalization may occur in the end market. As the supply chain members increase, such as retailers or third parties involved in sales or recycling, external competition can occur, which is specifically reflected in vertical sales or recycling, product, and channel competitions. Further increase of manufacturers, retailers, and third parties involved in sales or recycling can lead to various horizontal competitions (Wei and Zhao, 2011; Mitra, 2016a; Kleber et al., 2020). The supply chain structures have also become complex. In both vertical and horizontal directions, supply chain members survive through not only endless competition but also multiple modes of cooperation. Cooperators with similar positions can centrally make important pricing decisions, while others with different strengths have to make decisions in turn. Generally, one partner is the leader while the other is the follower.

Although there are many supply chain structures, few studies focus on suppliers' recycling or competition and cooperation between suppliers and other members, as mentioned above. For example, when a supplier participates in recycling and undertakes clean and repair of used components and then sells them to manufacturers or remanufacturers, what is the competition between supplier and recycler (including retailers that recycle used products)? How should a supplier cope with fierce competition or cooperate with other supply chain members to promote sustainable development? Furthermore, when selecting a fixed sales channel for different products, the structure of the supply chain changes, leading to different scenarios. These problems are worthy of further study.

4 Directions for future research

Based on previous literature, possible directions are proposed from the perspectives of governments' subsidies, consumers' environmental preferences and concerns about product quality, and channel selection, competition, and cooperation among members in the RSC or CLSC.

First, the above review shows that existing papers on pricing and production strategies in remanufacturing pay much attention to three points when considering government subsidy: i) to study the suitable recipient for government subsidies; ii) to determine the subsidy amount; and iii) to study the allocation of government subsidy for more than one recipient. However, existing literature rarely involves the internal coordination among members in the supply chain when the government subsidy has diverse recipients. Specifically, in such cases, most of the papers focus on the government allocation of subsidies and emphasize the government's moderating role in economic development. Nevertheless, with the continuous social development and progress of the supply chain, the relationships between members have become closer, and the competition mode has gradually evolved from individual to group competition, that is, members in the supply chain have a stronger sense of cooperation and strengthen their competitiveness through contracts or other cooperations. Therefore, the mechanism where members of the supply chain allocate the government subsidy rather than the government deciding the amount presents research significance, particularly when the cooperators have different power for decisions. In addition, the goal of the government is to maximize the utility of the whole society while the goal of firms is to maximize their profits. Finding a mechanism to balance these two goals or choose the better one for a specific scenario is a meaningful research direction.

Second, more and more firms are gradually shifting from product to consumer orientation when making pricing and production strategies. Firms engaging in remanufacturing activities pay much attention to consumer reaction, especially their acceptance of remanufactured products. Numerous papers find measurement metrics on consumers' environmental preferences, but rarely distinguish their differences. Specifically, given the diversity of customer types, different or even the same measurement

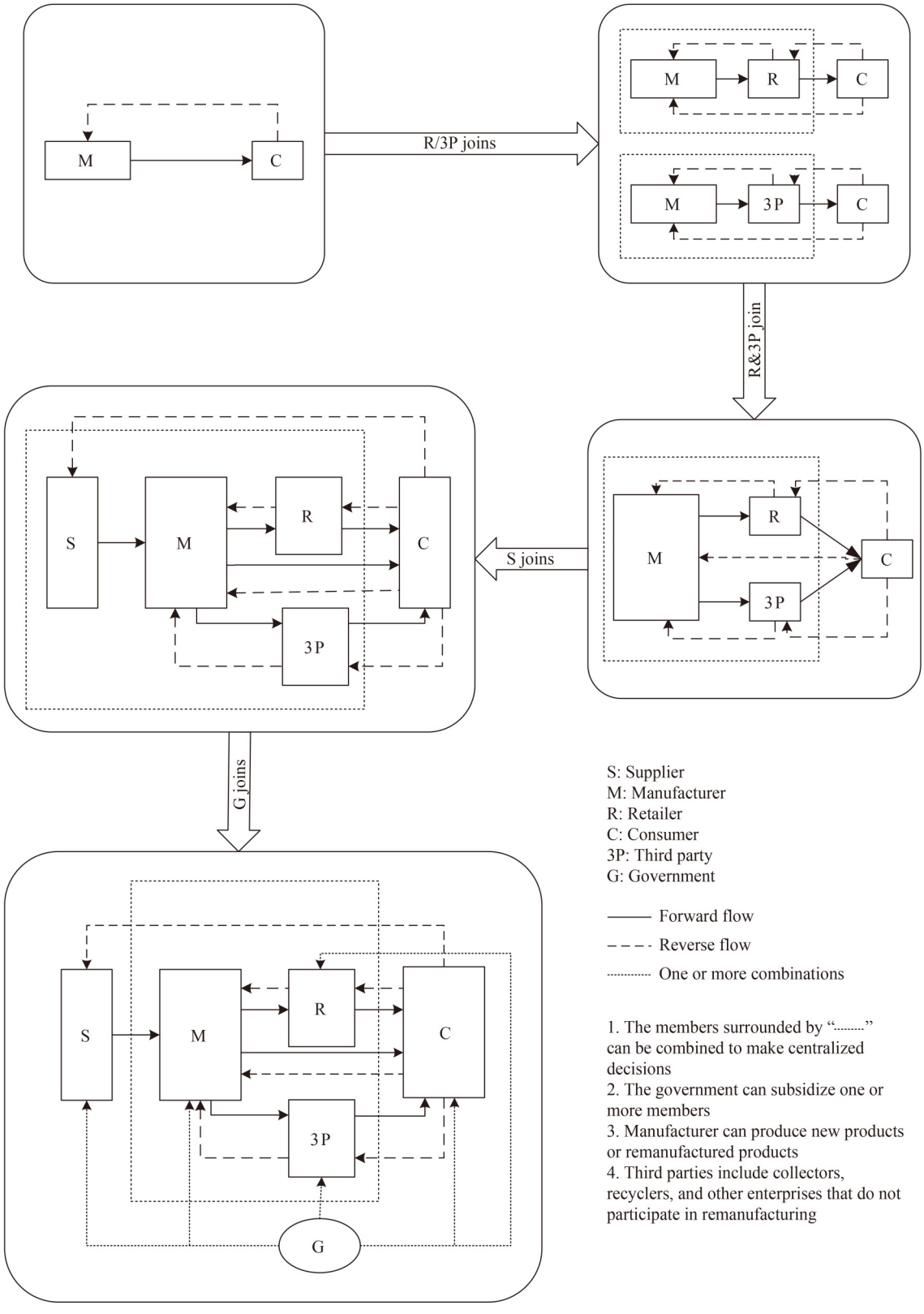

Fig. 4 Supply chain structures.

metrics on consumers' environmental preferences may have different effects on evaluating a customer group. Therefore, the application of different measurement metrics is worth exploring. The main reason why consumers have lower acceptance of remanufactured products is their concerns about quality. As a result,

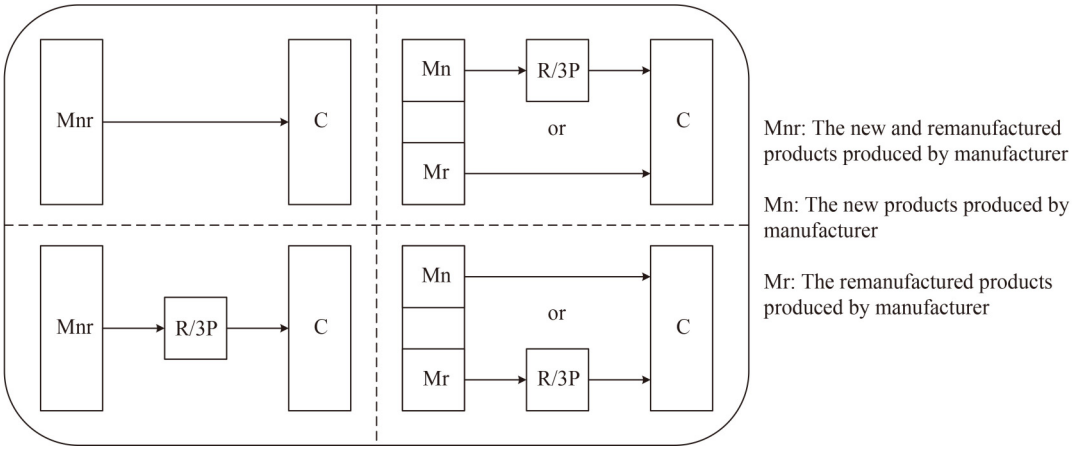

Fig. 5 Single channel for different products.

many studies examine pricing and production strategies in remanufacturing by dividing products into different grades. These papers certainly provide significant insights and accelerate the development of remanufacturing. However, we can still consider the effect of product quality on consumers and firms from other perspectives. For example, consumers' lack of trust in the quality of remanufactured products reflects their distrust of manufacturers or retailers. Therefore, a reliable mechanism for improving the trust relationship among (re)manufacturers, retailers, and consumers must be established.

Third, channel selection, competition, and cooperation among members in the supply chain are hot topics and are discussed in various papers. However, suppliers are largely ignored in such literature. When retailers engage in remanufacturing activities, manufacturers become the product suppliers who focus on new product development and production. The complex relationship of the supply chain then moves down, in which case we may consider the relationship between real raw material suppliers and manufacturers or even downstream members of the supply chain. When a supplier is a leader in the game, the optimal decisions may be different, such as in Li et al. (2023). Thus, further study can focus on the coordination mechanism between suppliers and manufacturers or the mechanism by which suppliers and manufacturers make centralized decisions especially when suppliers have more power than other members in the supply chain. In future research, we can pay more attention to firms' pricing and production strategies when suppliers engage in recycling activities. In addition, suppliers who provide raw materials occupy the production technology and supply channels, and thus may better recycle used components, making them "as-old-as-new", and finally sell them to manufacturers. Suppliers carrying out recycling activities can lead to interesting scenarios for research. For instance, competition and cooperation models can be constructed between recycling suppliers and other recyclers or suppliers of raw materials. The effect of consumers' environmental preferences for the suppliers' recycling and other channels on pricing and production strategies can also be examined. Considering suppliers when devising pricing and production strategies in remanufacturing can cause changes in supply chain structures, as reflected in Fig. 4.

5 Conclusions

This review discusses pricing and production strategies in remanufacturing from four perspectives, namely, governments, consumers, other supply chain members, and the entire supply chain. Specifically, we summarize the research status on pricing and production strategies in the remanufacturing activities when considering government policies, consumers' environmental preferences, product quality, channel selection, and competition and cooperation modes. Research methods and supply chain structures are also discussed. This study mainly proposes three suggestions for further study as follows. First, although game theory is a powerful tool used for dealing with optimization problems and analyzing competing behaviors of interacting members, intelligent optimization algorithms are worth using for answering questions on pricing and production strategies in remanufacturing practices. Second, when exploring such issues, the upstream members of the supply chain such as suppliers can prove an interesting focus, such as establishing competition and cooperation modes for suppliers who participate in recycling activities. Finally, how to balance the maximization of corporate profits and social interests under the background of remanufacturing is worthy of research.

Competing Interests The authors declare that they have no competing interests.

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