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Operations Management in the Era of Fast Fashion

Technologies and Circular Supply Chains

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Editors
Hau-Ling Chan
Hong Kong Polytechnic University
Kowloon, Hong Kong

Shuyun Ren
Guangdong University of Technology
Guangzhou City, China

Na Liu
Beijing Institute of Fashion Technology
Beijing, China

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Preface

The business models of fast fashion brands, such as Zara, H&M, and Primark are very successful in the marketplaces all over the world. Specifically, the common practices of fast fashion brands are to reduce the lead time (e.g., production) to better matching customers' demand and fast fashion brands' supply, create the products with highly trendy elements (e.g., colour) to satisfy the customers, and use an affordable pricing strategy to induce customer's purchase intention. However, fast fashion is regarded as the second dirtiest industry. It consumes huge amount of natural resources in the production process and poses a great threat to the environment even at the end of product life cycle. It is reported that the textile waste sending to the landfill increases significantly every year and it takes more than two hundred years to be decomposed. Over the past decade, the fast fashion brands are also under a considerable pressure from the stakeholders (e.g., customers, Greenpeace) to have sustainability commitment and they have adopted many green practices, such as eco-sourcing, using renewable energy, investing in technologies to enhance product design and create eco-friendly fabric. Recently, the fast fashion brands have expanded the scope and transformed their supply chains from linear structure to circular structure. The concept of having circular supply chain is to minimizing the amount of waste generated but maximizing the uses of resources that can be undergone for 3Rs principles (i.e., remanufacturing, recycling, or reusing).

Operations Management in the Era of Fast Fashion—Technologies and Circular Supply Chains aims to reveal the exploratory, qualitative empirical, and quantitative analytical studies on how to achieve the goal of being environmentally sustainable in the fast fashion era. This book reports the latest business practices, operations models, technologies, and circular supply chain structure of the fast fashion companies which provide many important managerial insights on the sustainable operations management in the fast fashion industry.

This book consists of three major parts, namely, (i) introduction and exploratory studies, (ii) intelligent fast fashion demand forecasting, and (iii) theoretical modelling research, reviews, and research agenda. These three major parts comprise the following specific topics:

- Sustainable Operations Management in Fast Fashion Era: An Introduction
- Sustainability in Fast Fashion Era: The Jan ‘N June Case
- Sustainable Practices in Fast Fashion
- Fast Fashion Demand Forecasting Models: A Comparative Study
- Impact of Search Index on Fashion Demand Forecasting—Panel Data Based Analysis
- Optimal Pricing, Green Advertising Effort and Advanced Technology Investment in Sustainable Fashion Supply Chain Management
- The Multi-Methodological Approach for Sustainable Operations Management in Fashion
- Overview and Research Agenda for Sustainable Operations Management in Fast Fashion Era.

Before closing, we would like to take this opportunity to express our sincere thanks to the operations team in Springer for their kindest support and advice. We are grateful to all the anonymous reviewers who have provided valuable review reports for all the chapters featured in this book. We are also thankful to all the authors who have contributed their research studies to this book. This book is partially supported by National Natural Science Foundation of China (Project account: 71801054). Last but not least, we would like to express our deepest gratitude to Prof. T. M. Choi (Jason) for his professional guidance, continued support, and insightful comments during the development of this book. We wish him all the success in his new journey at National Taiwan University.

Hong Kong, China — Hau-Ling Chan
Guangzhou, China — Shuyun Ren
Beijing, China — Na Liu

Contents

Contributors

Daniela Candeloro Sapienza University, Rome, Italy

Hau-Ling Chan Division of Business and Hospitality Management, College of Professional and Continuing Education, The Hong Kong Polytechnic University, Kowloon, Hong Kong, China

Tsan-Ming Choi Department and Graduate Institute of Business Administration, College of Management, National Taiwan University, Taipei, Taiwan

Zhicheng He School of Art and Design, Guangdong University of Technology, Guangzhou, China

Lei Lin Goergen Institute for Data Science, University of Rochester, Rochester, NY, United States

Na Liu Business School, Beijing Institute of Fashion Technology, Beijing, China

Shuyun Ren School of Art and Design, Guangdong University of Technology, Guangzhou, China

Ka-Man Sum Division of Business and Hospitality Management, College of Professional and Continuing Education, The Hong Kong Polytechnic University, Kowloon, Hong Kong, China

Shun-Mun Wong Division of Business and Hospitality Management, College of Professional and Continuing Education, The Hong Kong Polytechnic University, Kowloon, Hong Kong, China

Fengling Xie Business School, Beijing Institute of Fashion Technology, Beijing, China

Xiong Yu Guangdong University of Technology, Guang Zhou, China

Guangzhou Zhu School of Art and Design, Guangdong University of Technology, Guangzhou, China

Part I
Introduction and Exploratory Studies

Chapter 1
Sustainable Operations Management in Fast Fashion Era: An Introduction

Hau-Ling Chan, Shuyun Ren, and Na Liu

Abstract Being environmentally sustainable is one of the crucial activities in fast fashion supply chain management as the fast fashion industry has a serious impact on our planet. In the existing literature, numerous frameworks, methods, and studies have addressed the sustainable operations management (SOM) and circular supply chain management (CSCM). In this introductory chapter, we first highlight the importance of SOM and CSCM in fast fashion era. Then, we concisely review the recent literature and examine some important topics. We also introduce the papers featured in this book.

Keyword Fast Fashion · Sustainable Operations Management · Circular supply chain management

1.1 Introduction

Over the past two decades, we have observed that fast fashion is very popular and has expanded quickly. According to "Best Global Brand" reported by Interbrand in 2020, Zara and H&M are ranked as 35 and 37, respectively (Interbrand 2020). The common business practices of fast fashion brands are to reduce lead time (e.g., production) to better matching customers' demand and fast fashion brands' supply, create the

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H.-L. Chan (✉)
Division of Business and Hospitality Management, College of Professional and Continuing Education, The Hong Kong Polytechnic University, Hong Kong, China
e-mail: ling.chan@cpce-polyu.edu.hk

S. Ren
Guangdong University of Technology, Guangzhou, China
e-mail: Shuyun_shara@live.cn

N. Liu
Business School, Beijing Institute of Fashion Technology, Beijing, China
e-mail: sxyln@bift.edu.cn

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products with highly trendy elements (e.g., color) to satisfy the customers, and use an affordable pricing strategy to induce customer's purchase intention. However, in the fast fashion era, the public has a great concern on its negative impacts brought to the environment. Fast fashion is regarded as the second dirtiest industry, which significantly polluting our planet and negatively affecting the social well-being. For example, it is reported that over 300 tonnes of garments waste are sent to the landfills every day and more than 2.1 billion metric tons of air pollution are generated during the production process (McCarthy 2018; McKinsey & Company 2020). Therefore, the fast fashion brands should integrate the concept of "sustainability" in each stage of the product development process, from planning, design, manufacturing, to launching (Fung et al. 2021).

Sustainable Operations Management (SOM) is considered crucially important to relieve the negative impacts that the fashion industry has brought to our planet. The major challenge faced by the fast fashion brands for sustainable operations management is the dilemma between highly uncertain customer demand and considerable burden to our planet. The fast fashion products are characterized by short lead time, affordable price, highly trendy elements, which increase the complexity of conducting demand forecasting and the corresponding inventory planning. First, the trendy and short lead time features of the fashion products result in limited historical data for demand forecasting and the decision should be made "quickly". A poor demand forecasting performance may lead to overproduction, which will waste our scarce natural resources, generate unnecessary carbon emissions during the production process, and increase the landfill burden. Besides, consumers are environmentally conscious and they are more willing to pay more for a "green" product (Bemporad and Baranowski 2007; Zhang et al. 2015). With this consideration, it will significantly affect the decisions of each supply chain member when a sustainability program (e.g., cleaner technology, use of eco-materials) is implemented. Even though we have witnessed that many fast fashion brands have switched to employ different SOM approaches, the industrialists and academic researchers should keep exploring all the possible scientifically sound approaches to protect our environment and examine how the new approaches affect their operational decisions.

Recently, it is observed that the fast fashion industry has started generating values from those "disposal products" by using the 3R concepts (i.e., reuse, recycle, and remanufacture). For example, the fast fashion giant, H&M, has implemented the "unused apparels collection program" to gather the unwanted clothing from consumers for reuse, recycling and remanufacturing. Besides, H&M has also applied the advanced technology to separate the polyester and cotton blends fabrics collected from consumers and then use them for making new clothing. This sustainability commitment facilities the formation of "closed-loop supply chain" or "circular supply chain" (Choi et al. 2020). Circular supply chain management (CSCM) aims to minimizing the amount of waste generated maximizing the uses of resources that can be undergone for 3Rs principles. In other words, CSCM goes beyond SOM and it emphasizes the supply chain management with "zero wastes" and "regenerative" (Jabbour et al. 2019; Choi and Chen 2021).

The aim of this book is to present the current real-world practices on the circular supply chain formation and to reveal the methodologies and the optimal decision for sustainable operations in the fast fashion era. The findings and insights will serve as the foundation and evidence for further in-depth analysis, which can help to drive a better planet.

The book project consists of seven peer-reviewed articles on the sustainable operations or circular supply chain management in fast fashion industry. They are introduced according to the following classification, namely, (i) exploratory studies, (ii) intelligent fast fashion demand forecasting, and (iii) multi-methodological research, reviews, and research agenda.

1.2 Exploratory Studies

To better understand the fashion business practice to facilitate sustainable operations and circular supply chain management, an exploratory study can help to address it. Qualitative empirical (QLE) is the appropriate research method to give the details of the real-life practices or some observations by using the qualitative data (Hennink et al. 2011). Interviews with managers and case studies of companies are typical examples of the QLE research method.

In Chap. 2, Candeloro aims to show how a fast fashion company can contribute to environmental, economic, and social sustainability and reveal the possible opportunities and obstacles for having sustainable practices. She interviewed with managers in a German fashion company, Jan ‘N June (JNJ) and finds that the fast fashion brand JNJ has implemented numerous sustainable activities, includes using sustainable materials for producing the fashion products and packaging, supporting recycling, having social commitment, and improving the supply chain transparency. The author points out that the fashion brand owners should aware of the attainment of the certifications, controlling of the supply chain, and carefully selecting the right suppliers when.

In Chap. 3, Liu and Xie collect secondary information from literature and conduct observation on the industrial practice to investigate the current sustainable level of different processes of the supply chain, such as design, materials, retailing stores, packaging, and even marketing strategies, in fast fashion industry. The author suggests that the fast fashion brands should also consider the customer expectation on the sustainability when they implement different “green” programs, provide substantial education to the customers, and evaluate different impacts brought by the technology adoption for being sustainable.

1.3 Intelligent Fast Fashion Demand Forecasting

Having an intelligent fast fashion demand forecasting is crucial in sustainable operations management as a more accurate demand forecasting can reduce probability of having massive amount of unsold fashion product while satisfying the customer's wants and needs. Under this stream of study, quantitative empirical (QTE) is the commonly adopted research approach, which quantifies the quantitative performance and provides correlation verification on different operational decisions. For example, using machine learning algorithms to develop the forecasting models and then testing the performance of the models using real data belong to this category.

In Chap. 4, Xiong and Ren comprehensively review different computational models, including statistical panel data-based models, extreme learning machine models, and grey models, for performing demand forecasting in fast fashion industry. The authors then use the real data to compare the performance of the reviewed models in terms of speed, data sufficiency requirements, stability, ease of use, and accuracy. In addition, the authors also propose a panel data-based interval forecasting model and show that it performs better than that of the extreme learning machine-based model.

In Chap. 5, He et al. develop panel data-based models and explore the impact of search index on the performance of the forecasting accuracy when they are applied for fast fashion products. The authors then test the effectiveness of the proposed Search Index-based Panel Data (SIPD) model through a case study and statistically show that the panel data-based model with search index can better deal with the demand uncertainty and irregular pattern than that of the model without search index. The proposed SIPD requires fewer quantity of training data with a lower forecasting error level.

1.4 Multi-methodological Research, Reviews, and Research Agenda

The multi-methodological research approach means adopting two or more different research methods for one single study. For example, it can include case study, interviews and analytical modeling (Chan et al. 2020), case study and interviews (Sheffi and Rice 2005), survey and interviews (Speier et al. 2011). This research method can overcome the limitation of adopting one single research method.

In Chap. 6, Chan et al. first present the kinds of technologies that are implemented in the supplier's factory for sustainability commitment in fashion industry through a case study. The authors also develop an analytical model using game theory to derive the retailer's optimal pricing and marketing effort and the supplier's optimal wholesale price and technology commitment level. The authors find that it will result in a higher sustainability commitment when (i) the supplier's production cost or technology cost is higher or (ii) the retailer's marketing effort is higher.

In Chap. 7, Choi explains why it is important to conduct multi-methodological research approach for sustainable operations management in fast fashion era, explore how the multi-methodological research approach can be used, and propose the research directions in future study. To be specific, the author suggests that the "human–machine interactions" will be the future of the multi-methodological research approach to study the sustainable operations management.

In the last chapter, we discuss the emergence of circular supply chain structure in the fashion industry. We reveal the critical issues that should be analyzed in the sustainable operations management in fast fashion era, including advanced technology, customer involvement, collaborative strategy, and government support. In addition, we also propose the future research directions.

We believe that the findings of this book not only contribute to the literature in deriving more robust research findings but also provide more scientifically sound research guidance to practitioners and fashion companies in the real world.

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Chapter 2
Sustainability in Fast Fashion Era: The Jan ‘N June Case

Daniela Candeloro

Abstract Sustainability is an important topic in fast fashion system as the fast fashion companies have been blamed for causing harmful repercussions to the environment and society. This study aims to demonstrate the existence of a valid alternative to fast fashion, to achieve environmental, economic and social sustainability. A case study of a German fashion company, named Jan ‘N June (JNJ), which combines sustainability, voguishness and competitive prices is conducted to reveal the methods and solutions that are useful to develop a sustainable supply chain in fashion industry. From the case, we uncover that JNJ commits to use sustainable materials, conduct recycling, consider social welfare, adopting eco-packing as the measures for being sustainable and competitive in the market. Besides, we also find that transparency is important in achieving sustainability. Currently, there are some methods to apply transparency within the fashion company, including communicating the sustainable practices through online channels, using ECO-ID labels, and adopting textile certifications.

Keywords Sustainability · Fast fashion · Environment · Social · Economic

2.1 Introduction

In the fast fashion era, a significant number of consumers still demand more and cheaper products. One of the consequences of this behavioural attitude is that the fast fashion market worldwide increased impressively from 2008 to 2018, reaching respectively a global market value of 21 billion US dollars and 35 billion US dollars, and the forecast shows that the market will increase up to 44 billion US dollars in 2028 (O’Connel 2019). These data show that fast fashion consumerism is undoubtedly rooted in our culture, causing harmful repercussions to the environment and society.

Nevertheless, there are surveys and reports which ascertain a rising demand and interest in sustainable fashion from consumers. For example, in the McKinsey report

D. Candeloro (✉)
Sapienza University, Rome, Italy
e-mail: daniela.candeloro@uniroma1.it

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"The state of Fashion 2017" there is a relevant percentage of customers who seek sustainable fashion products (32% of customers in Europe and the US, 65% of customers of the emerging markets such as India and China) (Lam 2017). An additional survey, conducted by Fashion Revolution (2018), confirms that 68% of the 5,000 participants in Germany, UK, France, Italy and Spain believe that government "has a role to play in ensuring that clothing is sustainably produced". These data underline consumers' increasing need and attention regarding sustainable fashion, also demanding institutional regulation to guarantee sustainable aspects.

Consequently, sustainability is becoming a recurring topic within the fashion system, and simultaneously the whole planet is witnessing a revolutionary and rising mindset: the generation Z, along with older generations, are concerned about warning situations and are taking action for a better world. In this new social environment, many brands started to define themselves as "sustainable". However, is sustainability a mere trend? Greenwashing certainly is. If fashion companies promote themselves and their products through a marketing communication focused on buzzwords like eco, organic, environmentally friendly, or green, but do not practice any form of sustainability, creating misleading information towards consumers (Henninger et al. 2016). Indeed, sustainability requires a sincere and genuine willingness to change things for real, and it is vital to implement a new and different way to shape a more sustainable fashion system.

Therefore, if a big amount of people keeps buying these unsustainable products, despite there are a rising sensitivity and awareness towards sustainability, how can this situation be changed? Working on education or attractiveness for a more sustainable fashion item are excellent and practical solutions. However, in the meantime, what can a fashion operation management do to improve this critical condition?

Historically, human evolution has always been characterised by the presence of technology, and technological progress is undoubtedly one of the keys which can help to build a real sense of sustainability. Currently, for example, technology enables recycling, transforming waste into textiles, communicating transparency through the web, or measuring environmental (Candeloro 2020) and social impact which fashion companies can generate. There are different forms of sustainable fashion, all of them built on strong beliefs and technological progress. The following section explains the area of study, disclosing the real significance of sustainability and fast fashion.

2.1.1 Sustainability in Fast Fashion Era: Thematisation of the Problem

In 1987, the World Commission on Environment and Development defined sustainability as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Report of the World Commission on Environment and Development: Our Common Future 1987). This definition is still valid and meaningful, even though the concept has changed throughout time.

In the beginning, it was associated mainly with environmental meaning; nowadays, it extends its significance to the social and economic areas. The evolution of the concept changed along with the interest which institutions and consumers have demonstrated towards the topic. Indeed, the institutions, along with the people, claim the urgent need to change the world for the better. In 2015, United Nations defined 17 new Sustainable Development Goals (SDGs) and the 169 associated targets which is one of the most remarkable institutional worldwide documents. These 17 SDGs are part of the 2030 Agenda, and the European Union has also committed to making these goals effective (Europaeu 2017). The program aims to

> end poverty, to reduce inequality, to tackle climate change, to create collaborations for the goals, to develop responsible consumption and production, decent work and economic growth, good health and well-being, life below water, clean water and sanitation, climate action, life on land, peace justice and strong institutions, affordable and clean energy, gender equality, quality education, zero hunger, industry innovation and infrastructure, reduce inequality, sustainable cities and communities, no poverty (United Nations, 2015).

It is possible to identify three different, consistent and well-defined areas, where sustainability works towards the economy, environment and society. Therefore, fashion should address sustainability in terms of economic, social and environmental meanings. However, fast fashion and sustainable fashion have been, and still are, perceived as an oxymoron because fast fashion is under the spotlight for being reasonably perceived as unsustainable. More specifically, fast fashion is characterised by specific features such as speed, time, risk and cost. On one side, all these aspects of fast fashion production are implemented to create an efficient and fast industrial system (Buzzo and Abreu 2018); on the other side, fast fashion is identified as the glorification of waste due to the low quality and the short life cycle of its products (Joung 2014). It appears evident and consequential that most of these fashion products, as a result, become disposable within a shorter time and create and worsen the amount of global waste (Binet et al. 2018). These kinds of intrinsic features, along with the aesthetic attractiveness, empower fast fashion to create a social culture profoundly devoted to compulsive and spasmodic consumerism. Not surprisingly, consumers are increasing their shopping quantity in fashion each year, reaching 80 billion items of clothing. Furthermore, in this economic environment where the higher is the demand, the shorter is the production time, the fast fashion industry is contributing to the low quality of the fashion products (Buzzo and Abreu 2018).

However, this compulsive production and consumption have disastrous consequences, in fact, textile, clothing and fashion are recognised as one of the most unsustainable industries worldwide (Pal 2016), and it is becoming increasingly harmful from many points of view; therefore there is the need of fashion brands to create values according to sustainability.

Inside this worrying social phenomenon, there is also a rising number of consumers highly interested in buying sustainable fashion products, concerned about sustainability and wishful to consume responsibly. Consumers would like to know more and better about how a fashion product is manufactured, and the fashion industry should meet consumers' needs and should embrace a more respectful and responsible production.

For this reason, technology helps to create an industrial system focused on being more sustainable. This objective is not simple to embrace due to the complex supply chain model which implies the participation of many factors, but it is imperative that the planet needs this change and consumers are aware of this necessity. In this sense, there are several ways to transform the fashion system into an apparatus which is coherent with the fundamental concepts of sustainability, such as recycling, reusing, growing organic crops and supporting communities.

2.1.2 Sustainability in Fast Fashion Era: Research Objectives and Methodology

In view of the above, the overall aim of this study is to demonstrate the existence of a valid alternative to fast fashion, which is respectful of environmental, economic and social sustainability. This essay conducts a case study of a German fashion company, named Jan 'N June (JNJ), which combines sustainability, voguishness and competitive prices. The combination of these elements is important because if a fashion product is only sustainable but not appealing, it could not satisfy consumers' aesthetic needs (Beard 2008). In the meantime, price is still retaining a pivotal role in convincing numerous consumers to buy a conventional product rather than a sustainable one. In other terms, price is one of the factors which still trigger the so-called "behaviour gap" among those consumers who would like to buy more sustainably, but they eventually do not (Wiederhold and Martinez 2018). So, the specific goal of this research is to identify what are the possible keys to solve these ostensible incompatibilities. In particular, the present research, fuelled by the aforementioned case study, tries to investigate methods and solutions useful to make a sustainable supply chain, underling which characteristics encourage fashion companies to realise a business centred on the criteria of circular economy and sustainability in general.

For this purpose, this study gathers data from a wide variety of sources including academic journals, books, reports, periodicals and, for specific information about the German enterprise analysed, the official company website and a questionnaire filled by the co-founder of Jan 'N June, Juliana Holtzhei. Topic, aims, sources and the chosen method of research have shaped the essay text completely. More particularly, the case study, as a powerful tool to examine complex and multifaceted phenomena and theoretical concepts (Baxter and Jack 2008; Mitchell 1983), led to an accurate partition in sections of this study. Therefore, the sustainable materials, recycled textile, packaging, social commitment, transparency and other sustainable practices are revealed in Sect. 2.2. This partition, furthermore, is also valuable to show several of the dimensions composing sustainability and how many solutions exist to revolutionise certain harmful ways of production. In Sect. 2.3 we conclude a set of resolutions to balance environmental, economic and social sustainability. And this even though they are considered in mutual contrast, especially the environmental and economic dimensions (Genovese et al. 2017).

2.2 Case Study: Jan ‘N June

2.2.1 The Company: An Overview

Jan ‘N June (JNJ) is a German fashion company which has been able to create affordable fashion collections maintaining sustainable operation management within its supply chain. Most of the time, sustainable fashion is much more associated with slow fashion, luxury fashion, and it is seldom merging the sustainable idea of fashion with affordability. However, since JNJ was born in 2015, this challenging combination has been the main goal for the two CEOs, Juliana Holtzheimer, product management and Anna Bronowski, social media marketing, who want JNJ to be “an actual alternative to fast fashion”. Indeed, the two CEOs are passionate about fashion but also profoundly aware of how damaging it can be, willing to change the system for the better. Through the result of the questionnaire (refer to Appendix), it is known that CEOs desire to offer a sustainable but also fashionable product. Indeed, this company aims to differentiate itself from both sustainable fashion brands and fast fashion brands. JNJ declares its standards in terms of sustainability are high, all the materials are certified, and there is a consistent control of the production. The company is not certified yet; however, JNJ decides to work only with certified fabrics and to implement a transparent approach in the whole supply chain. Juliana Holtzheimer states that JNJ is based on their personal need and that they communicate sustainability and their values within all the supply chain, from their stakeholders to their final customers. Moreover, JNJ focuses on building a long-term relationship with its suppliers; the founders choose them mainly within Europe, due to the fact that they want to create shorter distances as possible. Sustainability requires the respect of ethical methods; therefore, it is crucial to assure that all the sustainable requirements are successfully addressed.

The company aims to have substantial control of the production, which is based in Poland, precisely in Wrocław. The process is regulated by straight and rigid contracts which guarantee a stable business relationship only and exclusively with just one supplier there, the Ciborski family. Moreover, the CEO assures that “they also produce in Portugal and all sewing facilities are being visited twice a year at least”. This pervasive control of the supply chain allows the management to assure consistent transparency and simplicity in all the productions processes.

The CEO also stresses the fashionable aspect of JNJ’s products, a characteristic that appears to lack in many sustainable fashion brands, which, she says, “especially in Europe, most are rather streetwear or basics”. JNJ competes with other brands also in terms of products’ price range: JNJ is about 65€ on average (T-shirts start at 33€ and coats can be up to 260€), the CEO says that it is not the same as Zara or H&M, but definitely in the same range as the brands &Other Stories and COS. She assures that JNJ can manage to sell its items on competitive price because the company has a smaller margin compared to those of other fast fashion brands and that it has “to make larger quantities from the beginning on to reach economies of scale”. These features allow the company to differentiate itself from many fashion brands. Simultaneously it builds an ecological and fair supply chain, becoming an effective alternative to fast fashion products. However, there could be some risks in this business strategy and the main one in JNJ is the financial one. Indeed, the CEO explains it is very hard to maintain liquidity because JNJ pays its suppliers out “an upfront or just after delivery while our shops and reseller usually take at least 30 days and more to pay their goods”.

2.2.2 Sustainable Materials

Nowadays, it does not exist any kind of textiles with 0% environmental impact yet, and the co-founders Juliana Holtzheimer and Anna Bronowski are highly conscious of that. Therefore, JNJ commits to choosing textiles whose life cycle has less impact as possible; the materials used for the products are coherent with the philosophy of sustainable fashion (ETE, 2019). Moreover, the fashion company intends to defeat any kind of greenwashing materials forms, requiring certifications from its suppliers. In this way, the sustainable qualitiesGlobal organic textile are reinforced and guaranteed by certifications, which enhance consumers’ trust in their purchase behaviour (Chen and Wei 2012). Most of its organic cotton fabric is GOTS, or IVN-best certified. GOTS stands for “Global organic textile standard”; producing organic cotton, rather than the conventional one, avoids the implication of toxic chemicals (Lakhal et al. 2008), respecting and protecting the environment. In terms of market opportunity, organic cotton production is globally increasing, for example, only from 2017 to 2018 there was a growth of 56%, reaching 180,971 metric tons and in 2019 reported a market share of 0.7% of the total cotton production worldwide (Worley 2019). Instead, IVN stands for International Association of Natural Textile Industry and guarantees the “highest level of textile sustainability by applying the maximum currently achievable parameters to production and product” (www.naturtextil.de). Hence, JNJ decides to produce its clothing with eco-friendly fibre, since the crop is regulated by biocontrol agents or botanical pesticides, avoiding the use of toxic pesticides which can alter the delicate equilibrium of the ecosystem. Cultivating organic cotton has positive consequences on the environment; indeed, water, air and soil are not poisoned thanks to the exclusion of fertilisers and pesticides. In fact, without synthetic chemicals, insects and pests help plants to grow naturally, as part of a symbiotic exchange. Besides this, social responsibility is crucial within organic cotton cultivation, because the latter uses resource already available on farms and engage the workforce to apply their skills in a socially responsible way (Shahid and Tassawar 2011), and respecting the workers avoiding work in contact with toxic substances which are harmful not only for the entire environment but also for humans.

JNJ also uses organic linen widely in the summer collection and GOTS-certified. Even though linen is already a sustainable natural fibre to produce, due to the almost complete absence of pesticide or fertilisers needed and the lower amount of water utilised compared to cotton (Jones 2019), the certification of being organic is an additional transparent method to certified the ethical character of the production. This organic fibre comes from the linen plant without chemical substances as those which soften, waterproof or whiten. It has higher resistance than cotton, and the longer fibre is usually used for finer-grained textile, whereas the shorter ones are destinated for producing unrefined textiles (www.naturalogico.it).

Along with organic cotton and linen, there is also recycled cotton within collections. However, the company specifies that it is impossible to produce 100% of recycled cotton with good quality and for this reason, it aims to have even more sustainable recycled cotton by mixing it with the organic cotton, rather than the virgin one. Another sustainable textile used by JNJ is Tencel. The origin of this fibre is environmentally friendly since it is created from a production “based on wood originating from sustainable forestry”. The respect of the environment is crucial in the manufacture of Tencel, which is a fibre obtained from wood pulp and then transformed into cellulosic fibre. The solvent-spinning process adopted in the transformation implies the use of recycled process water and the reuse of the solvent at a waste rate of less than 1%. Furthermore, Tencel Lyocell comes from renewable raw wood, created by photosynthesis, is compostable and biodegradable, and the microparticles released break completely down during the washing (www.jannjune.com). This fibre performs high textile qualities; indeed, this kind of fabric is similar to silk, in its fluidity and drape (Badr et al. 2016). This description is also confirmed by the CEO who says that “It is the clean version of a viscose mainly used for garments with a flowy and fluent look”. Other benefits of this botanic fibre are the following. First, the moisturising management typical of Tencel allows the skin to breathe correctly and to maintain stable and equilibrated body temperature. Furthermore, the fibre absorbs moisture more than cotton, which allows the fibre to support the body’s regular regulating system, keeps the skin fresh and dry. Therefore, the botanic fibre is versatile and shows greater strength compared to other cellulosic fibres (www.tencel.com/sustainability).

Along with the clothing, JNJ also sells jewellery, which is supplied by the company “Machete” from the US which furnishes itself from handmade pieces from Atlanta (GA), France, Italy and other small studios. Machete guarantees that the materials are not petrol-based, renewable and eco-friendly. The metals used are ethically sourced and recycled brass. This brand is specialised in tortoise acetate earrings and patterns, and other accessories made with cellulose acetate which is an “eco-friendly polymer derived from cellulose” and biodegradable and non-toxic (Marrez et al. 2019). Another eco-friendly material is the bio-acetate “phthalate-free and made from cellulose acetate (which comes from wood) and plasticiser (derived from the esters of citric acid) renewable and biodegradable” (Santamaria 2019). Machete is also frequently published in some of the leading fashion magazines worldwide such as Vogue, Bazaar, Instyle and Atelier Doré (www.shopmachete.com), which means that the media’s attention on sustainability is increasing.

2.2.3 Recycling

Recycling is one of the solutions which the fashion system can embrace, as already explained, for example, in the Machete company. It is an act of transformation, which gives a second and even better life to a used material: “better life” because it is meaningful since it expresses not only the need but also the “will” and “act” to change the business for the better. Following this concept, JNJ uses recycled polyamide, mixed with 35% of elastane. In this operation, the firm is supplied by the company Aquafil with its trademarked fabric Econyl®, which is created by gathering and transforming garbage and old fishing nets from the ocean into fabrics. The process consists of collecting the garbage cleaning the oceans from old fishing nets, and recovering all the possible nylon. The second step is to regenerate the nylon waste. The extraordinary aspect is that at the end of the transformation, there is not only a simple recycled nylon but a kind of recycled nylon which appears identical to virgin nylon. Afterwards, carpet yarns and textile yarns are created with nylon (www.econyl.com). Another highly positive aspect of Econyl® is that it can be continuously recycled. This fibre production is simultaneously able to help oceans and to reduce the global warming impact of nylon by more than 80%, saving 70,000 barrels of oil and 57,000 tons of CO_2 every 10,000 tons of Econyl® raw material, compared with the materials from oil (Acquafiland 2018). The fabric has “smooth and cool” sensations on the skin, moreover, it has thermo-regulated properties which enable the skin to breathe even in sporty circumstances. This sustainable recycled polyamide is also certified as GRS-certified (Global Recycling Standard). Another environmentally friendly fabric chosen by JNJ is recycled polyester derived from industrial waste or used plastic, like PET bottles and is certified by Global Recycled Standard -certified. Polyester is the most recycled fibre compared to other textiles, and it can be recycled 100%, and the recycling process is guarantee certified with the Global Recycled Standard (Muthu and Gardetti 2016). The Textile exchange organisation predicts that there will be an increasing volume of recycled polyester worldwide and that within 2030 all polyester will be recycled (van Elven 2020). The transformation process implies first the sterilisation of the bottle for then reduce them in small chips. The following step is to heat the chips and to put them into a spinneret where they can become yarn. There is the possibility to recycle it repeatedly not compromising the quality of the renowned textile material (Ross 2015). In this way, JNJ, producing its clothing with recycled polyester, encourages the creation of the closed-loop system, trying to minimise waste in landfills. Furthermore, JNJ supports the Tenowa® project, which stands for “textile no waste” supplied by the company Riopele. Tenowa® is a brand developed by Riopele which creates new textile from the reusing and recycling waste from the textile and agro-food industry. In particular, Riopele is specialised in using “all scraps from weaving production to make it into a new material which comes out with a look similar to raw silk” explained Juliana Holtzheimer, adding that it appears to be “quite unknown material” since it is a brand of one of their woven suppliers from Portugal. However, thanks to its technological application in the circular supply chain, which is also focused on low energy and water consumption (www.jannjune.com), Tenowa® won the "Product Innovation Award COTEC 2018" and "iTechStyle Awards' 18—Sustainable Product"; indeed, the textile is made from the application of high level of technologies and automation (www.vilanovadefamalicao.org, 2018). A critical aspect underlined by JNJ's CEO is the awareness that it does not exist the perfect sustainable material at the moment, but she seems to be highly hopeful that it is "yet" to come. Each textile owns its positive and negative features in terms of "sustainability, characteristics, usability and comfort." JNJ tries to use different fabrics in order not to compromise too much an aspect in favour than another one.

2.2.4 Bringing Environmental Sustainability with Social Commitment

The fashion industry is responsible for the fourth largest industrial disaster in history: on 24 April 2013 the Rana Plaza building collapsed, destroying five garment factories "all manufacturing clothing for the western market". 1,100 people died, and 2,500 were injured, most of them were young women (Fashion Revolution 2019). This episode was so tragic to push consciences to look at how fashion products are made and which are the working conditions. In this sense, sustainability also concerns the genuine willingness and the desire to embrace projects which aim to improve social environment.

JNJ is aware of this delicate aspect, and for this reason, it is involved in projects about social initiatives. One of their organic cotton suppliers and some of their favourite fabrics come from Uganda; JNJ can use and buy this material every season (e.g. white poplin), from the "Cotonea" project.

The cultivation of organic cotton is better than the conventional one not only for the environment but also for the safety of the workers. Conventional cotton usually requires the use of toxic pesticides, which causes health and environmental hight damages. In this situation, the developing countries are the most affected ones. Indeed, due to the weak regulatory system, farmers are neither well informed of the dangers nor protected with adequate equipment and skills (Myers 2001). By contrast, Cotonea provides natural seeds for the farmers in Uganda; and the cultivation of organic cotton allows the crop rotation (sesame, chilli, sunflower seeds, beans, etc.) which enables to feed the population of that area. Furthermore, the union of the local project partners and the sustainable oriented project of Cotonea creates possibilities and opportunities for people to have a livelihood and to support their education and to care about their health (www.cotonea.de). This aspect is crucial for a country which unfortunately has many social inequality aspects and where the total population is 47,258,684, of whom the 40%, precisely 19,562,313, live in extreme poverty situation (www.worldpoverty.io/map).

Moreover, the genuine focus on the sustainability of Cotonea also reflects respect for the environment, and as a matter of fact, there is an increased percentage of renewable electricity used. It is indeed reported that from 2016 to 2017 there has been a growth of hydropower and solar power: from 30 to 49%. Another social sustainable contribution is the collaboration with the offcut company KAPDAA, which supports local and fair production in India. KAPDAA is specialised in creating new products that utilise all the leftover fabric discarded from design or fashion companies. Offcuts generated during fashion production represent another environmental problem because part of the textile waste is often left in the landfill and conventional production of cotton for only one fabric-covered notebook requires 270 L of water. Instead, the utilisation of already existing fabrics to produce a new product reduces impressively the water and energy footprint left by textile industries. JNJ aims to regain textile offcuts making accessorise, notebook covers, scrunchies, headbands and face masks and the collaboration with KAPDAA helps the two companies to work for the same sustainable environmental objective. Furthermore, this project has a sustainable social aspect since it supports local and fair production in India.

2.2.5 Packaging

The e-commerce of the fashion industry is the largest within the B2C global market, and its value was US$620.6 billion in 2019, and it is predicted that it will grow up to 12.2% per year, reaching a total market size of US$991.64 billion by the end of 2024 (Shaulova and Biagi 2020).

E-commerce is a popular channel to buy fashion products; however, it implies the utilisation of disposable packaging for delivering fashion products, and it has a significant environmental impact. Indeed, the production of packaging material reaches 22% of one online purchase' carbon impact (Chueamuangphan et al. 2020). Only in the US, it has been estimated that 165 billion packages are shipped each year sacrificing more than 1 billion of trees for the cardboard (Bird 2018).

Therefore, JNJ decides to deliver its products with recyclable boxes and reuse them as often as possible (see Fig. 2.1). If a customer returns the product, the company aims to reutilise the carton box "as many times as possible". Naturally, the reuse has its limits and, indeed, Juliana Holtzhei specified that "usually a box can survive 2 × 2 transportation until we need to use a new one".

The company states to apply the same behaviour for every printed paper made by their recycled paper and only if necessary. By contrast, usually, it is highly common for fashion companies to wrap their products in plastics in their boxes, generating a harmful and negative environmental impact. JNJ does not use any plastics to protect its shipped items, assuring that they will arrive intact in their boxes to its consumers.

Fig. 2.1 June ‘N June’s boxes with sustainable claim message. Reproduced from www.jannjune.com/production-sustainability/ with permission from JAN ‘N JUNE

2.2.6 Supply Chain Transparency

The company appears to be highly devoted to transparency, which is more communicated through its official website rather than on its social media channels. In fact, on its website, there is a map that shows the locations of the offices, suppliers, and companies which provide trims and where they take the raw material. The points are differentiated in a scale of grey on the map, and passing on these points with the mouse, a vignette explains how JNJ relates to that place (see Fig. 2.2).

Another interesting aspect of JNJ’s transparency is the accessibility of the supply chain information on its clothing. At the beginning of the business, the company did not own significant financial resources to obtain costly certifications such as GOTS; however, the CEOs did strongly want to communicate their sustainable approach. JNJ then decided to sew the so-called “Eco-ID” label in its garments, which is still kept since the company believes “it is very valuable for the customer”. It is a label with a QR code which, when scanned, reveals each single step of the entire supply chain (see Fig. 2.3). In other words, it means that it discloses information from the raw

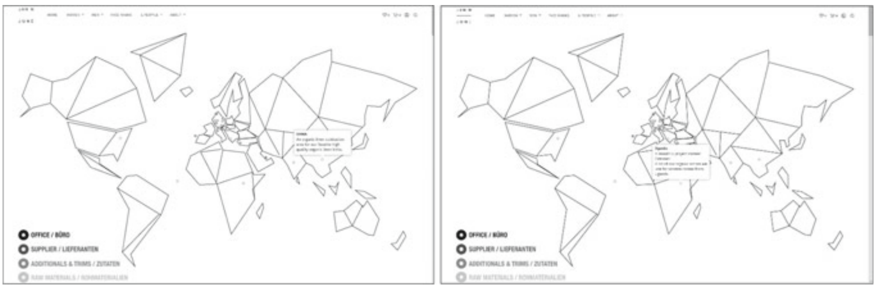

Fig. 2.2 JNJ’s supply chain geographical map. Reproduced from www.jannjune.com/production-sustainability/ with permission from JAN ‘N JUNE

Fig. 2.3 Eco-ID JNJ's label with QR code. Reproduced from www.jannjune.com/production-sustainability/ with permission from JAN 'N JUNE

material resources to the finished product. The CEOs assure to strongly emphasise the transparency through the "Eco-ID", which define as "the passport of each item".

2.2.7 Other Sustainable Practices

In order to reinforce the circular economy, JNJ is also trying "not to mix manmade fibres with natural fibres within fabrics since it is very hard to recycle them again (e.g. 50% organic cotton 50% recycled PES). The only exception is the use of elastane (which makes it possible to give a garment more longevity before each washing) and material that has been recycled already (e.g. TENOWA)". Furthermore, the CEOs believe "that recycling options will get better and better. But there is still a lot of development necessary". Moreover, when products are not sold, the company "just keeps selling them either online or at pop stores and samples sales" and sometimes it sells "products to circular online rental services for fashion".

2.3 Conclusion

The case study, enriched with the questionnaire, allowed the essay to have a comprehensive understanding of which are opportunities and limits that a fashion company can have in focusing on sustainability.

The fashion company JNJ has demonstrated that it is possible to implement sustainable approaches from the beginning to the end of the supply chain, concerning the impact a fashion company can have in terms of environment and society (see Fig. 2.4). First of all, the choice of the textiles and materials used by the company, and the awareness of the environmental footprint that the product can cause in its

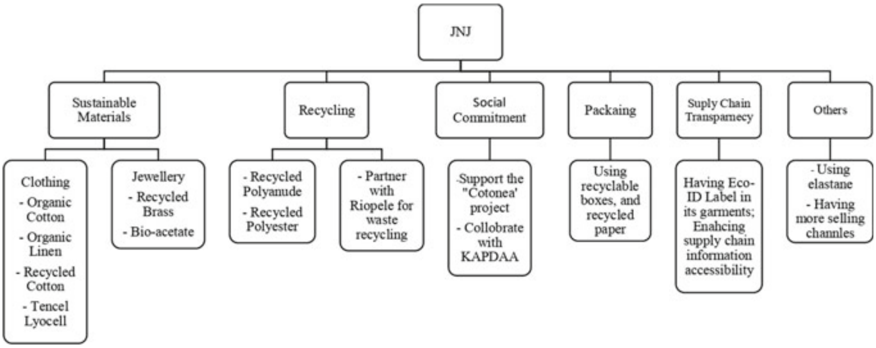

Fig. 2.4 Summary of the sustainable practices of JNJ (*Source* Created by author)

whole life cycle are crucial. Indeed, JNJ's environmental sustainability is expressed in heterogeneous areas of the supply chain: from textile production to the delivered product in online shopping. The logic is to start sustainability from the beginning of the creation of raw materials, i.e. from the farm; indeed, the fibre crops of organic cotton and organic linen are considered sustainable because the methods adopted for growing plants impact less as possible the environment, avoiding toxic chemicals which can be harmful also for humans. Along with the organic cotton and organic linen, the analysis underlines the positive environmental characteristic of the botanical fibre Tencel, since it is responsibly created without negatively impacting nature, creating fibres that have environmentally friendly features, and that are produced through a respectful process. In addition, the natural origin of these fabrics enables the fashion product to be biodegradable. Therefore, choosing organic textiles helps a fashion company to accomplish sustainable goals within the supply chain. Another sustainable practice which lets fashion companies help the planet is the production of recycled textiles. Recycling lightens the planet from polluting waste and transforming already used materials into new ones is an opportunity for sustainable fashion companies. JNJ decides, for example, to use Econyl, which derives from the ocean's waste, and recycled polyester. The company utilises also recycled polyester and recycled cotton and all the scraps from weaving production recycled.

An interesting aspect underlined during the study is that these fibres productions are environmentally friendly in their saving on energy and water. This characteristic discloses that those suppliers who manufacture sustainable textiles are committed to applying the same sustainable approach not only in the fabric itself but also in the whole system of production. Hence, these sustainable fibres have intrinsic sustainable characteristics which belong to the fabrics' features and also to the method used to produce them. The intention to preserve nature is also expressed within the e-commerce supply chain, where carton boxes are not disposable, but reused as long as possible, not throwing away materials which can still be used, avoiding useless waste.

Sustainability, as said, also regards social sustainability as well, and the company demonstrates to collaborate with projects which guarantee fair workers' conditions and that improve lives. Social sustainability generates value within the fashion company, creating social opportunities and enriching communities' lives and social environment; gaining positive results in this sense requires to have a genuine willingness to build well-being "for" and "with" society. Fashion companies should comply with sustainability and truly adapt their actions consistently. For this reason, transparency is extremely required. Currently, there are some methods to apply transparency within the fashion company; JNJ aims to communicate all its sustainable approaches through its online channels and its ECO-ID label. In this way, the company can share information about the origin of its product and how they are made. Moreover, JNJ reinforces transparency and credibility through textile certifications, which guarantee sustainable characteristics of the fibre in itself and a sustainable supply chain.

JNJ cares and encourages circularity in its production, trying to avoid mixing natural fibres with synthetic ones since it would be difficult to recycle. Nevertheless, it is necessary to specify that the recycling process also depends on the consumer's choice; hence, there is a realistic percentage of environmental risk that this product, even if made with fabrics that can be recycled, could end in the landfill due to the consumer's decision. In other words, consumers are crucial players in the circularity of the fashion system since their behaviours can affect the outcome of circular fashion models. Besides, producing garments without mixing too many different materials is essential because it allows recycling at the end of the clothing's life cycle, supporting organic production and reducing waste and decreasing pollution. Practicing social sustainability, respecting workers and enriching society is important as well. All these sustainable business initiatives need to be adequately supported by consumers, who are invited to investigate how their products are made and the impact that they can have, environmentally and socially, without consuming compulsively. This can be possible only if customers buy responsibly and behave accordingly. In this sustainable supply chain approach, JNJ decides to be a competitive alternative to fast fashion, offering also its product with a competitive price; every new business has challenges, and to pursue this objective, the company managed to have less margin compared to the leading fast fashion companies. This financial aspect, along with others, like the fact that it pays its suppliers in advance, implicates a certain financial risk which JNJ decided to face. Furthermore, the company underlines the fashionable features of its products, and characteristics which have in common with fast fashion companies; but, by contrast, JNJ also emphasises on sustainable textiles and practices sublimes aesthetics. Finally, it is worth underlining how the genuine interest in sustainable supply chain aspects reflects the CEOs' needs. Indeed, pursuing sustainable objectives requires more attention, multiple certifications and the control of the entire supply chain, along with a meticulous choice of suppliers who follow the same sustainable approach. In addition, if on one side fashion companies have the potential to drive their core business towards sustainable supply chain performance, on the other hand, consumers have to collaborate in order to endure sustainable consumption and to help to close the loop in the circular economy.

In conclusion, in the fast fashion era, some small but emerging fashion companies are able to implement sustainability through different innovative approaches to compete with other fashion brands. Their operations challenge the conventional way to think about supply chain management shaping it through innovative and respectful values that aim to pursue a more sustainable fashion system.

Appendix

Questionnaire

Questions	*Answers*
1. What does Jan 'N June have in common with the majority of the fast fashion brands?	What we definitely have in common is highlighting fashionable items. Many eco brands are very basic and therefore, not a real alternative to fast fashion. Our prices are not on the same level as H&M or Zara, but definitely in the same range as &other stories and COS
2. What are the differences between Jan 'N June and the majority of the fast fashion brands?	We are not only caring about how fashionable items and aesthetics but also about the fair and ecological supply chain
3. What does Jan 'N June have in common with the majority of the sustainable fashion brands?	Our standards in terms of sustainability are high and the core value of our brand. All materials we use are certified, and we produce in Poland and Portugal. All sewing facilities are being visited by us twice a year at least
4. What are the differences between Jan 'N June and the majority of sustainable fashion brands?	Currently, we are in the process of getting the GOTS certification since we do not have one yet Also, we are emphasising the fashionable party of clothing more than most sustainable fashion brands. Especially in Europe, most are streetwear or basics
5. What is the mission of Jan 'N June?	Being an actual alternative to fast fashion!
6. How do you make your mission valuable and trustworthy?	We founded this company because we enjoy fashion, but we could not close our eyes any longer from this dirty industry. So JNJ is based on personal need, and we communicated sustainability and our values with our customers and generally all stakeholders from the beginning on. Also, we strongly emphasise transparency as you can scan the hangtag of every item and see the "Eco-ID"—basically the passport of each item

(continued)

(continued)

Questionnaire	
Questions	*Answers*
7. Is Jan 'N June offering sustainable affordable fashion products? If yes, please explain how in terms of operation management, supply chain, costs…	The reason we can manage to sell our items on competitive prices is: (a) we are having a smaller margin than fast fashion brands (b) we had to make larger quantities from the beginning on to reach economies of scale
8. Which is the average price of Jan 'N June clothing and accessories?	It's somewhere around 65€. T-shirts start at 33€ and coats can be up to 260€
9. How does Jan 'N June manage the unsold fashion products?	We usually just keep selling them either online or at pop stores and samples sales. Sometimes we sell products to circular online rental services for fashion
10. Which are the main risks for Jan 'N June? (risk of credibility or financial risk or other risks…)	Definitely financial risk since with fashion cycles it's very hard to maintain liquidity. We need to pay out supplier upfront or just after delivery while our shops and reseller usually take at least 30 days and more to pay their goods
11. Why did Jan 'N June choose certified textile materials?	Because we need some kind of certainty that we are not getting any greenwashed materials that are supposedly sustainable
12. Why Jan 'N June produce its fashion product with organic cotton? Are you able to give me more information than the ones on the website about this textile, please?	Please check the blogpost that is coming soon. There are too many reasons why we would never use nonorganic cotton. This could fill a whole book!
13. Why Jan 'N June produce its fashion products with Tencel? Are you able to give me more information than the ones on the website about this textile, please?	Please check general information about Tencel®. It is basically the clean version of a viscose mainly used for garments with a flowy and fluent look
14. Why Jan 'N June produce its fashion product with Tenova? Are you able to give me more information than the ones on the website about this textile, please?	This is quite an unknown material since it is a brand of one of our woven suppliers from Portugal. They use all scraps from weaving production to make it into a new material which comes out with a look similar to raw silk
15. Why Jan 'N June produce its fashion product with acetate? Are you able to give me more information than the ones on the website about this textile, please? 16. Why Jan 'N June produce its fashion product with recycled polyamide? Are you able to give me more information than the ones on the website about this textile, please? 17. Why Jan 'N June produce its fashion product with recycled polyester? Are you able to give me more information than the ones on the website about this textile, please?	Currently, there is no perfectly sustainable material (yet). They all have their pros and cons when it comes to sustainability, characteristics, usability and comfort. So, we at JNJ try to use as many different fabrics as possible to get a certain aesthetic and show that sustainable fashion can be more than just cotton jersey and sweats

(continued)

(continued)

Questionnaire	
Questions	*Answers*
18. How do you choose your supplier?	We are focusing on long term relationships. Production should be based in Europe even though I have to mention it is possible to produce fair in Asia. But we want to keep distances as short as possible and decided to stay within Europe
19. Does Jan ‘N June’s support of Cotonea affect Uganda population? If yes, how?	Some of our favourite fabrics we use and buy every season (e.g. white poplin) are from the Cotonea project
20. Is Jan ‘N June involved in other social sustainable projects? What are the social projects about offcuts in Germany and India?	We have an offcut project we use to make accessories from fabric scraps, offcuts and overproduction. They are turned into scrunchies, headbands and currently face masks or into beautiful notebooks. The latter is a project we’re doing together with KAPDAA, The Offcut Company, which supports local, fair production in India
21. On Jan ‘N June website it is written that you use the carton boxes for the delivery “as often as possible”. What do you exactly mean? Do you use them again when consumers return your product, or do you mean something else?	Yes, we are reusing a carton box if a customer returns something as many times as possible. Usually, a box can survive 2 × 2 transportation until we need to use a new one
22. Is Jan ‘N June practising transparency? If yes, how? (I saw the “supply chain map” on the website and the “Eco-ID label”, are there some other aspects you would like to tell or underline?)	When we started, it was very hard for us to show how important sustainability is to us because we had no money to get a certification such as GOTS. This was the main reason why we started with the Eco-ID. But even though the GOTS certification is work in progress right now we will keep the transparent Eco Id since it is very valuable for the customer
23. Does Jan ‘N June encourage circular supply chain? If yes, which are the elements which enable Jan ‘N June to implement circular supply chain? What are the limitations and what the opportunities (or pro and cons)?	Currently we are trying not to mix manmade fibres with natural fibres within fabrics since it is very hard to recycle them (e.g. 50% organic cotton 50% recycled PES) again. The only exception is the use of elastane (makes it possible to give a garment more longevity before each washing) and material that has been recycled already (e.g. TENOWA). Also, we believe that recycling options will get better and better. But there is still a lot of development necessary
24. Which are the future goals of Jan ‘N June?	“I need a new shirt, let’s see if JAN ‘N JUNE has a sustainable option.” said by many many men and women

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Chapter 3
Sustainable Practices in Fast Fashion

Na Liu and Fengling Xie

Abstract Fast fashion provides consumers tremendous trendy clothes each season through quick response of the supply chain. Because of the short life cycle of fast fashion product, the pollution becomes more serious. In recent years, many fast fashion brands have tried more to make the brand image to be more environment friendly. In this chapter, we review research works related to sustainable fast fashion and real industry practices in different domains, such as sustainable fashion design, sustainable raw materials and production, sustainable brick and mortar store design, fast fashion sharing platforms, sustainable labels and packaging, sustainable marketing campaigns in fast fashion. We find that research on sustainable supply chain and operations deserve more exploration. Although fast fashion brands have done much on sustainability, consumer education should be put more efforts on. And the scope of sustainability may expand more, not only the environmental impact, but also includes labor conditions and animal welfare.

Keywords Fast fashion · Industry practice · Sustainable design · Operations · Marketing

3.1 Introduction

Fashion and textile industry has overwhelming number of chemical contaminants into the air and water during the production. A large number of chemicals are used in the production of clothing from raw materials, including thousands of chemicals are used in dyeing and finishing. Lots of water is used in the production and finishing process in order to remove these chemicals, and plenty of CO_2 is released at the same time. Fast fashion, which has shorter production cycle and increasing number of product variety, satisfies consumers with more varieties and high-frequency updating, makes

N. Liu (✉) · F. Xie
Business School, Beijing Institute of Fashion Technology, Beijing, China
e-mail: sxyln@bift.edu.cn

F. Xie
e-mail: hbxfl9633@126.com

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the environment even worse. The lower price promotes the sales much, but the poor quality of the fast fashion product leads to tremendous wasted products after wearing. Thus, the sought-after fashion products in turn contribute to its under-utilization and waste (Ellen MacArthur Foundation 2017). Some consumers and environmentalists even call fast fashion as disposable fashion.

It is definitely true that the environment pays a high price for cheaper clothes. The high demand for the latest fashion trend has turned the fashion industry into one of the world's worst polluters. According to the World Wildlife Fund, the textile industry annually emits 1.7 billion tons of carbon dioxide that is pumped into the air, 20,000 L of water is needed to produce 1 kg of cotton.[1] Large amount of the fashion products will be discarded after use, especially the fast fashion products, because of the poor quality and low salvage value. The wastes, ends up in land fill most of the time (Phillips et al. 2011), then becomes one of the major concerns in lots of countries. The shortage of landfill sites in urban areas makes the government and academics try to look for an alternative waste management system to reduce the land use and save more energy (Wen et al. 2009). Nayak et al. (2019) proposed that alternative uses of fibers which are extracted from the fashion waste can help to reduce the fashion waste in landfill, for example, the recycled waste clothing can be reused as the filling material in mattresses. However, more and more methods are still on the way to explore. Regarding the effective approaches to solve the problem of fashion waste disposal, scholars propose to reduce, reuse and recycle (Birtwistle and Moore 2007), and even further to redesign and reimagine the production process and supply chain (Pui-Yan Ho and Choi 2012). Durable design can extend the product life physically to reduce waste. Product-service business models like leasing or renting (Gwilt 2014) are conducive to stretch the product life circle. As can be found in fashion industry in recent years, sharing platforms like Rent the runway are popular.

Consequently, the supply chain management in fast fashion faces tremendous challenges as well, and tend to be more and more sustainable. Turker and Altuntas (2014) examine the situation of sustainable supply chain management in the industry by analyzing the reports from fast fashion companies. The findings reveal that the fast fashion companies focus significantly on supplier compliance with their code of conduct. They employ further monitoring and auditing activities to prevent production problems in developing countries, so as to improve overall supply chain performance and lay down sustainability criteria for their suppliers. Nevertheless, the size of the company may also affect the strategy with respect to sustainability. Federico et al. (2012) examine the sustainability in fashion supply chains, and indicate that large companies tend to focus more on products and processes improvement, although the changes are incremental. Whereas small business may reshape the supply chain completely both from inbound and outbound, compared to the big ones.

As can be observed, both academics and industrialists are paying increased attention to the topic as they are facing with the challenge of balance between sustainability and business achievement (Clarke and Clegg 2000). Fast fashion brands have made great efforts to change the image of waste and poisonous to public in response to

[1] https://www.forbes.com/sites/sap/2019/11/21/can-fast-fashion-be-sustainable/#32dd66e72c9c.

the environment protection. Therefore, in this chapter, we aim to study both from the literature and real industrial practice, to find a reasonable sustainable way for fast fashion brand. First, we learn from the literature within this scope. After that, we shift our focus to real sustainable practice in fast fashion industry. As observed from the industry, fast fashion brands improve the sustainability levels from different processes of the supply chain, such as design, materials, retailing stores, packaging, and even marketing strategies. In this chapter, we will discuss them in the following sections. The structure of this chapter is indicated as follows. Section 3.2 introduces the sustainable fashion design and Sect. 3.3 presents the sustainable raw materials and production. Section 3.4 indicates the sustainable brick and mortar store design to address the sustainability and Sect. 3.5 describes the fast fashion sharing platforms. Section 3.6 illustrates the sustainable labels and packaging. Section 3.7 shows the sustainable marketing campaigns in fast fashion. Finally, we have discussions and show the benefits and limitations of the current practices in Sect. 3.8. We also highlight opportunities and challenges for researchers and entrepreneurs interested in this topic.

3.2 Sustainable Fashion Design

In fashion industry, sensitive designers were shocked by the huge waste on the earth and serious hurt to the animals, and try to make the fashion waste more useful to protect the living beings. For instance, Claxton and Kent (2020) examine how design in the fashion industry can be successfully managed to contribute to environmental sustainability. Findings show that designers tend to have an influence on the decisions of materials, aesthetics, silhouette, trims, manufacturing quality, and the level of fashionability, which are highly correlated to design. Simple design style can help to reduce waste of fabric and materials that are used, and a simpler silhouette can be made more adaptable for a longer product life. Consequently, designers have influence on the quality and durability of clothes (Corvellec and Stål 2017). More than that, design for upcycling with the existing waste can also maximize the value of the fashion products (Early and Goldsworthy 2018). Durable design enables products to have a second or more lives, such as second hand and vintage clothing and handbags (Gwilt 2014). Extremely, a visionary waste management system named Zero waste has been presented as an alternative solution for waste problems in recent decades (Connett 2013). Zero waste design is one of the fundamental aspects of achieving zero waste goals because it eliminates unnecessary waste creation at the first phase of production through green engineering and production principles (Anastas and Zimmerman 2003). It has become an aspirational goal for tackling waste problems in many industries, and recently much popular in fashion industry. In the following, we will discuss some practical cases in sustainable fashion design from the fast fashion industry.

3.2.1 Design from the Waste

Parley Ocean is the world's official marine environmental protection organization, and has been engaged in marine environmental protection for years. Recently, Parley Ocean appeals to artists, fashion designers, architects, and other practitioners in the art field, as well as the product inventors and scientists, to construct alternative business models and ecologically sound products. The models and products are designed to provide consumers more choices to save the environment. In order to reduce the pollution to the ocean and the beach, as well as to response to the appeal, some fashion brands initiate to design and produce clothes and shoes by the trashes, which are collected from the ocean and beach.

In 2015, Adidas began to cooperate with Parley's, and became the global partner of Parley's. In the same year, Adidas launch environmental protection concept shoes, which are almost entirely made of marine plastic waste and fishnet, and named as "Adidas x Parley". Adidas and Parley worked together to adopt Parley Ocean Plastic recycled plastics into the shoes' design. The shoes' collection, inspired by the coral bleaching crisis, aims to make people pay more attention to the threat issues posed by marine ecology, to the issue of threats posed by marine ecology. Additionally, the upper of each pair of shoes needs approximately 11 bottles of plastic materials on average. More than 95% of the upper fabric is made of Parley Ocean plastic recycled plastic, which is from the ocean. The laces, heel laces, heel linings, and insole skins of ultra-boost parley, are all made from recycled materials. Same materials are utilized to make soccer uniforms for famous football teams such as Real Madrid and Bayern Munich.[2] Follow that, in 2017, Adidas sold more than one million pairs of sneakers which are made of marine plastic trash. From the above design activities, Adidas parley series convey the concept of sustainable environmental protection, and aim to arouse the public's awareness of marine pollution.

Same kinds of design ideas are also applied by other companies, such as Ecoalf. This company was founded as an environmental fashion brand in 2009. Ecoalf not only has advocated the use of marine garbage, but also reached cooperation with coffee shops so as to use coffee dregs as clothing materials. All the products designed by Ecoalf are the materials from waste recycling, so as to minimize the impact on the environment in the process of waste recycling and production.[3] Ecoalf has developed biodegradable and environmentally friendly materials from plastic bottles on the Mediterranean Sea floor. Up to now, Ecoalf has recycled more than 20 million plastic bottles for recycling.

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[2] https://www.sohu.com/a/151949890_276493.

[3] https://ecoalf.com/en/p/history-9.

3.2.2 Zero Waste Design

When making a piece of clothes, no matter it is plane cutting or dropping cutting, it is the truth that the fabric will be cut by irregular curves and the remains are trivial. Usually, the remained cloth cannot be used to cut to small pieces of clothes like collar or pocket, and then only to be wasted. The number can be up to 40% of the whole cloth. Although the compositor will try the best to save cloth, wastes cannot be prevented. To reduce the waste, designers attempt to save cloth by design ideas. Zero waste is then produced. Actually, zero waste fashion is not a new technology or material, instead, a new way of thinking. Oblique cutting, invented by Madeleine Vionette, is to cut fabric by rectangular curves instead of irregular shapes, so as to maintain the integrity cloth as much as possible to reduce the waste. Zero waste is a philosophy that forces designers to challenge the existing techniques to do their best to reduce rubbish, as it wastes money, energy, etc. Generally, there are two ways of strategies for zero waste fashion: creative pattern making that uses 100% of a given material, and upcycling when you generate garments from remnant materials.[4] In fashion design, one step forming and splicing are two common methods. There is much little fabric waste or even zero waste in one step forming design, because no cutting exists in production.

Nowadays, people are usually pursuing a curvy body shape. In order to fulfill this requirement, fabric is cut by curves. This leads to a waste of fabric scraps, because the remained fabric is difficult for second use. If it is substituted by straight lines, it will be of great help to cloth saving. Although there are a lot of design methods to reduce waste, there will inevitably remain fabric leftovers after cutting and sewing. For those leftovers, they can be dealt physically or chemically. Physical treatment refers to full play to the designer's intelligence and wisdom to reuse the leftovers. Chemical treatment refers to combining or collecting these leftovers material and dissolves it into raw material for reproduction. Recently, 3D clothes design follows this concept of the latter from the very beginning. The materials are hot-melt and shaped directly into the final form of the clothes.

Verloop brings the term "trash to treasure" into the fashion industry. It uses fabric scraps and excess materials to make accessories. The items are all made from knit yarns and have lots of colors and patterns. There are tons of options that make great gifts, such as cold weather accessories, slippers, bags, and even home decor.[5] It is a kind of real practice of physical treatment. For the cutoff fabrics with irregular shapes, some brands have full use of them. In 2019, British company New Gen and Covent Garden Market jointly produced Christmas stocking by materials scraps. Hence, the materials can be used nearly 100%. Another fashion brand Reformation's design mission is to make effortless silhouettes that celebrate the feminine figure.[6] All of the industrial practices are trying to reach the milestone of zero waste.

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[4] https://thelastfashionbible.com/2019/04/18/zero-waste-fashion/.

[5] https://www.goodhousekeeping.com/clothing/g27154605/sustainable-fashion-clothing/.

[6] https://www.thereformation.com/pages/our-stuff.

3.2.3 Design with Second Hand and Recycling

Most of the fast fashion brands has launched recycling program, which is an easier way to proceed sustainable fashion. H&M has partnered with I:Collect to launch a clothing recycling collection. I:Collect is a Swiss reuse and recycling logistics company, which has picked up clothing, shoes, and other fashion products from more than 60 countries. The H&M Garment Collecting program is a global initiative that aims to prevent customers unwanted clothes from going to landfill. Beginning in February 2013, customers have been able to donate used garments at all H&M stores in the chain's 48 markets worldwide. Any brand or any piece of clothing can be collected in the stores. Then I:Collect repurposes the collected clothes, and a voucher for each bag of donated clothes is delivered to customer.[7] Customers can use the voucher to buy new clothes for a certain discount, and I:Collect can reuse the collected clothes for recycling production. Such kind of practice can be observed in industry and other examples are listed below one by one. Levi's has also partnered with I:CO to collect clothing and footwear for reuse and recycling. I:CO provides the collection bins to sort the items, and then the items that are wearable can be sold for second use, and the remains can be recycled. Patagonia not only collects used clothing in its stores and through the mail, but also offers repair services so its customers can extend the lives of their garments.

Another case is Inditex, the parent firm of Zara and one of the fast fashion giant in the world. CEO of Inditex, Pablo Isla, indicated that, by 2025, Inditex will achieve a thorough sustainability of raw materials. All of the raw materials will be organic, sustainable, or recyclable fibers. Meanwhile, the proportion of renewable energy that is used in group activities will exceed 80% at that time, including the retail stores, logistics centers, headquarter offices, and so on. Inditex's recycling program has covered 24 countries and regions around the whole world, and totally of 1382 recycling bins were filled in by the used clothes. Family collection service has also been provided in several cities in Spain and China. In Spain, with cooperation of Caritas Hong Kong, Inditex has installed 2000 used clothes recycling bins. At present, 34,000 tons of shoes and clothing accessories have been recovered in the old clothes recycling plan. And the number is still growing.

Freitag is a recycling bag brand in Swiss. In Freitag, all of the bags are made from truck tarp. The feature, has become a design icon very soon of Freitag, and each product has a vintage style and is water proofing. The products, actually are made of the wasted tarp. In 2014, the Freitag brothers crossed another hurdle in the "circular" ready-to-wear economy with their F-ABRIC project. The fully biodegradable fabric is made of hemp, beech, and linen, which is a textile known not only for its biodegradability, but also for using far less energy to grow than wool or cotton.[8] Not only the product is made sustainably, the service is also provided sustainably, which is called S.W.A.P. service for consumers. When customers use the Freitag bag for a while and wants to change another one, then they can log in this service system

[7] https://www.environmentalleader.com/2012/12/hm-launches-global-clothing-recycling/.

[8] https://www.livingcircular.veolia.com/en/eco-citizen/its-recycled-bag-freitag-brothers.

to seek whether there is another Freitag bag that they are fond of. Other customers with same requirement may have uploaded the picture of their bags into the system to wait for swap. If one customer has interested in his bag, they can discuss whether to swap and also the swap method. Through this S.W.A.P. system, bags of Freitag has come true of recycling. Another brand, Raeburn, was found in UK, utilizes used fabrics including kites and vintage parachutes and other military stock and leftover fabrics to make clothes.[9]

Different to the Freitag truck tarp bags, Vera Bradley's ReActive collection is unique because the bags are made out **of** recycled plastic bottles**.** Through that, this brand has already diverted millions of water bottles from going to landfills. The products are diverse, backpacks, totes, travel bags, and more can be found in Vera Bradley's. Plastic bottles transformed into the recycled polyester fabric, which is lightweight, durable, and water-repellant.[10] Thus, the products are more suitable for daily use and the product life is extended. Other brands like skate brand Bureo makes skate from recycled fishnets, Pet Lifestyle and You which is a pet products brand, uses recycled plastic bottles to make pet's beds.

Some brands use the chopped fibers from recycling. Sustainable fashion startup, For Days, has set up a closed-loop fashion system, which aims to avoid waste by endlessly recycling materials. A total organic T-shirt, tank top, or sweatshirt from For Days costs $38 and this contains a lifetime membership for customers. If it ever needs to be replaced, customers have to pay $8 for substitution. The returned items are then recycled in the firm's manufacturing plant in Los Angeles in the US. Then, each piece of the items is chopped up, pulped and reinforced with virgin material before being spun back into yarn. Then, the yarn is used to make the fabric for new products. The brand offers a points system for customers, that allows members to accumulate credits used in future swaps or products purchase.[11] Australian designer brand, ABCH, is sustainable as possible from each process. Every piece they make is 99% compostable. Once the tag, which is made of recycled polyester is removed, the clothes can be cut up and buried or put on a compost heap. A recycling program allows customers to return their used clothes to be re-sold, re-made into a new piece, or have their raw materials recovered via cellulose recycling.[12] In this case, the used recycled product comes to cellulose and then the second life.

Besides that, the design of second hand products are increasingly popular recently. In the past, parents may cut their own clothes to fit for children, this is a kind of home practice of second hand use, which is economically and environment friendly. Many designers try to cut the clothes that people do not wear anymore or that were discarded, and then change them for second hand use. Designers re-examine the clothing and materials, and then bring out breakthrough ideas with modern aesthetic. Nowadays, the style has become a new fashion mode and trend, which a large number of designers bend their efforts for.

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[9] https://www.raeburndesign.co.uk/.

[10] https://www.goodhousekeeping.com/clothing/g27154605/sustainable-fashion-clothing/.

[11] https://www.dezeen.com/2019/09/24/sustainable-fashion-roundup-for-days-pangaia/.

[12] https://www.raeburndesign.co.uk/.

Mud Jeans is a such kind of brand as well. Each pair of Mud Jeans is composed of 23–40% recycled denim. Its first 100% recycled cotton pair of jeans has been launched in 2020. It shows that denim can be a part of the circular economy. Because one piece of denim may cost more than 3000 L of water, and is deemed to be the one of most polluted fashion items. Moreover, in Mud Jeans, some of the old pairs of jeans are collected and sent to the Recovetrex recycling plant in Spain, where they are broken down, turned into new yarn, and then into fabric.

Asos has its own recycling system ASOS Doddle, in which the used products are collected for second use or redesign. From 2016, customers can recycle last season's unwanted but wearable items in this system and another fashion reuse charity of TRAID. The charity aims to reduce the social and environmental cost of the textiles industry.[13] ASOS has many other activities to show the big concerns in fashion sustainability. In 2018, ASOS launched a circular design pilot training program in collaboration with London College of Fashion's Centre for Sustainable Fashion.[14] In March 2019, ASOS participated in the Ellen Macarthur wearnext campaign in New York, joining forces with the fashion industry to tackle waste together.

Some brands started to cooperate with retailer in the procedure of recycling. Reclaim to Wear (founded in 1997), focuses on reducing textile waste by creating a debut upcycled capsule collection made entirely from discarded materials, such as surplus stock or production scraps. The stocks are collected from the retailors and the brand has been part of the retailer's partnership, which means the sustainability has changed the supply chain relationship. In collaboration with Reclaim to Wear, TopShop first began to sell the recycled clothes in 2012. The new styles are made of the old garments and excess material. Such collaboration of brand and retailor can be found more in industry, which can get a win–win situation of the two sides.

3.3 Sustainable Raw Materials and Production

Chemicals are used in every part of the textile production, like fibers, bleaching and dyeing fabrics, etc. Some clothing products still contain a lot of chemicals when showing on the shelf in stores, even for the 100% natural fiber. Human's skin can absorb anything on it, including chemicals remains in the clothes, which is harm to people's health. Some fast fashion brands use colored cotton and other environmentally friendly biodegradable fabrics to avoid the harms. In the dying process of the fabric production, a large number amount of water is needed to dye and wash, this is a huge waste of energy and resource. For example, a simple cotton T-shirt can use up to 2700 L of water for dyeing color. Garment finishing is another procedure that waste huge amount of water. Therefore, chemists are eager to find ways to reduce

[13] https://www.asos.com/men/fashion-feed/2016_04_25-mon/give-something-back-with-asos-traid-and-doddle/.

[14] https://www.asosplc.com/corporate-responsibility/our-products/sustainable-sourcing-programme.

the chemical remains. Pattanaik et al. (2019) focus on possible reuse of both solid and liquid waste generated from the natural indigo dye production process, in order to achieve a possible zero waste in a sustainable process. The use of sustainable technologies such as natural dyeing, super critical carbon dioxide dyeing, air dyeing, plasma technology, laser processing, and digital printing are also gaining popularity to become sustainable in the fashion manufacturing process (Nayak et al. 2020). Such technologies are not rare in industry. In 2011, many fashion brands signed a commitment to phase out hazardous chemicals in textile and leather supply chains by 2020.

ZARA created a new collection of Join Life from September in 2016. In order to meet up “Join Life” theme, the items should be made of organic cotton (conventional cotton requires 90% more water to produce than organic cotton), recycled wool, or tencel (a wood fiber sourced from sustainably managed forests). This allows ZARA to “avoid felling of some 21.840 trees and reduce CO_2 emissions by 1.680 tonnes a year”.

Some of H&M products use organic cotton and organic colored cotton as well. Organic colored cotton is planted and reaped with original colors, which needs no dyeing process, and is friendly to the environment and also less harmful to human body. In order to get the organic cotton for a long period, H&M has reached a long-term agreement with Bangladesh government. The company provides jobs for education and training to the local staffs and invests in infrastructures, to establish their own raw material supply areas, and establish long-term cooperative relationship. The organic cotton has been applied in production. In 2018, H&M releases the brand’s Conscious Exclusive series, which uses sustainable recycled pure silver and 100% recycled polyamide fiber. The recycled fiber can be weaved into transparent chiffon to get a better performance. In 2020, the spring summer season’s Conscious Exclusive collection is made from discarded grape skins, fashion waste, and undyed organic cotton. Other sustainable fiber includes a high-quality recycled polyester, recycled glass beads, and denim made from 100 percent undyed organic cotton.

Reebok invented Cotton + Corn shoes, which focused on its eco-minded fans. The brand uses the sustainable materials as leather alternatives to attract the eco-friendly customers. The upper of the shoes are entirely made of Cotton + Corn based soles, castor bean oil insoles. Especially, the packaging is also 100% recycled. C&A, another Fast fashion retail brand, recognizing the environmental effects of cotton farming, has launched efforts to purchase only organic cotton by 2020.

More efforts on cutting down the waste and pollution during the production are made in industry. One pair of denim jeans usually takes over 2,000 gallons of water from growing the cotton to dyeing and finishing. Levi’s focuses on the finishing processes to remove water wherever possible with its Water < Less collection, which are said save up to 96% water in finishing. As the dominated retailor in the denim industry, steps like this can actually have big impact in the industry.

3.4 Sustainable Brick and Mortar Store Design

As consumers become more and more aware of the impacts of their lifestyles on the environment, visible sustainable strategies are welcome to show the effects in sustainability to consumers. The brick and mortar store, which is the main channel and connection to link brand and consumers, speeded up the visual sustainable steps. In 2019, all stores of Zara have met the energy efficiency standard, and all brand stores of Inditex may achieve it by 2020. Different to others, Gap focuses on handling the waste. The company try to divert 80% of store waste from landfill by 2020.[15]

Ecoalf has always insisted in being a 100% sustainable store. The materials used in the building are all from recycled waste, and the walls are made of environmentally friendly mineral pigments. The indoor lighting is also gathered as natural as possible. In order to reduce the emission of CO_2 and waste of resources, there is no air conditioning in stores. A large number of natural plants are also placed inside the store. In order to help consumers understand the efforts made by the enterprise to protect the environment, a special "act now" space is set up in the store to show the measures taken to reduce the impact of fashion clothing industry on the environment. It's a fully eco-friendly store, for which combines design, architecture, fashion, and technology to better interact with consumers.

Australian fashion retailer Country Road, opened its flagship store in Melbourne in 2019 with sustainable application everywhere in the store. The space is made from recycled materials such as yoghurt containers, fishing nets and recycled paper. The fitting room hooks are made by using ocean plastic and tables from recycled plastic. The sustainable store design continues to expand in the country, and has received a 5-star Green Design review from the Green Building Council of Australia.

Sustainable accessories brand, Bottletop, opened the world's first 3D printed store, created by robots using upcycled plastic in London. The store is located on Regent Street, which is zero waste and a location show the brand's sustainable handcrafted collection of leather goods, and also show the company's core mission of sustainable design and creative culture. The flooring of the store is made from reworked rubber tyres, and the interior is made from upcycled plastic bottles. The store aims to reimagine the future of ecologically responsible construction through zero waste store design.[16]

Fashion brand Reformation puts sustainability as the core of company mission, from local manufacturing and sustainable dyeing to green buildings and fabrics. Its Los Angeles stores and headquarters are all made green, implementing strategies to save energy, elevate the water efficiency and reduce CO_2 emissions. Reformation builds its stores by starting with the construction footprint calculation. The materials in store are also sustainable with LED fixtures, recycled fabric insulations, and natural rammed earth materials.

Under Armor relies on LEED to support sustainability and shows the transparency and environmental responsibility to its customers. LEED is short for Leadership in

[15] https://www.gapincsustainability.com/sites/default/files/Gap%20Inc%20Report%202018.pdf.

[16] https://thecurrentdaily.com/2019/09/12/9-brands-pushing-sustainable-store-design/.

Energy and Environmental Design, is a green building certification program that recognizes best-in-class building strategies and practices globally and is one of the most popular green building certification programs in the world. New retail stores use LEED elements in construction, including the controlled LED lighting, recycled rubber flooring, VOC (volatile organic compounds) free paints, etc. Along with other sustainability efforts like recycled packaging and reduced environmental influences, the brand further shows its commitment to a cleaner and healthier world.[17]

3.5 Fast Fashion Sharing Platforms

As sharing economic spreading all over the world, many kinds of products are emerged in the sharing platform, such as rooms, cars, bicycles, bags, and also fashion products. Todeschini et al. (2017) investigate innovative business models in the fashion industry that take sustainability as their main mission and value. The work shows that renting clothing allows each piece of garment to get the most possible use during its lifecycle, and the platforms accelerate the whole process and provide consumers better services. The sharing platform can get the sustainability because renting clothing allows each garment to get the most possible use during its lifecycle, and it helps customer to buy less to reduce the production from the demand side. Being criticized of wasting, fast fashion brands are found more and more in sharing platform to show the efforts on sustainability.

Rent the Runway, the largest fashion sharing platform in US, was founded in 2010 and provides lots of fashion products for renting. The platform provides single rental service for special occasions and daily rental services with monthly membership, for which customer can get several pieces clothes each time. More recently, a lot of sharing platforms are established, such as Le Tote, Armoire, Haverdash, and Y closet, Ms Paris in China, and the competition is more severe. These fashion sharing platforms provide rental services of multiple fashion brands for customers. The brands include luxury brand, designer's brand, and fast fashion brand. Some fashion retailing giant companies, like Gap, Banana Republic, and Urban Outfitters, have access to this niche market on its own platform as well, by offering the subscription models for everyday fast fashion items. Some cases are listed below.

H&M opened a rental store in 2019 at its flagship store in Stockholm, where H&M members can rent, sew or customize clothes for $37 membership fee a week. The rental program is limited to a collection of 50 garments, which are offered to company's loyal members.

In July 2019, Urban Outfitters launches a new clothing rental company Nuuly. The platform provides lots of brands for customers, not only its own brand. It carries more than 1,000 items from more than 100 different brands. The members can rent six items at a time for one month at a membership of $88 per month. Nuuly offers its subscribers the opportunity to rent from the brands included in URBN's portfolio

[17] https://www.q20lab.com/retail-sustainability.

such as Free People and Anthropologies, as well as with over 100 third-party labels like Levi's, AYR and Gal Meets Glam. Additionally, subscribers will also be able to choose from a collection of one-of-a-kind vintage pieces. Moreover, the sizing system is also friendly to customers. The available options is ranging in sizes from 00 to 26, even for the petite sizes which have fewer demand than the normal sizes.[18]

Banana Republic introduced "Style Passport" subscription from August 2019, that customers can pay $85 per month for a three-garment plan. The plan includes free priority shipping, unlimited exchanges or returns and complimentary laundering services. The members of this plan can follow the fashion styles of the brands, keep at least eight pieces in the cart, and then the three select pieces from the cart are sent at one time to the members. Members can wear the clothes as long as they want, and thus experience an unlimited rotation of new styles service with free shipping and returns during the membership. Thus, the sharing system increases the sustainability level of Banana Republic.

3.6 Sustainable Labels and Packaging

In recent decades, the number of packaging and related items are growing more and more fast and become a polluted problem, because most of the packages are made of plastics. Plastic takes decades to decompose, and in the decomposing process, it releases harmful chemicals into the earth, the ocean and the air, and make the lives of a wide variety of species in danger. As is often reported, plastic bags are found from the beach and the ocean, in the city and town. Polar bear, whale, and turtle are found dead with full of plastic bags in stomach, etc. As landfills is getting full and occupy a large number of lands, retailers are investing in research of plastic alternatives and encouraging customers to reuse the packaging. Numbers of companies engage to find new materials or recycled waste to produce package bags.

As reported, New York City has 1700 tons of domestic waste every week, which is a very serious environmental pollution. After Hawaii and California, New York formally implemented a plastic ban order to prohibit businesses from providing disposable plastic bags to customers. Actually, lots of cities in different counties have promulgated the plastic ban. In order to solve this problem, a Japanese designer Sho Shibuya who lives in New York, has designed a creative and environmentally friendly shopping bag. The bag is made of a 100% biodegradable bamboo fiber, which is sustainable materials. The design is sustainable too. When it is tiled, it is a piece of common paper with a smiling face painted. When it is loaded and lifted, the paper transforms to a bag. This precut hollowed bag not only helps to make the paper form a bag that can hold things, but also reduces the production materials, and

[18] https://fashionunited.uk/news/retail/urban-outfitters-launches-clothing-rental-company-nuuly/2019073044488.

makes the bag easier to decompose after use as well.[19] Multiple purposes can be reached from the special bag.

An eco-friendly end product will also need an eco-friendly label. EE Labels is such a kind company which was found in 1900. The polyester threads of the labels are made from 100% recycled PET bottles, and 12% of thread consumption consists of Newlife threads. The company supplies labels printed on GOTS-certified biological cotton band. These labels are printed with environment-friendly inks that also have the Oekotex-100 certificate, making it the best possible combination. The woven labels are made of biological cotton with threads that are GOTS certified.[20] The label is environmental friendly and healthy and comfortable for consumer, preventing allergies on skin.

Inditex brands such as Zara, Zara home, Massimo dutti and uterq ü e have begun to reduce the use of plastic shopping bags. In 2018, the proportion of plastic bags used by Inditex group accounted for only 18% of the total number of shopping bags. All Inditex brands promise to do not use plastic bags any more by 2020. And by 2023, disposable plastic products will be completely eliminated in Inditex. In order to reduce the waste, Zara also began to recycle the containers, with a maximum of six times in the life cycle, which is much higher than currently. Zara reduces the use of disposable plastics in turn to use the recycled plastics. In addition, Zara is developing a recyclable hanger system, all of the items in this system will continue to be used until they are completely broken down and then put them to make the recycled new ones. Thus, the system is a real recycled hanger system and can reduce the majority of the waste.

H&M has this concern of packaging waste as well. H&M has signed The New Plastic Economy—Global Commitment, which is an initiative by the Ellen MacArthur Foundation to prevent plastic pollution. The brand committed to reduce plastic packaging by 25% on the baseline by 2025, and replace single-use plastic packaging with reusable alternatives where possible. In the commitment, the brand also intend to move away all of problematic or unnecessary plastic, and ensure that at least 25% of the plastic is recycled.[21] H&M uses Kraft paper to make retail bags, which can shift to a clothes hanger by folding with the given lines. The material and the idea make the retail bags sustainable with multiple use.

In February 2020, C&A was phasing out the sale of single-use plastic bags in all of its stores of 18 countries in Europe. Then in March, the fashion retailer launched the durable program "bag-for-life", which is made of 80% recycled PET and more durable to use. When the bag is worn out, it will be returned to any of the stores and exchanged for a new one free of charge.

Some of the beauty brands take durable bags into consideration. Aether Beauty is a zero waste beauty brand, and in this brand, all of the packaging is recyclable. For example, the package of lipstick is made of 100% recycled plastic. Alima Pure, another fashion beauty brand has been testing soy-based refillable palettes for eye

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19 https://hypebeast.com/2020/2/sho-shibuya-placeholder-biodegradable-bamboo-bag-design.

20 https://www.eelabels.com/en/products/sustainable-labels/.

21 https://hmgroup.com/sustainability/circular-and-climate-positive/packaging.html.

shadow and lip gloss, and the boxes are made from 100% post-consumer recycled paper. The products including the concealer, foundation, and eyeshadow can all be refilled when the product runs out, which is quite different from the current brand in beauty industry. Rather than buying a new one, refilling a product significantly cuts down on plastic and chemical waste by reducing the use of the containers. In practice, the products that are available for refills are usually higher end and come at a higher cost. For Alima Pure, refills tend to cost less than buying the product again. The refill mode is not always manageable or practical for all consumers and retailers, but it's a meaningful trial for brands to consider how they can help shift the mindset of consumers to pay more for sustainable brands. Such kind of practice can also be found in industry other than fashion.

3.7 Sustainable Marketing Campaigns in Fast Fashion

Popularity in consumers leads to much more public attentions in fashion industry. Fashion brands, which are challenged by the sustainability concerns from public, receive emerged discuss and repercussion in the media and public. Awareness of the need for more sustainable strategies and practices has led to the development of a circular model of fashion production and consumption. Slow fashion which opposes the fast fashion paradigm, is a social movement similar to the slow food movement that emerged in Italy aims at fighting against fast food chains (Fletcher 2010). Slow fashion drives innovation in value proposition and customer relationship (Todeschini et al. 2017; Brewer 2019). Firms orient their offering toward increased perceived quality and authenticity and address customer concerns in terms of the environmental and social issues. Like firms may increase the reusing or recycling materials in production and logistics to address the sustainability concern, and can prioritize locally-made products and partners that adopt fair trade principles to show the social responsibility.

In order to promote the sustainable ethic and state the social responsibility of the fashion brand clearly that has taken with respect to global environment, fast fashion brands have initiated many campaigns to consumers. Most of the fast fashion brands have sustainability page online or sustainability report each year. For instance, H&M has sustainability page on its website, including the innovation, cleaning up, and other aspects to show their responsibility. From 2017, Adidas has carried out the "run for the ocean" activity globally for three consecutive years. The aim is to arouse people's understanding of marine plastic pollution, and encourage more and more people to participate in the positive action of protecting the environment. In 2019, Adidas launched "running out of the blue" running activities in New York, Shanghai, Barcelona and other cities, 2.2 million runners from all over the world joined the activities.[22] The activities, promote the firm's views on sustainability and attract the environmental sensitive customers.

[22] https://www.sohu.com/a/403658695_120267334?_f=index_pagefocus_2.

Other practice in industry including C&A, NOAH, and ELLE, etc. In order to help customers more informed on purchasing decisions in the sustainable development of clothing, C&A has launched a global multi-channel sustainable development promotion campaign since 2016, which is named "wear the change green new fashion" in stores around the world. NOAH developed a T-shirt product named as 100% recycled cotton T-shirt. The brand redesign the recycled products and come up with the advertising slogan "The Tee is Garbage". Not only that, NOAH has produced a series product together with Dover Street Market, for which the aim is protecting the sharks and ocean. The simple application is easier to implemented and can get more attentions from consumers and the society.

A new campaign launched with some help from "the female Banksy" is encouraging people to bin their old clothes—but for recycling, not landfill. In this campaign, recycling banks have been installed around London, decorated by the street artist Bambi.[23] The Love Not Land fill campaign aims to raise awareness of the consumers that the hot fast fashion habit might be having serious damages on the environment and it's time to change it for a cleaner and better earth. Love Not Landfill, which is funded by the European Clothing Action Plan and London Waste And Recycling Board, proclaim that one-third of the young people aged 16–24 have never used a clothes recycling bank before. The aim of the program is also to promote the idea of "slow down the pace of fast fashion". Actually, slow fashion is not new in fashion industry. Classic and durable are the keywords, and the feature makes fashion products can be used for many times and last for a long period. In other words, the idea of slow fashion manually improves the fashion industry to be more sustainable. ELLE and Cosmopolitan are partnering with the Comfort Swap Shop to provide consumers the opportunity to trade in the fabulous-but-neglected items and exchange them for something else.[24] Some of the clothes are also for sale in the swap shop, with all proceeds going to the Prince's Trust charity, helping young people to get into jobs, education and training.

3.8 Discussions

In this chapter, we reviewed a large number of sustainable practices in fast fashion industry, from the perspectives of sustainable fashion design, sustainable raw materials and production, sustainable brick and mortar store design, fast fashion sharing platforms, sustainable labels and packaging, sustainable marketing campaigns in fast fashion, etc. Although increasingly firms have joined the force of sustainability, companies should still pay more attentions to consumer expectations with respect to sustainability. Consumer education should be put more efforts on, and this is consistent with Todeschini et al. (2017), as the work points out that potential cause of failure

[23] https://www.huffingtonpost.co.uk/entry/do-you-recycle-your-old-clothes-heres-why-and-how-you-should_uk_5b9a43e8e4b041978dc054f3.

[24] https://www.elle.com/uk/fashion/a28334245/comfort-swap-shop-with-elle/.

of many sustainable business models is related to consumer education. This means the companies still have a long way to train more sustainable customers. Moreover, the scope of sustainability may expand more, not only the environmental impact, but also includes labor conditions and animal welfare, such as Reebok's sustainability practices focus on. Some of the practices indicate that the sustainability has changed the supply chain relationship, like the program of Reclaim to Wear. It is the evidence that sustainable supply chain management must be put on more research effort and it can be seen that increasingly works within this domain have been published. As technologies may have huge potential impacts in industry and management, to check the new technology's influence (such as the implementation blockchain (Choi and Luo 2019)) on the supply chain sustainability and profitability is very important in the near future.

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Part II
Intelligent Fast Fashion Demand Forecasting

Chapter 4
Fast Fashion Demand Forecasting Models: A Comparative Study

Xiong Yu and Lei Lin

Abstract Fast fashion is a well-established and timely business model in the fashion industry. The common characteristics of fast fashion include a short product life cycle and the need for quick production and distribution of highly trendy products. In order to support the fast fashion business model, fast fashion companies have to conduct quick predictions of the highly volatile demand of a lot of stock keeping units (SKUs). In this chapter, we first examine a carefully selected set of computational models which can be applied for fast fashion demand forecasting. Supported by real data analysis, insights regarding the strengths and weaknesses of these versatile models are discussed. Then, a panel data-based interval forecasting model that can effectively reflect the uncertainties in the forecasting results for decision makers is proposed. By conducting comparison studies with popularly used ELM-based interval forecasting model, some important conclusions are generated.

Keywords Industrial applications · Interval demand forecasting · Computational models · Risk analysis · Inventory control

4.1 Introduction

In the fashion industry, fast fashion is a timely and well-established business model. Nowadays, it is widely implemented and advocated by many international companies such as H&M, Mango, Uniqlo, and Zara (Choi 2014). Under fast fashion, companies tend to achieve a very fast response to market preference changes and offer the most trendy items to satisfy customer needs. As a result, the common characteristics of products offered by fast fashion companies include (i) very short product life cycle, (ii) relatively simple product design, (iii) very trendy and fashionable, and (iv)

X. Yu
Guangdong University of Technology, Guang Zhou, China
e-mail: yasin1006@163.com

L. Lin (✉)
Goergen Institute for Data Science, University of Rochester, Rochester, NY 14526, United States
e-mail: Lei.Lin@Rochester.edu

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possessing volatile demand with very high uncertainty (Choi 2014). Undoubtedly, fast fashion operations involve a high level of risk.

In the operations research and systems engineering literature, fast fashion has been widely examined over the recent decade. For example, Cachon and Swinney (Cachon and Swinney 2011) study fast fashion supply chain systems in the presence of forward-looking strategic consumers. They argue that fast fashion companies are developing their competitive edge by offering a short lead time and an improved product design to deal with different kinds of consumers in the market. By deriving a dynamic programming-based optimal inventory policy, Caro and Gallien (2007) identify the optimal product assortment plan for fast fashion business. After that, Caro and Gallien (2010) analytically explore the product assortment planning problem based on Zara's real industrial case. They develop analytically and study the optimal inventory allocation in the fast fashion network. Most recently, in Li et al. (2014), analytical mean–variance analysis of a fast fashion supply chain is conducted. The authors examine the use of channel returns policy to achieve supply chain optimization with multiple risk-averse retailers under the mean–variance framework. They show analytically the conditions under which a simple returns policy can be used to coordinate the multi-retailer fast fashion supply chain. For more related research on fast fashion supply chain operations, refer to Choi (2014). As we can see from the above-reviewed studies, for proper supply chain operations management of fast fashion companies, important decisions on procurement (Serel 2014), supply chain coordination mechanism (Wang et al. 2014; Ho and Choi 2014), product assortment planning, risk analysis, and distribution and inventory management (Mostard et al. 2011) are all necessary. However, before these decision-making problems can be properly explored, one fundamental issue which has to be addressed first is the "demand forecasting of fast fashion products".

In fact, demand forecasting (Ning et al. 2009) is a very critical area in fast fashion business models. As we note from the prior discussion, demand uncertainty is very high for fast fashion products (as it relates highly to the ever-changing fashion trend and consumer preference), and the fast fashion companies have to make their production, and inventory and assortment planning decisions based on forecasts with a very short lead time and hence a very tight schedule (P.S.: The real-time data-driven approach (Wang 2012) for forecasting operations are highly desirable.). As a result, fast fashion companies have to conduct demand forecasting for their products (i) on a nearly "real-time" basis (a very short lead time) (Wang 2012) using technological devices such as RFID (Choi 2011; Gaukler 2011), (ii) for a lot of products, and (iii) with a very limited amount of available data (because of the short selling season of the related demand data for forecasting). Let's consider the well-known case in the renowned fast fashion company Zara, which is known to achieve the two weeks magic of offering the well-designed trendy product from conceptual design to the ready-to-sell merchandise on sales floor in just two weeks' time (Ghemawat and Nueno 2003). For each particular SKU, we can see that prior to production and distribution, Zara has to make a forecast regarding its demand. Unfortunately, the product demand is highly unpredictable. Even worse, there is only a very limited amount of data available, yet the forecasting has to be done very quickly (so that the forecasting result can be feasibly incorporated into the production and distribution processes). Last but not the least, Zara is not selling just one or two products, but a large variety of SKUs. As a result, conducting demand forecasting for fast fashion companies is a very practical but challenging topic.

Owing to the importance of demand forecasting for fast fashion, this chapter conducts a technical review of the topic. We focus on reviewing the recently published novel studies which employ scientifically sound analytical models for conducting demand forecasting for fast fashion. We systematically divide the review into different sections with respect to the methods employed. From the review of these models, we generate insights into their strengths and weaknesses. The other related reviews include Liu et al. (2013), Nenni et al. (2013), Thomassey (2014), and Choi et al. (2011b). Considering operational risk management and the uncertainty demand of fashionable products, we then propose interval forecasting for the fashion industry by extending the panel data forecasting model. The panel data model is a statistical method that is easy to implement and performs better than other methods on conducting fashion sales forecasting. In order to study the interval forecasting performance, we compare the panel data-based method with ELM-based interval forecasting method. ELM is proposed by Huang et al. in 2004. It is a type of feed-forward neural network, which has better generalization performance and is straight-forward with local minimum issues. ELM has been proved to be very powerful for conducting interval forecasting in previous studies. For example, Huang et al. (2004) predict the short-term electricity load using ELM. Wan et al. (2014) combine particle swarm optimization and ELM to predict the interval of wind power.

This chapter contributes to the literature and advances knowledge in the following ways: (i) This chapter aims at reviewing the specific advanced analytical models and conducting an analysis on their specific strengths and weaknesses. (ii) This chapter focuses solely on fast fashion and hence emphasizes functional aspects on forecasting speed, data requirements, ease of implementation, etc., in addition to forecasting accuracy. (iii) This chapter proposes an interval forecasting concept for the fast fashion industry. By conducting a comparison study, this chapter provides a deeper analysis of the forecasting performance of both statistics method-based and AI method-based interval forecasting. To the best of my knowledge, this chapter is the first study which specifically examines the analytical models for fast fashion demand forecasting. It is also the first study which conducts interval forecasting for fashion sales forecasting. The findings are useful for both practitioners and academicians.

The rest of this chapter is organized in the following. Section 4.2 presents the detailed literature review of fast fashion demand forecasting models and analyzes the strengths and weaknesses of the reviewed fast fashion demand forecasting models. Section 4.3 conducts panel data-based and ELM-based interval forecasting models. The case study and computational analysis are shown in Sect. 4.4. Section 4.5 concludes the chapter with a discussion of future research.

4.2 Analytical Models

In this section, we examine various popular and important models for conducting fast fashion demand forecasting. We discuss them one by one following their specific modeling characteristics.

4.2.1 Statistical Panel Data-Based Models

In conducting demand forecasting for fashion products, the classical approach starts by analyzing the product features (Nenni et al. 2013). After that, fashion companies need to determine the forecasting approach. In fast fashion, since the time of conducting forecasting is critically important, a quick forecasting approach is desirable. Being quick, intuitive, and easy to apply, statistical methods such as Auto Regression Integrated Moving Average (ARIMA) and Seasonal Auto Regression Integrated Moving Average (SARIMA) approaches are commonly used for quick demand forecasting. Since this chapter aims at reviewing the more advanced analytical forecasting models, we refer readers to other papers, such as (Liu et al. 2013; Thomassey 2014; Box et al. 2008), on the use of these classical simple models. However, the use of these methods is obviously insufficient because demand for fashion products depends on a lot of other factors, such as price and other correlated products' demands. Based on this argument, recently, Ren et al. (2014) conduct a panel data analysis for time-series demand forecasting in fashion. Ren et al. (2014)'s model basically employs the popular panel data regression method in which multiple items' demand as well as other critically important factors (such as selling price) are incorporated into the time-series forecasting model. We review their specific model as follows.

First of all, they represent the demand of fashion product i at time interval t, by D_{it}:

$$D_{it} = L_{it} + NL_{it}, \tag{4.1}$$

where L_{it} represents the linear component of demand D_{it}, and NL_{it} denotes the nonlinear part.

Under the panel data analysis, Ren et al. (2014) represent L_{it} as a linear function of the previous time period's linear component of demand D_{it-1} and the product selling price P_{it} as follows:

$$L_{it} = K_i + \gamma D_{it-1} + \beta P_{it} + \varepsilon_{it}, \tag{4.2}$$

where K_i is a constant and it is product item dependent, and ε_{it} is the white noise which is normally distributed with a constant variance and zero mean.

Conducting demand forecasting using the panel data model as shown in (2.1) and (2.2) above can incorporate (i) the demand correlation across multiple products, and (ii) the respective product selling price, into the forecasting process. This "pure panel data (PPD)" method expectedly helps provide a more sophisticated and accurate demand forecast than the simple statistical methods such as ARIMA and SARIMA.

In Ren et al. (2014), in order to have forecasting on the nonlinear part, i.e., NL_{it}, they further explore a forecasting method called panel data particle-filter (PDPF). For the PDPF, they employ the well-known particle filter to help predict NL_{it}, and the final forecasting is done by combining the forecasted results on both L_{it} and NL_{it}. Based on real data computational experiments, they report that both the PPD and the PDPF methods outperform the traditional statistical methods. They also interestingly show that increasing the amount of historical data does not necessarily improve forecasting accuracy under PDPF. They hence propose that the PDPF method is suitable for conducting quick demand forecasting for fashion products in the presence of only limited data. This fits the requirements of fast fashion forecasting very well.

4.2.2 Extreme Learning Machine

For fashion demand forecasting, another popular set of forecasting models for predicting fashion products' demand is by artificial neural networks (ANN) (Choi 2014; Hamzaçebia et al. 2009). It is well known that even a simple ANN would take a substantial amount of time to complete a forecasting task (e.g., it may take several minutes, and evolutionary neural networks (ENN) may take hours Au et al. 2008). The long computational time becomes a major barrier for the deployment of many ANN- and ENN-based forecasting models in real-world fast fashion demand forecasting. Relatively recently, there is a proposal for a fast single-hidden layer feed-forward neural network (SLFN) called the extreme learning machine (ELM) (Sun et al. 2007, 2008; Hsu and Wang 2007; Huang et al. 2006; Rong et al. 2008; Xia et al. 2012). ELM is able to learn much faster than many conventional gradient-based learning methods reported in the classical neural networks literature. To the best of my knowledge, Sun et al. (2008) is the first piece of work which applies ELM in conducting fashion demand forecasting. In the following, we review this pioneering demand forecasting model. For more details (including detailed illustrations and figures), please refer to Sun et al. (2008).

As we mentioned above, the ELM is a SLFN with the inputs of variables x_{ij}. By its nature, it randomly assigns the input weight matrix $\mathbf{W}$, and analytically determines the output weight matrix $\boldsymbol{\beta}$. To be specific, suppose that we want to train the "SLFN" of the ELM with K hidden neurons and an activation function vector $\mathbf{g}(x) = (g_1(x), g_2(x), \cdots, g_K(x))$ to learn from N distinct samples (x_i, t_i), where $x_i = [x_{i1}, x_{i2}, \ldots, x_{in}]^T \in R_n$ and $t_i = [t_{i1}, t_{i2}, ..., t_{im}]^T \in R_m$. If the SLFN in the ELM can approximate these N samples with a zero error, then we have $\sum_{j=1}^{N} ||\mathbf{y}_j - \mathbf{t}_j|| = 0$, where $\mathbf{y}$ is the SLFN's output.

In the ELM, the parameters $\boldsymbol{\beta}_i$,$\mathbf{w}_i$ and $\mathbf{b}_i$ satisfy the following system of equations:

$$\sum_{i=1}^{K} \boldsymbol{\beta}_i g_i(\mathbf{w}_i \cdot \mathbf{x}_j + b_i) = \mathbf{t}_j \,, \;\; j = 1, \ldots, N$$

where

$\boldsymbol{\beta}_i = [\beta_{i1}, \cdots, \beta_{im}]^T, i = 1, \cdots, K$ links the i th hidden neuron and the output neurons, $\mathbf{w}_i = [w_{i1}, \cdots, w_{in}]^T$ is the weight vector linking the i th hidden neuron and the input neurons, and b_i is the i th hidden neuron's threshold.

Note that in the ELM, by default, the input weights and hidden biases are all randomly generated instead of tuned. As a result, we can determine the output weights by finding the least-square solution to the given linear system of equations.

To employ ELM in fast fashion demand forecasting, from Sun et al. (2008), we have the following steps:

Step 1 Get the demand data, and select the factors that have significant effects on the product demand as the inputs of ELM; note that the statistical analysis conducted in Ren et al. (2014) can be used to identify the factors which have significant effects on demand.

Step 2 With the given dataset, divide the data into training data, testing data, and forecasting datasets randomly. Normalize the training data and the testing data, and select the activation function of a hidden neuron and choose the neuron number of a hidden layer of ELM.

Step 3 Input training data and testing data, compute the outputs of ELM, un-normalize the outputs, then obtain the predicted demand time series of the training data and the testing data.

Step 4 Based on the input and output weights obtained by Steps 2 and 3 above, compute the predicted demand time series and the corresponding predicting error.

Note that even though ELM runs much faster than the classical ANNs and ENNs, it still requires a certain amount of time to complete the demand forecasting task and it also requires a sufficient amount of data for training in order to yield good demand forecasting results.

4.2.3 Grey Model Based

To conduct time-series demand forecasting with insufficient historical data, the grey method (GM) has been known to be a very good candidate (Choi et al. 2012; Hsu and Wang 2007; Chen and Ou 2009; Lei and Feng 2012; Lin and Lee 2007; Li and

Xie 2014; Wang 2014; Xia and Wong 2014). Observe that GM is derived from the systems science literature which proposes that a system often faces uncertainty, and it is often difficult, if not impossible, to classify the system purely as "black" or "white". Thus, based on this argument, Deng (1989) cleverly defines a system which has both "known" and "unknown" information as a grey system.

In the analytical model, a GM is usually represented by GM (l, k), where l is the order of differential equations employed, and k is the number of variables in the GM. Note that the simplest yet most commonly used GM is GM (1, 1), which is called the single-variable first-order grey model (SFGM) (Choi et al. 2012; Li and Xie 2014; Li et al. 2011). In Choi et al. (2012), the SFGM has been used to conduct time-series forecasting for fashion demand. We review their analytical model as follows.

First, in the time series analysis by using SFGM, the original demand time series is represented by $X^0 = [x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(\mathrm{n})]$, where is the demand data point of time series at time i (i = 1,2,…,n). With X^0, we can get a new "aggregated demand time series" X^1 by the following simple operation:

$$X^1 = \left[x^{(1)}(1),\ x^{(1)}(2), \ldots, x^{(1)}(n)\right] x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i).$$

Under the SFGM-based demand forecasting method, the forecasting of X^1 at time k, given by $\hat{x}^{(1)}(k)$, can be derived using the method in Deng (1989), and the forecasted future demand value of X^0 at time k + 1 can be found by the following:

$$\hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k).$$

Undoubtedly, the SFGM is a simple and easy to apply forecasting method. It, together with other GM-based methods, is suitable for conducting time-series demand forecasting with very few historical data (which is commonly the case in fast fashion business operations). Thus, GM is a good candidate with which one can develop fast fashion demand forecasting applications. However, kindly note that the SFGM- and other GM-based methods are known to be unreliable. This is especially true for those time series which are highly volatile.

4.2.4 Analysis and Comparisons

In the above section, we have discussed and reviewed the recent advances of analytical demand forecasting models which can be applied for conducting demand forecasting in fast fashion companies. In this section, we conduct an analysis of its performance.

A. Accuracy

First of all, the most critical measure to compare is accuracy. In order to have a fair and scientific comparison, we employ real data collected from a fashion boutique

Table 4.1 Accuracy Comparison

	ARIMA		GM		ELM		Panel data (PPD)	
Item	MSE	SMAPE	MSE	SMAPE	MSE	SMAPE	MSE	SMAPE
1	62.8	9.8	154.2	20.2	86.9	12.4	64.5	10.6
2	3.4	29.8	4.0	35.6	4.8	40.1	3.0	27.4
3	18.1	44.9	1.6	23.4	3.9	40.3	1.0	17.4
4	19.6	16.1	44.5	28.1	19.1	15.1	13.1	10.8
5	4.8	42.8	5.9	55.4	4.0	38.4	3.3	30.3
6	2.4	48.3	2.8	56.7	2.5	41.4	1.8	34.4
Mean	18.9	32.0	35.5	36.6	20.2	31.3	14.5	21.8

in this analysis. To be specific, this set of data refers to 6 different kinds of fashion apparel items sold in a fashion boutique in Hong Kong. Table 4.1 shows the accuracy comparison.

B. Speed

First of all, note that all these methods are known to be able to yield forecasting results in a timely manner, and hence they are "fast". If we go deeper in terms of how fast each method performs, we can see that in terms of speed, PPD, IFSFM, and 3F are all fastest because they all have the capability in making super-fast demand forecasting (in seconds) by employing the pure statistical-based component methods. To be specific, PPD is a pure statistical method which must be super-fast. IFSFM and 3F have the time limit constraint. If there is a need to complete the forecasting within a second or even less than a second, it can be done by the hybrid algorithms of them which directly call the pure statistical methods to help. This feature gives these methods a niche.

C. Data Sufficiency Requirements (DSR)

In terms of data requirements, some methods have a higher demand for data sufficiency than others. To be specific, ELM, EELM, and IFSFM all need to have more data in order to do a good job. Interestingly, PPD, PDPF, SFGM, and 3F have much less demand for having a lot of data because (i) For PPD and PDPF, the panel data puts high emphasis on correlation-related information. Thus, there is no need to have a lot of historical data for each item in making sound forecasting; (ii) For SFGM and 3F, they all include GM which is known to be functional even in the absence of enough data. FFC's data requirement is probably in between SFGM and 3F because its component methods are basically simple statistical-based models and data sufficiency would affect them in a rather significant way. However, the FFC method also includes the part on expert advice and the dynamic updating on the "weights". This helps reduce the effect on the issue of initial data insufficiency.

D. Stability

For stability of forecasting results, the case is rather clear. First of all, PPD and PDPF are known to generate stable and reliable forecasting results (Ren et al. 2014). However, ELM and SFGM are known for their shortcomings in terms of yielding unstable forecasting results. FFC is a fuzzy logic-based approach and hence its stability varies. Since EELM is the extended ELM with the repeated run of ELM with the goal of generating a more stable forecasting result, its stability is reasonably high. As IFSFM and 3F are EELM-based methods, their stability is also high.

E. Ease of Implementation and Others

For the issue of whether the forecasting method is easy to use, we find that PPD requires only the basic regression of the available panel data which can be done automatically by many commercial software packages; it should hence be easiest to implement. For FFC, since it requires human expert advice, its real-world implementation requires the presence of a knowledgeable user. For the other methods, they all can conduct demand forecasting in an automatic way after implementing the respective algorithms. Thus, they are also easy to use from that sense. Finally, for accuracy, depending on data sufficiency and also the available computational time (for conducting forecasting), the methods perform differently.

F. Summary

From the above investigation, we have further discussed and identified the strengths and the weaknesses of these recently developed demand forecasting models. As a summary, Table 4.2 shows the item-to-item systematic comparison among the reviewed fast fashion demand forecasting models. From Table 4.2, among these important models, it is crystal clear to observe that both the ELM and the PD-based hybrid models are especially versatile and helpful for developing fast fashion demand forecasting systems.

Table 4.2 Comparisons among the reviewed models

Methods	Five factors				
	Speed	DSR	Stability	Use	Accuracy
ARIMA	Fastest	Low	High	Easiest, intuitive	Medium
PPD	Fastest	Low	High	Easiest, intuitive	Highest
ELM	Fast	High	Low	Easy	Medium
GM	Fast	Low	Low	Easy	Lowest

4.3 Interval Forecasting

In conducting demand forecasting for fashion products, the classical approach starts by analyzing the product features (Nenni et al. 2013). After that, fashion companies need to determine the forecasting approach. In fast fashion, since the time of conducting forecasting is critically important, a quick forecasting approach is desirable. Being quick, intuitive, and easy to apply, statistical methods such as Auto Regression Integrated Moving Average (ARIMA) and Seasonal Auto Regression Integrated Moving Average (SARIMA) approaches are commonly used for quick demand forecasting. Since this chapter aims at reviewing the more advanced analytical forecasting models, we refer readers to other papers, such as (Liu et al. 2013; Thomassey 2014; Box et al. 2008), on the use of these classical simple models. However, the use of these methods is obviously insufficient because demand for fashion products depends on a lot of other factors, such as price and other correlated products' demands. Different from point forecasting, interval forecasting provides a prediction interval that is able to effectively reflect the uncertainties in the forecasting results for decision makers. The prediction interval contains the true distribution of fashion sales with an assigned probability. Forecasting the prediction interval of the sales has the advantage of taking into account the variability and uncertainty. Therefore, it is much important for decision makers to arrange the inventory and estimate their risks. Interval forecasting has been explored to deal with forecasting problems; it also plays an increasingly important role in many research areas. Interval forecasting of electricity demand is fundamental to the success of reducing the risk when making power system planning and operational decisions by providing a range rather than point estimation. It could prove to be a potential tool for both power generators and consumers to make their plans (Xiong et al. 2014).

From the above comparison, we easily find that the panel data regression method proposed by Ren et al. (2014) shows better performance compared with the other three models. In the panel data model, multiple items' demand as well as other critically important factors (such as selling price) are incorporated into the time-series forecasting model. It is an easy-to-implement method with the highest forecasting accuracy. Therefore, in this section, we extend the panel data-based point forecasting model into the interval forecasting model. Then, a comparison study is conducted to evaluate the panel data-based interval forecasting performance when compared with the popularly used AI interval forecasting model for fashion sales forecasting.

4.3.1 Panel Data-Based Interval Forecasting

As mentioned above, the panel data forecasting error ε_{it} is a random white noise that follows the normal distribution. Therefore, the Prediction Interval (PI) of the panel data can be achieved easily by calculating the point forecasting value and the errors' confidence interval. The distances between the lower and higher bounds of PIs is the same as the one of the conduce interval of the updated forecasting error series. We can obtain the forecasting interval by.

$$I_{it} = L_{it} \pm \frac{\sigma_{it}}{\sqrt{n}} z_{\alpha/2},$$

where σ_{it}^2 denotes the variance of error ε_{it} and n is the number of observations. For the first forecasting period, the variance σ_{it}^2 is derived from the model training error. When a new observation arrives, the variance is updated step by step. α represents significance level.

4.3.2 ELM-Based Interval Forecasting

Note that in ELM, the weights a_i and the hidden layer biases b_i are randomly assigned; the task is to find β^* that can minimize the cost function of the traditional gradient-based back-propagation learning algorithm

$$C = \sum\nolimits_{j=1}^{N} \left[\sum\nolimits_{i=1}^{K} \beta_i \varphi(a_i * x_j + b_i) - t_j \right]^2 \tag{4.3}$$

Similarly, as the norm least-squares solution of the linear system, β^* can be calculated as

$$\beta^* = H^{\dagger} T \tag{4.4}$$

where $H^{\dagger}$ is the Moore–Penrose generalized inverse of the hidden layer output matrix H, which can be derived through the singular value decomposition (SVD) method.

The advantages of ELM is that it can overcome many limitations of traditional gradient-based NNs training algorithms, such as the local minima, overtraining, and high computational burdens. The traditional gradient-based NNs learning algorithms always involve a number of iterations that affect the training speed. The ELM training features extremely fast speed because of the simple matrix computation, and can always guarantee optimal performance (Huang et al. 2006). Thus, the ELM-based interval forecasting is conducted by the following steps:

Step 1: Prediction Intervals

Prediction Intervals with nominal confidence $100(1-\alpha)\%$ of the future target t_i, represented as

$$\hat{I}_t^{(\alpha)}(x_i) = [\hat{L}_t^{(\alpha)}(x_i), \hat{U}_t^{(\alpha)}(x_i)] \tag{4.5}$$

where $\widehat{L}_t^{(\alpha)}(x_i)$ and $\widehat{U}_t^{(\alpha)}(x_i)$ denote the lower and upper bounds of PI $\hat{I}_t^{(\alpha)}(x_i)$, respectively, such that the future target t_i is expected to be enclosed by $\hat{I}_t^{(\alpha)}(x_i)$ with coverage probability.

$$P\left(t_i \in \hat{I}_t^{(\alpha)}(x_i)\right) = 100\,(1-\alpha)\%. \tag{4.6}$$

The proposed method aims to directly generate the lower and upper bounds of the expected PIs by ELM.

Step 2: Multi-objective Optimization

PI Evaluation Criteria

a. Reliability

Reliability is regarded as a major property for validating probabilistic forecasting models. According to the PIs definition, the future targets t_i are expected to be covered by the constructed PIs with a nominal probability of $100(1-\alpha)\%$, which is called PI nominal confidence (PINC). PI coverage probability (PICP) is represented by $\widehat{P}_t^{(\alpha)} = \frac{1}{N_t}\sum_{i=1}^{N_t} K_i^{(\alpha)}$, where N_t is the size of test dataset, and $K_i^{(\alpha)}$ is the indicator of PICP, expressed as.

$$K_i^{(\alpha)} = \begin{cases} 1 & t_i \in \hat{I}_t^{(\alpha)}(x_i) \\ 0 & otherwise \end{cases}.$$

The PICP should be as close as possible to PINC. The average coverage error (ACE) is represented by.

$$A_t^{(\alpha)} = \hat{P}_t^{(\alpha)} - PINC.$$

Therefore, we can get the conclusion that the smaller the absolute ACE is, the higher reliability the obtained PIs possess.

b. Sharpness

High reliability can be easily achieved by increasing the distances between the lower and higher bounds of PIs, which will make the PIs useless in practice because wide PIs may not provide accurate quantifications of uncertainties involved in the real-world processes. This section will introduce another criterion called sharpness to improve this aspect.

The width of PI $\hat{I}_t^{(\alpha)}(x_i)$ represented by $v_t^{(\alpha)}(x_i)$ can be calculated through

$$v_t^{(\alpha)}(x_i) = \widehat{U}_t^{(\alpha)}(x_i) - \widehat{L}_t^{(\alpha)}(x_i).$$

The sharpness represented by $S_t^{(\alpha)}(x_i)$ can be calculated as (Wan et al. 2014).

$$S_t^{(\alpha)}(x_i) = \begin{cases} -2\alpha v_t^{(\alpha)}(x_i) - 4\left[\hat{L}_t^{(\alpha)}(x_i) - t_i\right], & if\ t_i < \hat{L}_t^{(\alpha)}(x_i) \\ -2\alpha v_t^{(\alpha)}(x_i), & if\ t_i \in \hat{I}_t^{(\alpha)}(x_i) \\ -2\alpha v_t^{(\alpha)}(x_i) - 4\left[t_i - \hat{U}_t^{(\alpha)}(x_i)\right], & if\ t_i > \hat{U}_t^{(\alpha)}(x_i) \end{cases}$$

The score is calculated for each prediction point and then the overall sharpness can be derived as average over the entire test dataset,

$$\overline{S}_t^{(\alpha)} = \frac{1}{N_t}\sum_{i=1}^{N_t} S_t^{(\alpha)}(X_i).$$

We can see that lower $\overline{\mathrm{S}}_{\mathrm{t}}^{(\alpha)}$ indicates a higher sharpness.

Multi-objective Function

Both reliability and sharpness are important criteria to evaluate the quality of the PIs, therefore, we need to define a multi-objective function to adjust the trade-off between the two criteria. The ELM weights β are optimized to minimize the objective function F.

$$_{\beta}{}^{\min}\mathrm{F} = \gamma\left|\mathrm{A}_{\mathrm{t}}^{(\alpha)}\right| + \lambda|\overline{\mathrm{S}}_{\mathrm{t}}^{(\alpha)}|_{\mathrm{norm}}$$

where $\left|\mathrm{A}_{\mathrm{t}}^{(\alpha)}\right|$ is the absolute value of ACE of PIs with corresponding PINC $100(1-\alpha)\%$; $|\overline{\mathrm{S}}_{\mathrm{t}}^{(\alpha)}|_{\mathrm{norm}}$ denotes the average of normalized $\mathrm{S}_{\mathrm{t}}^{(\alpha)}(\mathrm{x}_{\mathrm{i}})$, represented by $\mathrm{S}_{\mathrm{t}}^{(\alpha)}(\mathrm{x}_{\mathrm{i}})_{\mathrm{norm}}$,

$$S_t^{(\alpha)}(x_i)_{norm} = \frac{S_t^{(\alpha)}(x_i) - \min\left(S_t^{(\alpha)}(x_i)\right)}{\max\left(S_t^{(\alpha)}(x_i)\right) - \min\left(S_t^{(\alpha)}(x_i)\right)},$$

γ and λ are importance weights of reliability and sharpness.

4.4 Case Studies and Comparison Analysis

4.4.1 Datasets

In our dataset, the real daily sales data of 9 months from a boutique in Hong Kong are used to measure the performance of different kinds of interval forecasting models in the empirical study. Three fashion items (including T-shirt, pants, and an accessory) together with other related properties of the items are included. The sample of dataset and basic descriptive statistics are listed in Table 3a and 3b, respectively. We have

Table 3a Samples of dataset for comparison analysis

Day	Item code	Color	Quantity	Price
1	1	Black	10	89
2	3	Yellow	6	39
3	2	Brown	9	63
4	2	Red	3	76
5	3	Blue	1	79
6	1	Black	6	69
7	1	Blue	7	99

Table 3b Basic descriptive statistics

Mean	Median	Maximum	Minimum	Std. dev	Jarque–Bera	Probability
7.805556	3	50	0	9.809306	136.2878	0

total 260 data samples. The first 200 samples (about 7 months) are used as the training data (for estimating the model parameters), and the remaining 60 samples (about 2 months) are used to do the forecasting test.

4.4.2 Experimental results and analysis

Following Panel Stationarity Tests and Hausman Test, the panel data point forecasting model can be conducted as

$$S_{it} = m + \alpha_i^* + \gamma S_{it-1} + \beta \cdot \mathrm{P}_{it} + \mu_{it}, \qquad i = 1, ..., N, t = 1, ..., T.$$

Table 4.4 summarizes the outcome of the estimation procedure using a panel of data. For a detailed description of the modeling process, please refer to Ren et al. (2014).

In our study, the structure of ELM is designed through experiments, the number of input neurons is set as 3, so is the number of hidden neurons, and there are two output neurons, which correspond to the lower bound and upper bound of the predictions. As mentioned earlier, the weights α_i and the hidden layer bias b_i are randomly generated. In order to find the optimal output weight β of ELM, PSO is applied. The

Table 4.4 Estimation result of the sales forecasting model

Coefficient	m	γ	β	α_1	α_2	α_3
Estimation	1.04	0.09	0.02	1.03	0.06	0.97
T-Statistic	6.95	2.32	8.75	–	–	–

population number in PSO is set as 200, the iteration number is also set as 200. The maximum speed of the particle is 1. The values of w, c_1, c_2 in the equation are 0.9, 1, and 1, respectively. φ in the equation is tuned as 0.5. Because of the randomness of ELM, for different confidence levels, it is run 100 times, and we select the one which brings the lowest multi-objective function value as the result.

In order to better derive the forecasting feature of these two kinds of interval forecasting models. We set different significant levels for panel data-based model, 10%, 5%, and 1%. Correspondingly, for ELM-based interval forecasting model, PIs with different PINCs (involving 90%, 95%, and 99%, respectively) are constructed to evaluate the forecasting performance for different fashion items. The forecasting results of panel data-based model and ELM-based model are illustrated in Figs. 4.1 and 4.2, respectively.

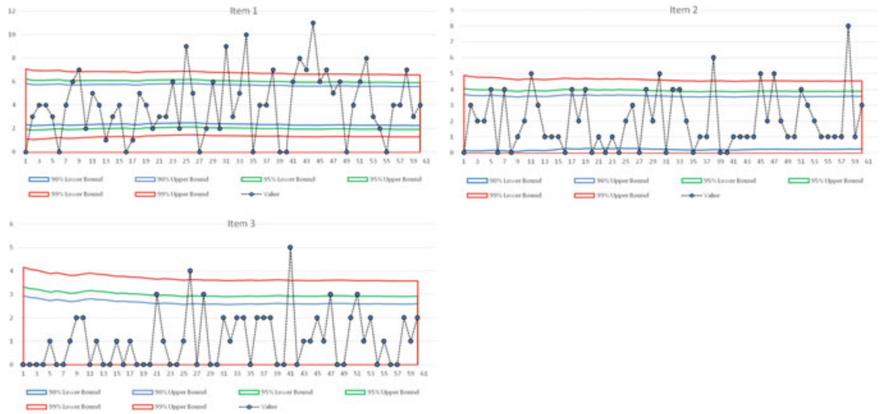

Fig. 4.1 Interval forecasting results of panel data-based model in different significant levels

Fig. 4.2 Interval forecasting results of ELM-based model in different significant levels

From Figs. 4.1 and 4.2, it can be observed that the different objective confidence levels do not lead to significant difference for ELM-based interval forecasting results. That means the result is not observably affected by the expected confidence. However, in the panel data-based model, a lower significant level generates a wider prediction interval. The forecasting results are dramatically affected by the setting confidence of forecasting error.

Figure 4.3 illustrates the forecasting performance comparison between the two methods for studied three items. From Fig. 4.3, it is obviously noted that the panel data model generates a better prediction interval than ELM-based forecasting model under the same objective significant level, while the ELM-based model derived a higher forecasting reliability than the panel data-based model. Based on this result, it is difficult to simply conclude which method achieves a better performance in interval forecasting. So, how to evaluate the performance of interval forecasting models? In fact, for any interval forecasting method, the forecasting confidence level (forecasting reliability) is defined as the percentages of the true observations that have fallen into the interval. Usually, a higher forecasting confidence level would lead to a wider PI. A higher forecasting confidence level indicates significant reliability. In other words, if we require the highest accuracy of forecasting that all observations have fallen into the interval, the PI will be very wide. However, a large PI is meaningless for practical application.

To further investigate the effectiveness of different models, both forecasting confidence level and the absolute distance of PI are taken into account in this study. The effectiveness is calculated as follows:

$$Effectiveness = \gamma|forecasting\ confidence\ level| + \lambda|distance\ of\ PI|$$

Considering that decision makers may have different preferences for the evaluating criteria under different industry scenarios, we conduct a comparison analysis by assigning different weights (namely γ and λ) for two evaluating criteria (namely forecasting confidence level, distance of PI) as shown in Tables 4.5, 4.6 and 4.7.

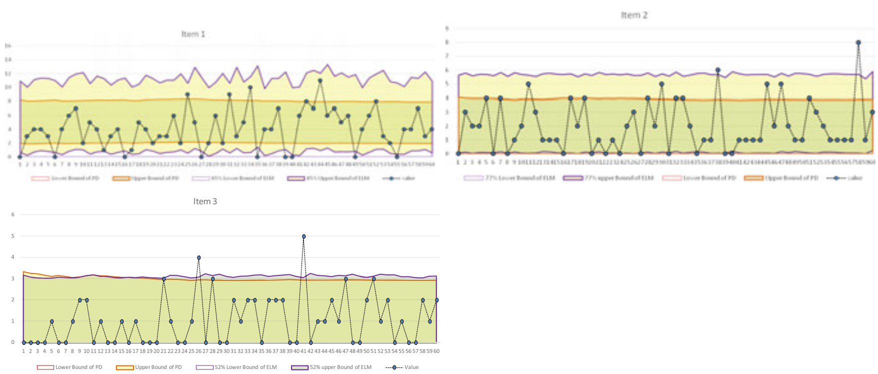

Fig. 4.3 Comparison of forecasting performance of two methods for studied items

Table 4.5 Forecasting performance of panel data-based and EML-based model for item 1 by different weighting (panel data: 50%, 4.06; ELM: 85%, 9.95)

Weight	Panel data	ELM	Weight	Panel data	ELM
1:1	4.56	10.80	**1:1**	4.56	10.80
1:2	8.62	20.75	**2:1**	5.06	11.65
1:3	12.68	30.70	**3:1**	5.56	12.50
1:4	16.74	40.65	**4:1**	6.06	13.35
1:5	20.8	50.60	**5:1**	6.56	14.20
1:6	24.86	60.55	**6:1**	7.06	15.05
1:7	28.92	70.50	**7:1**	7.56	15.90
1:8	32.98	80.45	**8:1**	8.06	16.75
1:9	37.04	90.40	**9:1**	8.56	17.60
1:10	41.1	100.35	**10:1**	9.06	18.45

Table 4.6 Forecasting performance of panel data-based and EML-based model for item 2 by different weighting (panel data: 80%, 3.93; ELM: 77%, 5.51)

Weight	Panel data	ELM	Weight	Panel data	ELM
1:1	4.53	6.28	**1:1**	4.53	6.28
1:2	8.46	11.79	**2:1**	5.13	7.05
1:3	12.39	17.3	**3:1**	5.73	7.82
1:4	16.32	22.81	**4:1**	6.33	8.59
1:5	20.25	28.32	**5:1**	6.93	9.36
1:6	24.18	33.83	**6:1**	7.53	10.13
1:7	28.11	39.34	**7:1**	8.13	10.9
1:8	32.04	44.85	**8:1**	8.73	11.67
1:9	35.97	50.36	**9:1**	9.33	12.44
1:10	39.9	55.87	**10:1**	9.93	13.21

It can be seen from Tables 4.5, 4.6 and 4.7 that Panel Data-based PI forecasting constantly yielded a smaller value than ELM did in all weighting assignment settings. It can be concluded that the panel data-based interval forecasting model obviously outperforms the ELM-based model for a comprehensive evaluation, although forecasting confidence level and the absolute distance are assigned different importance.

Table 4.7 Forecasting performance of panel data-based and EML-based model for item 3 by different weighting (panel data: 73%, 2.99; ELM: 52%, 3.11)

Weight	Panel data	ELM	Weight	Panel data	ELM
1:1	3.44	3.63	**1:1**	3.44	3.63
1:2	6.43	6.74	**2:1**	3.89	4.15
1:3	9.42	9.85	**3:1**	4.34	4.67
1:4	12.41	12.96	**4:1**	4.79	5.19
1:5	15.4	16.07	**5:1**	5.24	5.71
1:6	18.39	19.18	**6:1**	5.69	6.23
1:7	21.38	22.29	**7:1**	6.14	6.75
1:8	24.37	25.4	**8:1**	6.59	7.27
1:9	27.36	28.51	**9:1**	7.04	7.79
1:10	30.35	31.62	**10:1**	7.49	8.31

4.5 Conclusion

In this study, we have first reviewed different analytical demand forecasting models for fast fashion business models. After that, we have examined the related literature on inventory operational planning with a focal point on risk.

From the review and discussions, we have identified the strengths and weaknesses of reviewed fast fashion demand forecasting models. Insights regarding when and which model should be selected have been found. After that, we have proposed a panel data-based interval forecasting model. By conducting a comparison study with the ELM-based model, we find that the panel data-based model generates a smaller prediction interval with a lower forecasting confidence level than ELM. To further investigate the forecasting performance of these two models, a comprehensive evaluation that combines both forecasting confidence level and the absolute distance of prediction interval is conducted. Considering that decision makers may have different preferences for these two kinds of evaluating criteria, we preset different weights to them. We find that the panel data-based model outperforms the ELM-based model for any kind of weight setting.

For future research, on the one hand, in terms of forecasting methods, one most promising direction is to examine further how different analytical forecasting methods can be further combined to develop new and more robust methods (Liu et al. 2013; Choi et al. 2011a, b; Štěpnička et al. 2013). This extension potentially can yield even better forecasting performance for fast fashion companies. As pointed out by Yesil et al. (2012), it is critically important to consider the specific needs of every individual fast fashion company before we can develop the right demand forecasting model to achieve the optimal forecasting result. As a consequence, there is a fruitful area for future research on whether there is a generalizable forecasting framework for conducting forecasting across multiple companies in fast fashion supply chains

(Zhu et al. 2011). On the other hand, it is important to examine the real-world implementation of the specific forecasting model for inventory control problems with risk consideration. The proposed optimization model in Sect. 4.1 provides an example for this study. This direction of exploration is crucial because even though a higher forecasting accuracy is always more preferred to a lower one, how much "more" business value the fast fashion companies would gain with the consideration of risk by having this "higher forecasting accuracy" is largely unknown. Thus, it is hard for fast fashion companies to decide if it is wise to invest in the implementation of a better demand forecasting system. In addition, how to incorporate a better demand forecasting model into the existing business intelligent operations management scheme (Duan and Xu 2012) in the fast fashion companies for making scientifically sound decisions on production, inventory, and distribution with risk analysis is another critical issue which deserves future research. Lastly, in a multi-agent data-driven (Chan et al. 2014) supply chain environment with high demand uncertainty (Chan and Chan 2006) and information asymmetry (Mukhopadhyay et al. 2008), how the agents could coordinate (Cao et al. 2013; Chen and Bell 2011; Asian and Nie 2014) in the presence of the demand forecasting tool and the related risk minimization inventory control model is a challenging area for further explorations.

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Chapter 5
Impact of Search Index on Fashion Demand Forecasting—Panel Data-Based Analysis

Zhicheng He, Shuyun Ren, and Guangzhou Zhu

Abstract Fashion demand forecasting has been a challenge for long as it is influenced by not only explicit factors such as historical selling data and price, but also implicit factors such as consumers' purchasing intentions and fashion trend. This paper focuses on exploring how to forecast fashion demand using panel data model, based on historical sales data and search index. Further, this study demonstrates how search index can improve the performance of the forecasting model. The daily sales data from a small size fashion company focus on niche market and search index in 2018 were used to examine the effectiveness and usefulness of our proposed SIPD. The feature of the proposed SIPD model is in line with the situation that small size fashion enterprises who have little useful data in most cases.

Keywords Fashion · Demand forecasting · Search index

5.1 Introduction

Fashion industry has developed significantly in recent decades and contributed a lot to its economy. The fashion service industry is characterized by short product cycle, long operation process, large production scale, and complex supply chain structure Ren et al. (2014). In addition, with the massive growth of social media and its adoption by millions of people globally as part of their everyday life, the need of advanced demand forecasting technologies increases significantly (Ren et al. 2020). It is very vital for fashion business to predict the fashion demand because the fashion demand fluctuates greatly and the fashion product life cycle is short (Ren et al. 2019a, b). Fashion demand is affected not only by explicit factors such as price, weather, season, and economic indicators, but also implicit factors such as fashion trends and hot topics (Jain and Rao 1990). The improvement of consumers' quality of life and aesthetic

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Z. He · S. Ren (✉) · G. Zhu
School of Art and Design, Guangdong University of Technology, Guangzhou, China
e-mail: Shuyun_shara@live.cn

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demand, fashion trends, product elements, personal preferences, and other subjective factors have increasing influences on fashion demand. Therefore, the market capacity of fashion products is always varying dramatically, which makes fashion service industry difficult to control their inventory. Moreover, fashion products are different from other products. A fashion company uses to spend a lot in its inventory to maintain multiple supporting SKUs even though it has only one manufacturing chain. To have a better inventory forecasting and planning, it can significantly better match the demand to satisfy customers and reduce the negative impacts brought to the environment due to the overproduction.

The common practice to decide the SKUs level of multiple supporting inventory is based on experts' knowledge, which always differ with the actual fashion demands significantly (Ren et al. 2019a, b). To reduce the abundant cost of the inventory in fashion service industry, an accurate forecast not only for the style (i.e., color, price, etc.) of fashion products, but also for their corresponding demand is required (Liu et al. 2013). There are increasing amount of studies using search data to forecast the demand but seldom explore how to use search index to perform fashion demands (Ren et al. 2019a, b). Further, no study has investigated how search index can improve the performance of the forecasting model. This paper conducted a panel data-based analysis to investigate how search index influence the fashion demands statistically, and more importantly, to quantitative measure the impact of search index on the forecasting accuracy. The proposed Search Index-based Panel Data (SIPD) model exhibited superior performance, being reliable and practical in real fashion business operations. Finally, the daily sales data from a small size fashion company focus on niche market and search index in 2018 were used to illustrate the effectiveness and robustness of our proposed SIPD for fashion product forecasting and some important findings are also obtained.

First, as far as we know, this paper is the pioneering study on fashion demand forecasting using panel data model and based on historical sales data and search index. Second, we demonstrate how search index can improve the performance of the forecasting mode by comparing two panel data models (with and without using search index). This is an important contribution because quantitative measurements of the impact of search index on the forecasting accuracy are missed in existing literature. Finally, the daily sales data from a small size fashion company focus on niche market and search index in 2018 were used to illustrate the effectiveness and robustness of our proposed SIPD for fashion product forecasting and some important findings are also obtained.

5.2 Literature Review

This paper relates to two fields of studies. In the following, we concisely review some related prior research and also show the literature positioning of this paper.

5.2.1 Fashion Demand Forecasting

The available forecasting methods can be broadly classified into two categories: statistical-based methods and AI-based methods. Statistical-based methods have been commonly applied in fashion demand forecasting because of fast and simple features (Liu et al. 2013). Several methods have been developed under this category, such as Exponential Smoothing (ES) model, Autoregressive Integrated Moving Average Model (ARIMA), Seasonal Autoregressive Integrated Moving Average model (SARIMA), Holt-winters, and Autoregressive Conditional Heteroskedasticity model (ARCH). However, statistical-based methods' performance relies heavily on the factors which the model has taken into consideration. It is difficult and sometimes impossible to quantify all factors into the forecasting model (Ni and Fan 2011). AI-based methods derived from Neural Networks (NN) and other data mining technologies have made significant progress in past decades. Comparing with statistical-based methods, AI-based methods usually provide more accurate results (Li et al. 2013) but need more data and longer training time (Ma L and Khorasani 2004).

Both statistical-based methods and AI-based methods have their limitations, hybrid models integrating advantages of both categories thus became popular recently (Liu 2016). Aburto L. et al. (2007) improved the accuracy of their predictions by combining the ARIMA model from traditional statistics with neural networks. Thomassey et al. (2005) combined a variety of traditional statistical models with logic fuzzy, neural network, and other computer algorithms to create a new neural clustering and classification system to solve the problem of medium-term sales forecast when data is lacking. Choi et al. (2011) proposed a hybrid model combining SARIMA and wavelet transform. Wong et al. (2010) investigated an intelligent hybrid model that integrates harmony search algorithms with a limit learning machine, which can improve prediction accuracy through constant fine-tuning. Vorman et al. (1998) combined cubic exponential smoothing and fuzzy adaptive model to study a predictive model in an unstable environment. In terms of domestic research status, since Deng (1990, 2002) put forward the grey system theory model, some robust methods have been obtained through the research in recent years. For example, Zhong and Xiao (2002) proposed a new combined prediction crime based on the basic theory of rough set, which eliminated subjective influence from the weighting of coefficient and simplified the calculation process.

5.2.2 Impact of Search Index on Demand Forecasting

Fashion demand has been influenced by several factors, namely, "explanatory variables". Now that people spend lots of time to search relevant information of fashion products on the Internet before they decide to purchase a fashion item, search index is considered a useful explanatory variable reflecting some trends of fashion demand accordingly. An explicit advantage of adopting search index as an input in demand forecasting is that the index is generated by users, which provide some implicit factors and trends to improve the forecasting power. Virtually, Internet search engine plays a role of "demand collection". Internet search data, including content data and index data, content index refers to the content searched by users, index data refers to the search volume of that content.

The fashion industry is one of the most beneficial industries from the booming of search data, from forecasting the trend of fashions to future purchase decisions. Search index has played an increasingly important role in both industry and academia, especially when applying to fashion forecast process as a source (China Internet Network Information Center 2019). However, the biggest difficulty in adopting search index for analysis and prediction lies in the selection of keywords. A common way is to filter and determine keywords related to fashion products based on experts' knowledge, then to apply different methods to obtain a comprehensive index. Brynjolfsson et al. (2015) proposed a crowd square-based method to select keywords. This method asks interviewers to select the most suitable keyword and then pick up the highest selected one as the result. A comprehensive case study has proven the feasibility effectiveness of this proposed method. Many researchers propose using search index to forecast demand based on panel data model (Ren et al. 2018; Li et al. 2015; Shen et al. 2019). However, there is a need for more conclusive research which evaluates whether big data in the form of search index can help predict actual sales for fashion products.

To address the problem of fashion demand forecasting and, more importantly, to investigate how search index can improve the performance of the forecasting mode, we propose a SIPD model in the following section.

5.3 Fashion Demand Data and Search Index for Fashion Demand Forecasting

5.3.1 Fashion Demand Data

The fashion sale data used for analysis and forecast is from a company located in The Cotton Tree International Fashion City in Guangzhou (hereinafter referred to as "K Company"). The dataset covers 6 items and 8 colors in 60 days, codes of which are shown in Tables 5.1 and 5.2.

In order to analyze the data, we assort the fashion sale data (shown in Table 5.3) according to item (shown in Table 5.4) and color (shown in Table 5.5).

To reduce the data interference in advance due to the small size of sample, data preprocessing is conducted before the establishment of panel data. We reorganized the dataset into 14 assortments according to item and color, and found that there were many missing data. There are two methods used to handle missing data: data interpolation and data screening. In our case, Lagrangian interpolation was applied.

Table 5.1 Color codes

Color	Code	Remark
Black	B	–
Red	R	–
Azure blue	a	Cyan
Yellow	Y	–
Grey	G	–
Jasper	J	Dark green
White	W	–
Purple	P	–

Table 5.2 Item codes

Item	Code
T-shirt	1
Shirt	2
Trousers	3
Dress	4
Sweater	5
Coat	6

Table 5.3 Fashion sale data

Date	Item	Color	Volume	Price
20171019	2	W	25	120
20171020	1	W	20	88
20171021	7	Y	12	130
20171022	7	R	13	100

Table 5.4 Item assortment data

Date	Item	Volume	Price
20171019	2	25	120
20171022	7	13	100

Table 5.5 Color assortment data

Date	Color	Volume	price
20171019	W	25	120
20171022	R	13	100

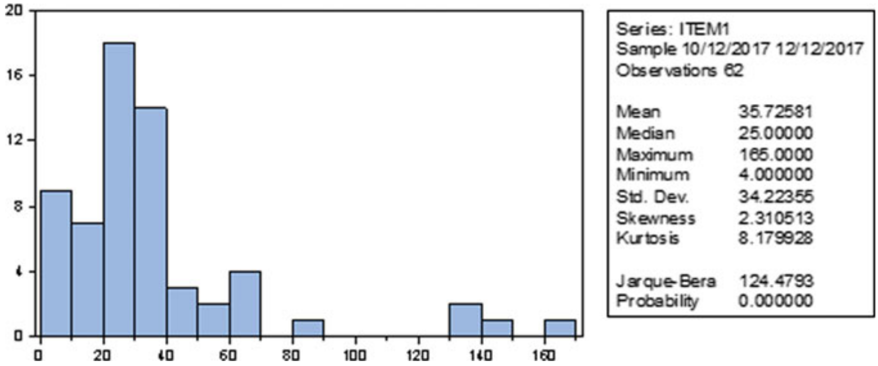

Fig. 5.1 Statistical summary of item 1

After the preprocessing, we select item 1, 2, 3, and 6 (namely, T-shirts, shirts, pants, and coats) for further analysis. Statistical summary of item 1 is shown in Fig. 5.1.

5.3.2 Search Index

With the rapid development of information technology, consumers get used to search relative information online before purchasing fashion products (Xie 2012). The big data, such as search index, reflects consumers' potential purchasing desire, and purchase behaviors (Ren et al. 2018). Search index usually includes search engine index and search content index, among which search engine index is generated by company such as Google and Baidu, and search content index is a complex index related to target fashion products. The most important procedure of including search index into demand forecasting model is to determine the keywords. It should be noted that search engine data is adopted in this paper.

According to the characteristics of K company, a small size fashion company focusing on niche market, we developed a comprehensive approach to obtain the search index for fashion demand forecasting. Generally speaking, the approach selects keywords based on unbiased principle, apply principal component analysis (PCA), and data fusion technology to achieve a composite search index. The flow chart of this approach is shown in Fig. 5.2.

5.3.2.1 Keywords Selection

Considering that the Company K we investigated is focused on middle-aged and elderly women's fashion product. We use image search to look for Company K's top selling items on Taobao (the largest E-commerce platform in China) and obtain keywords for each item. The advantage of adopting keywords on Taobao is to

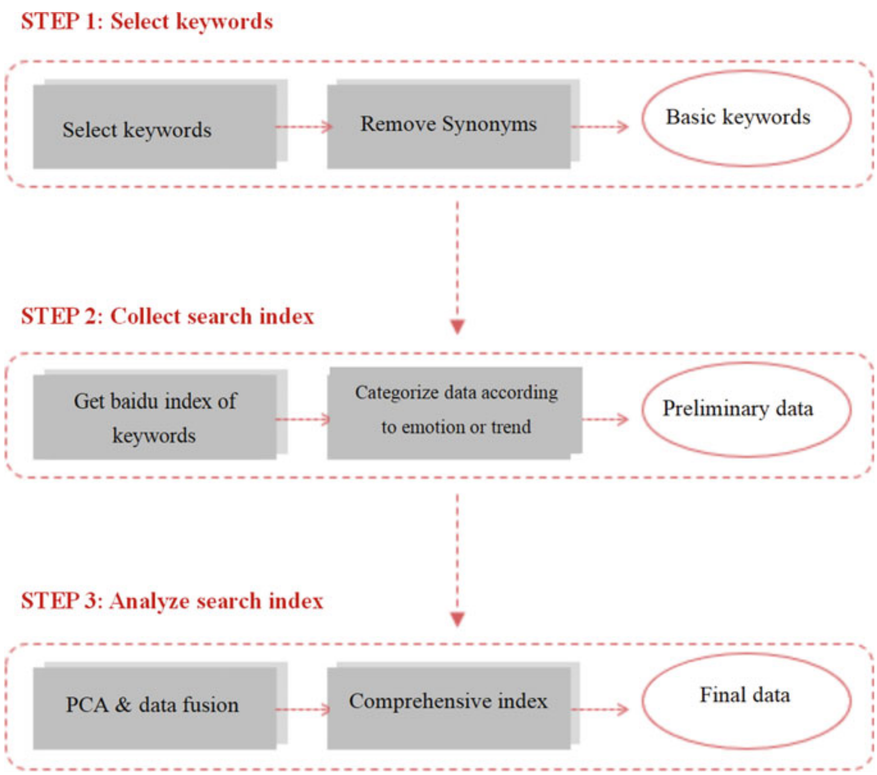

Fig. 5.2 Flow chart of this approach

reduce the impact of the subjective factors on keywords' selection. After sifting some keywords which have not been included in Baidu (the largest search engine in China) Index, such as "T-shirt for women", "shirts for women", etc., and substituting some synonyms, we determine 11 keywords to process the search index.

5.3.2.2 Collect Search Index

More than 85% domestic netizens regard Baidu search engine as their first choice (China Internet Network Information Center 2019). Because all business of Company K is located in China, we choose Baidu Index as the search engine index. The 11 keywords are classified into 4 groups according to emotional and descriptive and listed in Table 5.6.

A total of 671 data was collected for the 11 keywords during the period of October–December 2017. The descriptive statistics of search index was listed in Fig. 5.3.

Table 5.6 Classification of keywords

Basic keywords	Keywords	Basic keywords	keywords
The trousers	Panty	T-shirt	Women's T-shirts
	Slim trousers		Korean
Shirt	Women's wear	Coat	women's wear
	Chiffon		Korean
	Korean		Trendy
	Blouse		Noble
	Vintage		Sweater
	Noble		–

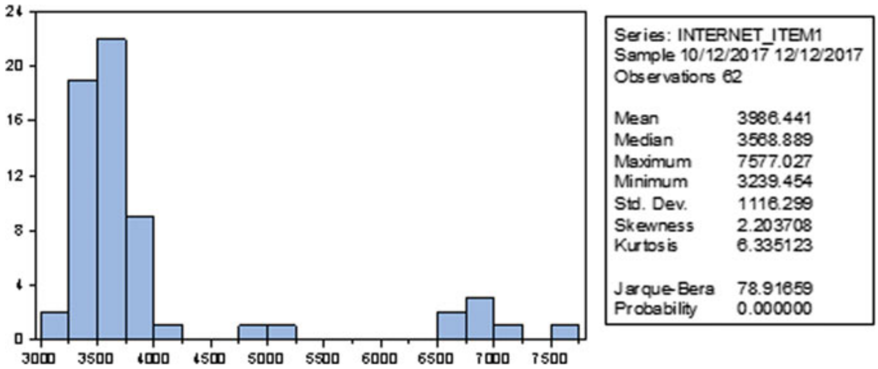

Fig. 5.3 Descriptive statistics of search engine index

5.3.2.3 Analyze Search Index

To solve the multicollinearity and overfitting problems when adopting the search index, Principal Component Analysis (PCA) is applied to obtain a composite index (Li et al. 2015). PCA is a method used to transform the high-dimensional data to lower dimensional one by maximizing the variance of each dimension. A higher variance of a dataset is mathematically considered with more information. In addition, simple data fusion according to the classification is applied as well to retain the diversity of the search information.

The procedure of obtaining a composite index using PCA is expressed as follows:

(1) To normalize the n characteristic principal component $x_j^{(i)}$, which is the jth linear combination of the search index:

$$\overline{\mathrm{x}_{\mathrm{j}}^{(\mathrm{i})}} = \frac{\mathrm{x}_{\mathrm{j}}^{(\mathrm{i})} - \frac{1}{n}\sum_{i=1}^{n} x_j^{(i)}}{\sqrt{\frac{1}{n}\sum_{1=1}^{n}\left(x_j^{(i)}\right)^2}} \tag{5.1}$$

(2) To calculate the covariance matrix C: calculate the covariance matrix:

$$C = \frac{1}{n}\overline{x_j^{(i)}}^T \cdot \overline{x_j^{(i)}} \tag{5.2}$$

(3) To rank the eigenvectors of the covariance matrix and sift the first N eigenvectors which account for at least 85% of the total data information.

(4) To project the four groups of search index listed in Table 5.6 to lower dimensional according to the ranking in step (3).

Taking the item "coat" as an example, the process result of the total variance interpretation and the component matrix in SPSS was shown in Tables 5.7 and 5.8.

(5) To calculate the coefficients of principal components in each linear combination, factor in each comprehensive score model, and determine the weight coefficients of each keyword obtained in Step 2. The processes are as follows:

Calculate the coefficient of principal component in each linear combination:

$$\omega_{ij} = \frac{\beta_{ij}}{\sqrt{\delta_i}} \tag{5.3}$$

Calculate the coefficients of each factor in the comprehensive score model:

Table 5.7 Total variance interpretation

COM	Initial eigenvalue			Sum of squares of loads			Sum of squares of rotating loads		
1	Total	PV%	Sum%	Total	PV%	Sum%	total	Total	PV%
2	2.720	45.338	45.338	2.720	45.338	45.338	2.212	36.863	36.863
3	1.235	20.586	65.925	1.235	20.586	65.925	1.636	27.267	64.130
4	981	16.354	82.279	981	16.354	82.279	1.089	18.149	82.279
5	627	10.450	92.729	–	–	–	–	–	–
6	257	4.279	97.008	–	–	–	–	–	–

Table 5.8 Component matrix

	Component		
	1	2	3
Women's wear	0.793	−0.345	0.000
Blouse	0.659	−0.388	−0.426
Korean	0.926	−0.127	−0.034
Sweater	0.710	0.528	0.011
Vintage	0.445	0.782	0.055
Noble	0.314	−0.245	0.892

Table 5.9 Coefficients of principal components in linear combinations

	Component		
	1	2	3
Women's wear	0.481	−0.051	0.000
Blouse	0.593	−0.085	−0.052
Korean	0.934	−0.031	−0.004
Sweater	0.897	0.163	0.001
Vintage	0.879	0.378	0.006
Noble	0.740	−0.141	0.089

$$v_i = \frac{\sum_{i=1,j=1}^{n} w_{ij} \times \varphi_i}{\sqrt{\delta_i}} \tag{5.4}$$

Calculate the weight coefficient of each keyword obtained in Step 2:

$$\gamma_i = \frac{v_i}{\sum_{i=1}^{n} v_i} \tag{5.5}$$

where β_{ij} represents the load of the jth column of the ith principle component matrix; δ_i represents the sum of the initial eigenvalue of the ith principle component matrix; represents the coefficient of the ith principle component in the jth linear combination; φ_i represents the variance of the initial eigenvalue of the ith principle component; v_i represents the coefficient of the ith principle component in the comprehensive score model; and γ_i represents the weight coefficient of the ith basic keyword among the primary keywords. The results of coefficients of principal components in linear combinations, coefficients of each factor in the comprehensive score model, and weight coefficient of each keyword are shown in Tables 5.9, 5.10, and 5.11, respectively.

(6) To calculate the weighted sum of all principle component for the same item as the jth composite search index, which is calculated as follows:

Table 5.10 Coefficients of each factor in the comprehensive score model

Women's wear	0.457
Blouse	0.555
Korean	0.920
Sweater	0.971
Vintage	1.050
Noble	0.675

Table 5.11 Weight of each factor

Women's wear	0.099
Blouse	0.120
Korean	0.199
Sweater	0.210
Vintage	0.227
Noble	0.146

Table 5.12 Composite search index for item "coat"

Time\search index	Women's wear	Blouse	Korean	Sweater	Vintage	Noble	Composite search index
2017/10/12	2381	1371	1557	435	255	320	905.02

$$\text{Index}_j = \sum_{i=1}^{n} index_{ij} * \gamma_i \tag{5.6}$$

where Index_i represents the composite index of the jth keyword; $index_{ij}$ represents the jth principle component of basic keywords for the item i. Taking item "coat" as an example, the composite search index is as follows (Table 5.12).

5.4 SIPD Model for Fashion Demand Forecasting

5.4.1 Panel Data

According to the nature of statistics, statistic data can roughly be divided into three types: Cross-Sectional Data, Time Series Data, and Panel Data. Among them, panel data is also known as parallel data, time series-cross-sectional data, which refers to the multi-dimensional time series obtained through continuous observation of multiple observation individuals on the time series by intercepting multiple cross sections (Pan 2013). Panel data model is a regression model for panel data. It can be divided into single panel data model and simultaneous panel data model, and can also be divided into linear panel data model and nonlinear panel data model according to the panel's linearity (Ren and Choi 2016).

Considering there are several implicit factors affecting the fashion demands dynamically, it was impossible to include all possible variables into the model for analysis and forecasting. For common statistical models, losing possible variables or including uncorrelated variables can easily result in cumulative errors in forecasting. Let us assume the following model:

$$y_i = \beta_1 x_{i1}^{'} + \beta_2 x_{i2}^{'} + \mu_i \tag{5.7}$$

where x_1, x_2 are vectors independent to the disturbance item μ_i. The final estimation model is

$$y_i = \beta_1 x_{i1}^{'} + \varepsilon_i \tag{5.8}$$

By comparing Eqs. (5.13) and (5.14), we can see that the omitted variables $\beta_2 x_{i2}^{'}$ are included in the new disturbance item $\varepsilon_i = \beta_2 x_{i2}^{'} + \mu_i$. There are two possible reasons. The first reason is that the omitted variables are not correlated with explanatory variables, that is, in this case, the disturbance term is not correlated with explanatory variables, and the parameter vectors can be evaluated consistently, where $\mathrm{Cov}(x_{i1}, x_{i2}) = 0$ (Chen 2014). However, because the omitted variables are included in the disturbance term, the variance of the disturbance term will increase, thus reducing the accuracy of the prediction. The second reason is that the omitted variables are related to explanatory variables, where $\mathrm{Cov}(x_{i1}, x_{i2}) \neq 0$, the model can no longer carry out consistent evaluation on parameter vectors, thus causing the so-called "omitted variable error" (Pan 2013). The second reason is more common in practice because it is impossible to include all possible variables into the model, which usually lead to fatal estimation errors.

Panel data model can reduce the estimation error of a single data item without sacrificing the diversity of the data. For macro-data analysis, panel data can reduce cumulative errors by including microscopic data such as individuals, families, and businesses. Therefore, panel data model is suitable for multivariate regression analysis and able to effectively handle the implicit factors. The linear panel data model can be expressed as follows:

$$y_{it} = \alpha_{it} + \beta_{it}^{'} x_{it}^{'} + \mu_{it} (i = 1, \ldots, n; t = 1, \ldots, t) \tag{5.9}$$

where α_{it} represents the constant term; $\beta_{it}^{\prime} = \beta_{1it}^{\prime}, \beta_{2it}^{\prime}, \ldots \beta_{kit}^{\prime}$ is the parameter vector, k is the number of exogenous variables,n is the number of cross-sectional data items, t is the total period of time, $x_{it}^{\prime} = x_{1it}^{\prime}, x_{2it}^{\prime}, \ldots x_{kit}^{\prime}$ is the number of explanatory variables, *and* μ_{it} is the random disturbance term.

In addition, if it is assumed that the random interference terms μ_{it} are independent of each other and meet the normal distribution, and their variance is σ_{μ}^{2}, then the panel data model can also be written as follows:

$$y_{it} = \alpha_i + \beta_i^{'} x_{it}^{'} + \mu_{it} (i = 1, \ldots, n; t = 1, \ldots, t) \tag{5.10}$$

A common panel data's format is shown in Table 5.13.

Considering panel data can reduce the "omitted variable error" due to the difficulties in obtaining the implicit factor (Chen 2014), we propose a SIPD model to analyze and forecast the fashion demand.

Table 5.13 Panel data format

	y_{it}	x_{it}	…	x_{nt}
Individual 1: t = 1				
Individual 1: t = 2				
Individual 1: t = 3				
…				
Individual n: t = 1				
Individual n: t = 2				

5.4.2 *Establishment of SIPD Model*

In view of the disadvantages of time series data, the panel data is used to identify both the impacts of inter-temporal dynamics and inter-item search index on the fashion demand. The establishment of SIPD model among variables requires to test whether the panel data is (i) stationary (integrated of order zero) or non-stationary (integrated of order one) and (ii) cointegrated. The cointegration test is an alternative test in case the panel data is non-stationary. The flow chart of panel stationary and cointegration tests is shown in Fig. 5.4.

There are occasionally some similar or common trends existing in the non-stationary time series, which lead to a relatively high R^2 when doing regression, namely, pseudo-regression. To avoid pseudo-regression which would mislead the further analysis, unit root test is a common method to ensure the panel data is stationary. Unit root test is generally divided into three scenarios: the first is that the panel contains both trend term and intercept term; the second one is that the panel only contains intercept term; and the third one is that the panel contains neither.

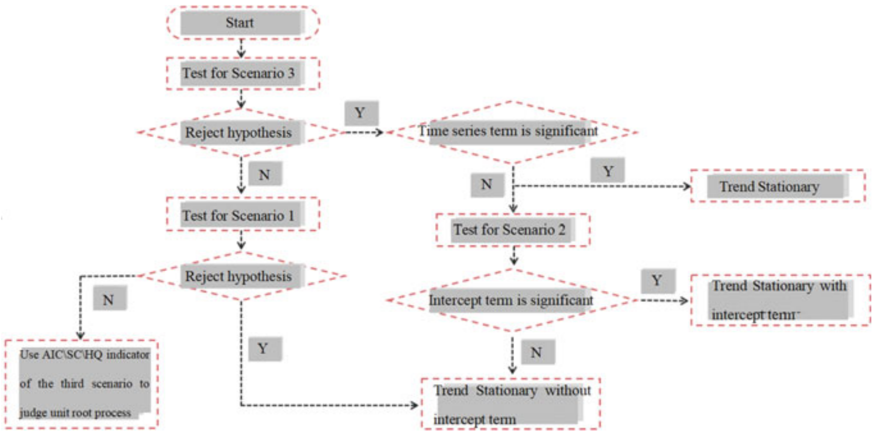

Fig. 5.4 Flow chart of panel stationary tests

Augmented Dickey–Fuller (ADF) test (Dickey and Fuller, 1979) is one of the most widely used unit root tests. The test is to assume the null hypothesis first and check whether it was rejected or not. As shown in Fig. 5.4, we firstly check whether the panel data contains intercept term and trend term (scenario 3), then check whether it contains intercept term (scenario 2), and finally check the case of neither (scenario 1). The test would be terminated if either scenario is confirmed. Following formulae correspond to these three scenarios:

$$\text{Scenarios 1}: \Delta_{y_t} = \rho y_{t-1} + \sum_{i=1}^{p-1} \emptyset \Delta y_{t-i} + u_t \tag{5.11}$$

$$\text{Scenarios 2}: \Delta_{y_t} = c + \rho y_{t-1} + \sum_{i=1}^{p-1} \emptyset \Delta y_{t-i} + u_t \tag{5.12}$$

$$\text{Scenarios 3}: \Delta_{y_t} = c + \gamma t + \rho y_{t-1} + \sum_{i=1}^{p-1} \emptyset \Delta y_{t-i} + u_t \tag{5.13}$$

where u_t is white noise term, $\rho = \left(\sum_{i=1}^{p} \alpha_i\right) - 1$, $\varnothing_i = -\sum_{j=i+1}^{p} \alpha_j$

The null and alternative hypotheses for ADF are as follows

$$\begin{cases} \mathrm{H}_0 : \rho = 0 \\ \mathrm{H}_1 : \rho < 0 \end{cases} \tag{5.14}$$

If the null hypothesis is not rejected, y_t is a non-stationary time series with unit root. If the null hypothesis is rejected, the stationary time series y_t is in the first and second scenarios, and the trend stationary series y_t is in the third scenarios.

The ADF test result of the proposed SIPD model is shown in Table 5.14. The test result indicated that all series in the model is first-order integration and the stationary time series is in the first scenario. Following that the cointegration test is required to test whether there are long-term and stable relationship among each variable.

To achieve a rigorous model to forecast the fashion demand efficiently, two cointegration tests have been applied, namely, Kao (1999) and Pedroni (1999) tests. The reason we adopted both tests is that the assumption of Kao test is a homogeneous panel and Pedroni is not. The cointegration test results are listed in Tables 5.15 and 5.16.

Table 5.14 ADF test results (Scenario 3)

ADF test results of raw data					ADF test results after first-order difference				
Series	Prob	Lag	Max Lag	Obs	Series	Prob	Lag	Max Lag	Obs
COLOUR_B	0.0053	0	10	61	D(COLOUR_B)	0.0000	0	10	60
COLOUR_G	0.1010	1	10	60	D(COLOUR_G)	0.0000	1	10	60
COLOUR_J	0.0020	0	10	61	D(COLOUR_J)	0.0000	0	10	60
COLOUR_R	0.0000	0	10	61	D(COLOUR_R)	0.0000	1	10	60
COLOUR_W	0.0001	0	10	61	D(COLOUR_W)	0.0000	1	10	60
COLOUR_Y	0.0203	0	10	61	D(COLOUR_Y)	0.0000	0	10	60
INTERNET_ITEM1	0.0000	0	10	61	D(INTERNET_ITEM1)	0.0000	0	10	60
INTERNET_ITEM2	0.0001	0	10	61	D(INTERNET_ITEM2)	0.0000	0	10	60
INTERNET_ITEM3	0.0002	0	10	61	D(INTERNET_ITEM3)	0.0000	0	10	60
INTERNET_ITEM6	0.0004	0	10	61	D(INTERNET_ITEM6)	0.0000	1	10	60
ITEM1	0.3257	4	10	57	D(ITEM1)	0.0000	2	10	60
ITEM2	0.0617	0	10	61	D(ITEM2)	0.0000	0	10	60
ITEM3	0.0095	0	10	61	D(ITEM3)	0.0000	0	10	60
ITEM6	0.0001	0	10	61	D(ITEM6)	0.0000	0	10	60
PRICE_COLOUR_B	0.0000	0	10	61	D(PRICE_COLOUR_B)	0.0000	1	10	60
PRICE_COLOUR_G	0.0027	0	10	61	D(PRICE_COLOUR_G)	0.0000	0	10	60
PRICE_COLOUR_J	0.0008	1	10	60	D(PRICE_COLOUR_J)	0.0000	2	10	60
PRICE_COLOUR_R	0.0000	0	10	61	D(PRICE_COLOUR_R)	0.0000	2	10	60
PRICE_COLOUR_W	0.0010	0	10	61	D(PRICE_COLOUR_W)	0.0000	0	10	60
PRICE_COLOUR_Y	0.0157	1	10	60	D(PRICE_COLOUR_Y)	0.0000	0	10	60

(continued)

Table 5.14 (continued)

ADF test results of raw data					ADF test results after first-order difference				
Series	Prob	Lag	Max Lag	Obs	Series	Prob	Lag	Max Lag	Obs
PRICE_ITEM1	0.0433	0	10	61	D(PRICE_ITEM1)	0.0000	0	10	60
PRICE_ITEM2	0.0349	0	10	61	D(PRICE_ITEM2)	0.0000	0	10	60
PRICE_ITEM3	0.0040	0	10	61	D(PRICE_ITEM3)	0.0000	1	10	60
PRICE_ITEM6	0.0068	0	10	61	D(PRICE_ITEM6)	0.0000	1	10	60

Table 5.15 Kao test results

ADF	ADF	Prob
	−4.26287	0.0000
Residual variance	1459.412	–
HAC variance	104.4581	–

Table 5.16 Pedroni test results

Alternative hypothesis: common AR coefficients (within-dimension)				
	Statistic	Prob	Weighted statistic	Prob
Panel v-statistic	1.786878	0.0370	0.427897	0.3344
Panel rho-statistic	−10.3401	0.0000	−10.734	0.0000
Panel PP-statistic	−10.4802	0.0000	−10.81876	0.0000
Panel ADF-statistic	−8.67592	0.0000	−6.291999	0.0000
	Statistic	Prob	Weighted statistic	Prob
Alternative hypothesis: individual AR coefficient (between-dimension)				
	Statistic	Prob	–	–
Group rho-statistic	−10.5334	0.0000	–	–
Group PP-statistic	−12.4473	0.0000	–	–
Group ADF-statistic	−8.92671	0.0000	–	–

5.5 Case Study

5.5.1 Model Estimation

There are two important tasks in this case study: (1) To examine the effectiveness of using panel data model and based on historical sales data and search index to forecast the fashion demand; (2) To demonstrate how search index can improve the performance of the forecasting mode by comparing two panel data models (with and without using search index). The fashion sales data span 60 days from October 14, 2017 to December 12, 2017, among which first 40 days are used for training and estimation, the last 20 days are used for validating the forecasting performance of the proposed SIPD model.

There are three types of panel data model, namely, fixed effect, random effect, and mixed model. The redundant effect test is applied and result is listed in Table 5.17 (Hsiao 2014). The test result indicated that the panel has individual fixed effect but no fixed period effect. Thus, the mixed model is selected and the SIPD model is established to forecast the forecast demand for multi-item simultaneously:

$$S_{it} = c + \beta_1 S_{i(t-1)} + \beta_2 I_{i(t-lag)} + \beta_3 P_{it} + u_i \tag{5.15}$$

Table 5.17 Redundant effect test for item

Effects test	Statistic	d.f
Cross-section F	3.519626	−3,180
Cross-section chi-square	14.137083	3
Period F	1.198045	−61,180
Period chi-square	84.506432	61
Cross-section/Period F	1.293655	−64,180
Cross-section/Period chi-square	93.846485	64

Table 5.18 Redundant effect test for color

Variable coefficient	c	β_1	β_2	β_3	u_1	u_2	u_3	u_6
The estimate	11.2953	0.5199	0.0044	0.0375	−15.5542	−1.5505	18.1309	−1.0262
T-value	1.2999	9.4174	1.1797	0.8853	–	–	–	–

where S_{it} is the fashion demand of item *i* on day *t*, $S_{i(t-1)}$ is the fashion demand of the item *i* on day *t*-1, $I_{i(t-lag)}$ is the search index of item *i* in the optimal lagging period, P_{it} is the selling price of the item *i* on day *t*, and u_i is the residual term of item *i*. The parameters for the SIPD model have been estimated in EViews and shown in Table 5.18.

In order to compare the accuracy of the prediction results, we excluded the search index of item *i* from the model and used only the sales data for the prediction. The test result indicated that the panel has individual fixed effect, but no fixed period effect and the panel data (PD) model was established as Eq. 5.16.

$$S_{it} = c + \beta_1 S_{i(t-1)} + \beta_2 P_{it} + u_i \tag{5.16}$$

The parameters for the PD model have been estimated in EViews and shown in Table 5.19.

Table 5.19 Parameters for the PD model

Variable coefficient	c	β_1	β_2	u_1	u_2	u_3	u_6
The estimate	18.5709	0.5150	0.0345	−4.7256	−4.6434	13.5905	−4.2215
T-value	3.0303	9.3395	0.8147	–	–	–	–

5.5.2 *Study the Impact of the Search Index on the Fashion Demand Forecasting*

To demonstrate how search index can improve the performance of the forecasting mode by comparing two panel data models (with and without using search index). According to the above estimation results, we have an SIPD model as listed in 23 and a PD model as listed in 24.

$$\mathrm{S(SIPD)_{it}} = 11.2953 + 0.5199\mathrm{S_{i(t-1)}} + 0.0044\mathrm{I}_{\mathrm{i(t-}lag)} + 0.0375\mathrm{P_{it}} + \mathrm{u_i} \quad (5.17)$$

$$\mathrm{S(PD)_{it}} = 18.5709 + 0.5150\mathrm{S_{i(t-1)}} + 0.0345\mathrm{P_{it}} + \mathrm{u_i} \quad (5.18)$$

The forecasting results of the four fashion items by both SIPD and PD models are shown in Fig. 5.5 for comparison. These results show that the SIPD method can capture the variation of fashion demands better than PD. Although the PD model can well model the regular trends of fashion demands in all items, it fails to predict most of the irregular spikes. The proposed SIPD well models the complex time series pattern. In addition, it helps to predict the most "frequently appeared" peak which occurs frequently. The reason that the proposed SIPD model predicts the variation characteristics well might be because the search index reflects customers' purchasing intentions and fashion trend of different items. The comparison indicated that the search index can improve the performance of fashion demand forecasting.

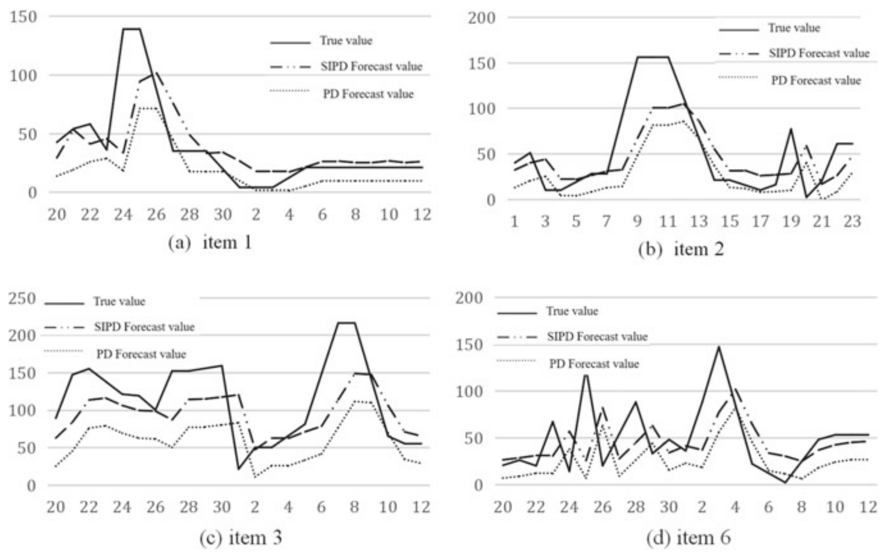

Fig. 5.5 Forecasting results of the four fashion items by both SIPD and PD models

Table 5.20 MAE and MAPE of SIPD and PD models

MSE					
	Item 1	Item 2	Item 3	Item 6	Average MSE
SIPD	714.06	1049.07	2121.31	1196.21	1270.16
PD	8086.78	1807.49	4950.64	1876.40	4180.33
MAPE					
	Item 1	Item 2	Item 3	Item 6	Average MAPE
SIPD	21.57%	27.84%	21.96%	23.74%	23.78%
PD	81.58%	83.33%	52.89%	82.34%	75.03%

To further assess and investigate how much the search index can enhance the performance of the models, mean square error (MSE) and mean absolute percentage error (MAPE) are adopted in this paper.

$$\text{MSE} = \frac{1}{n} \cdot \sum_{t=1}^{n} \left(x_t - \hat{x}\right)^2 \tag{5.19}$$

$$\text{MAPE} = \frac{1}{n} \sum_{t=1}^{n} \left| \frac{x_t - \hat{x}}{x_t} \right| \tag{5.20}$$

Table 5.20 compares the fashion demands forecasting performance of SIPD and PD models on the basis of MAE and MAPE. It demonstrates that the proposed SIPD model achieves a much better performance than PD in all four items under study. In fact, the proposed SIPD model can improve the PD model's forecasting MSE and MAPE by at least 56.86% and 140.85%, respectively. This is a significant improvement. SIPD shows strong forecasting capability since it utilizes the big data's power to capture different aspects of the fashion patterns. This superiority is especially clear when comparing with the PD model at some items with fluctuate demands. At some items with varying demands such as item 1 and item 6, the proposed SIPD model can improve the PD model's forecasting MAPE by 278.21 and 246.71%.

5.5.3 *Sensitivity Analysis*

The above analysis divided the data into training data and forecast data. The first 40 days were used for training and the last 20 days were used for out-of-sample evaluation. A sensitivity analysis is conducted to investigate the impact of training length on the forecasting performance. We fixed the out-of-sample data length to 10 days and set the training data length to 10 days (day 41–50), 20 days (day 31–50), 30 days (day 21–50), 40 days (day 11–50), and 50 days (day 1–50), respectively.

Both SIPD and PD models have been trained in EViews, parameters of which are listed in Tables 5.21 and 5.22, respectively.

Figure 5.6 compares the fashion demands forecasting performance of SIPD model with different training data lengths on the basis of MAPE. It is observed from the grey average MAPE bars that increasing training data can reduce the MAPE of prediction results, that is, improve the accuracy of prediction results. However, this improvement is not guaranteed. For example, MAPE of item 4 decrease along with the increase of training data length, but the MAPE of item 2 slightly accordingly. To sum up, the SIPD model has a low sensitivity and a low requirement on the amount of training data, which make it suitable in real practice.

In addition, we also analyze the sensitivity to the model of PD. Figure 5.7 compares the fashion demands forecasting performance of PD model with different training data length on the basis of MAPE. The improvement of the forecasting accuracy is not constant. For example, MAPE of item 2 decreases significantly while item 6 increases along with the increase of training data length. In terms of sensitivity, we can draw a similar conclusion as SIPD model that the PD model does not require of large training data.

5.6 Conclusion

Fashion demand forecasting has been a challenge for both academic and industry for long as it is influenced by not only explicit factors such as historical selling data and price, but also implicit factors such as consumers' purchasing intentions and fashion trend. To have a better inventory forecasting and planning, it can significantly better match the demand to satisfy customers and reduce the negative impacts brought to the environment due to the overproduction. Different from existing studies using search data to forecast the demand, this paper focuses on exploring how to use search index to perform fashion demands. Further, this study is the first to investigate how search index can improve the performance of the forecasting model. Some significant conclusions can be drawn as follows:

(1) It is of importance to explore the fashion demand forecasting using panel data-based framework and search index. The panel data-based analysis in this study has investigated how search index influences the fashion demands statistically.
(2) The proposed SIPD model exhibited superior performance, being reliable and practical in real fashion business operations. An accurate forecasting model which has a low requirement for the amount of training data is an advantage.
(3) By comparing two panel data models (with and without using search index), we quantitatively measure the impact of search index on the forecasting accuracy. The proposed SIPD model can improve the PD model's forecasting MSE and MAPE by at least 56.86% and 140.85%, respectively.
(4) By processing a series of testing, we found that the impact of search index on the fashion demands usually lags for a week. This phenomenon can be easily

Table 5.21 SIPD model parameters with different training data lengths

Training lengths	Coefficient	c	β_1	β_2	β_3	u_1	u_2	u_3	u_6
10	Estimate value	86.5785	0.5611	−0.0323	−0.0719	55.2669	−10.9830	−18.5221	−25.7618
	T-value	1.0683	3.9695	−0.5578	−0.6833	–	–	–	–
20	Estimate value	32.1591	0.5545	−0.0031	−0.0216	1.5280	−3.2338	10.7044	−8.9986
	T−value	2.2589	5.3966	−0.5835	−0.2684	–	–	–	–
30	Estimate value	20.0262	0.5854	0.0004	0.0035	−6.6648	−2.0928	11.8142	−3.0566
	T-value	1.9112	7.0363	0.1062	0.0537	–	–	–	–
40	Estimate value	18.1266	0.5093	0.0012	0.0346	−10.5428	−1.0602	14.5325	−2.9294
	T-value	1.7594	7.6970	0.3341	0.5664	–	–	–	–
50	Estimate value	14.1190	0.4850	0.0064	0.0080	−19.8415	0.6549	18.5321	0.6544
	T-value	1.3011	7.5199	1.3516	0.1460	–	–	–	–

Table 5.22 PD model parameters under different training data lengths

Training lengths	Coefficient	c	β_1	β_2	u_1	u_2	u_3	u_6
10	Estimate value	42.1344	0.5588	−0.0633	−13.8794	8.0817	11.1573	−5.3597
	T-value	2.8093	3.9569	−0.6090	–	–	–	–
20	Estimate value	26.4097	0.5641	−0.0171	−6.2158	−0.9072	13.5439	−6.4208
	T-value	2.4797	5.5603	−0.2121	–	–	–	–
30	Estimate value	20.7274	0.5848	0.0027	−5.7344	−2.3643	11.4309	−3.3322
	T-value	2.5312	7.0446	0.0424	–	–	–	–
40	Estimate value	20.1672	0.5081	0.0325	−7.8162	−1.8504	13.3817	−3.7151
	T-value	2.4346	7.6920	0.5352	–	–	–	–
50	Estimate value	24.8014	0.4814	0.0010	−4.3974	−3.6894	11.9222	−3.8353
	T-value	3.3352	7.4594	0.0182	–	–	–	–

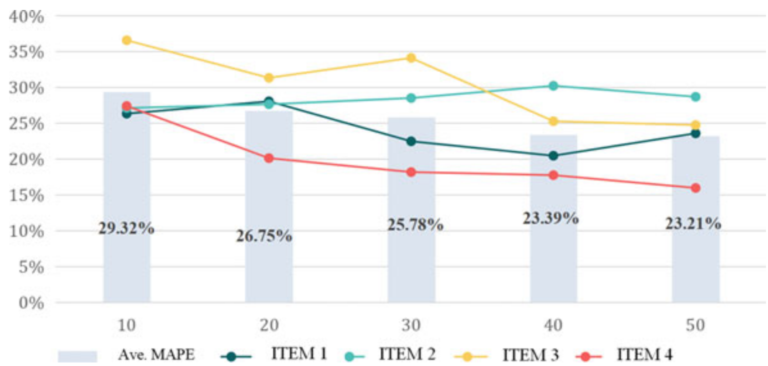

Fig. 5.6 Sensitivity test results of SIPD model

explained by the fact that consumers' purchasing behavior will be influenced by many factors such as fashion trend and social media. The purchasing intention does not happen at the same time with the search behavior, and it will go through a certain "investigation period". The optimal length of lagging can be determined by stationary analysis and cointegration analysis.

The daily sales data from a small size fashion company focus on niche market and search index in 2018 were used to illustrate the effectiveness and robustness of our proposed SIPD. The feature of the proposed SIPD model is in line with the situation that small size fashion enterprises who have little useful data in most cases.

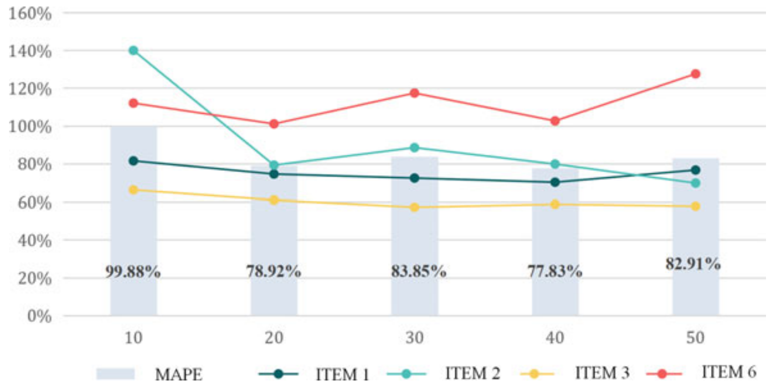

Fig. 5.7 PD model sensitivity test results

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Part III
Theoretical Modelling Research, Reviews, and Research Agenda

Chapter 6
Optimal Pricing, Green Advertising Effort and Advanced Technology Investment in Sustainable Fashion Supply Chain Management

Hau-Ling Chan, Shun-Mun Wong, and Ka-Man Sum

Abstract This article applies a multimethodological approach to study a marketing and operations management interface problem in fashion supply chain management. This article first conducts a case study to reveal how a fashion supplier can adopt advanced technologies to commit sustainability in real-world practice. Then, a Stackelberg game is built to analyze the optimal pricing, advertising level, and sustainable technology investment decisions for a supply chain with environmentally conscious consumers. It is found that the optimal wholesale price is dependent on the supplier's production cost but independent of technology cost rate and promotion cost rate. There are three situations that the supplier will commit a higher sustainability level. Specifically, the supplier has either a higher production cost or a higher technology cost rate will result in a higher sustainability level. In addition, when the retailer's promotion cost rate increases, supplier will react by having a higher sustainable commitment level if her technology cost rate is significantly large.

Keywords Multi-methodological approach · Fashion supply chain management · Sustainability

6.1 Introduction

6.1.1 Background and Motivation

Being sustainable is one of the crucial issues in fashion supply chain management as the fashion industry has been blamed for constituting substantial carbon emission

H.-L. Chan (✉) · S.-M. Wong · K.-M. Sum
Division of Business and Hospitality Management, College of Professional and Continuing Education, The Hong Kong Polytechnic University, Kowloon, Hong Kong, China
e-mail: ling.chan@cpce-polyu.edu.hk

S.-M. Wong
e-mail: helen.wong@cpce-polyu.edu.hk

K.-M. Sum
e-mail: carmen.sum@cpce-polyu.edu.hk

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and water pollution in the production process (Chan et al. 2018b; Guo et al. 2020). It is reported that over 300 tons of garments waste are sent to the landfills everyday (McCarthy 2018). On the other hand, consumers are also environmentally conscious (Shi et al. 2020a) and they are more aware and sensitive to the sustainability practices of the fashion brands. To address the concern from the public, over the past years, fashion brands have adopted various measures to be environmentally friendly and responsible by reducing the use of natural resources and energy consumption (Chan et al. 2020). For example, Zara has created a sustainability conscious product line, "join life" in which the fashion garments are made by sustainable fabric such as organic cotton or recycled polyester while Nike uses recycled plastic bottles to produce Flyknit running shoes. Recently, fashion brands have focused on launching a circular supply chain. Circular supply chain refers to a supply chain addressing the environmental sustainability by minimizing wastes and maximizing reuse, recycle and remanufacture practices (Choi et al. 2020). It is a kind of circular economy which seeks a way to optimize the resource through the extension of the product life cycle (Genovese et al. 2017; Lahane et al. 2020). There are three critical successful factors for circular supply chain management, they are technology, optimality decisions, and government regulations (Mangla et al. 2018; Choi et al. 2020). Under circular supply chain, textiles manufacturers can implement advanced technology to produce new fabric from recycled garments. From the upstream supplier's perspective, it will be a competitive advantage if they can develop a new business model with the help of technology which can cope with the sustainable concerns of both the downstream retailers as well as the final end customers. Therefore, some fashion suppliers have invested in advanced technology to develop sustainable fabric and mitigate the negative impact brought to the environment such as Crystal International Group Limited (see Sect. 6.3 for details).

In supply chain context, the end customers in the market are hard to understand the supply chain's sustainability level especially for a long supply chain. Customers may rely on the advertisement and green promotion campaign from the downstream retail brands to collect information about the sustainable commitments of both the retail brands and upstream suppliers. In real-world practice, it is observed that fast fashion brands have exerted substantial efforts in promoting their supply chain sustainability practices. For example, H&M has documented sustainability reports, advertised its sustainable commitment through youtube channel, press, and its website to visualize the sustainable practices.

In this article, we apply a multimethodological approach to study marketing and operations interface problem in sustainability commitment. This approach can be used to enhance the exhaustiveness of a research study (Singhal et al. 2014; Choi et al. 2016). First, we conduct a case study to examine the types of advanced technologies adopted by the fashion supplier for sustainability commitment. Next, we develop a stylized game theory model to explore the operations decision in a sustainable supply chain. We consider a two-echelon fashion supply chain in which a supplier implements an advanced technology to commit sustainability while the retailer utilizes green advertising to promote the sustainability commitment of its supplier to attract the environmental conscious customers. The aim of this article is to address the following research questions:

(1) What kinds of technology that the fashion manufacturer has implemented for sustainability commitment?
(2) What is the optimal retail price and optimal promotion effort from the fashion retailer's perspective?
(3) What is the optimal wholesale price and optimal advanced technology commitment level from the supplier's perspective?
(4) What are the factors that govern the optimal decisions of the fashion retailer and supplier?

6.1.2 Contribution Statement and Structure

This article contributes to the marketing and operations management interface literature by using a multimethodological approach. To the best of our knowledge, this is a first study which applies multimethodological approach and considers that environmental conscious consumers will not know about the sustainable practice of the supply chain if the retailer does not advertise it. We adopt a Stackelberg game to analyze the optimal decisions of the fashion retailer and supplier under a wholesale pricing contract to derive the optimal pricing, advertising level, and sustainable technology investment for a supply chain with environmentally conscious consumers. We uncover that the optimal wholesale price is dependent on the supplier's production cost but independent of technology cost rate and promotion cost rate. There are three situations that the supplier will commit a higher sustainability level. Specifically, the supplier has either a higher production cost or a higher technology cost rate will result in a higher sustainability level of the supplier. In addition, when the retailer's promotion cost rate increases, supplier will react by having a higher sustainable commitment level if her technology cost rate is significantly large.

The organization of this article is shown as follows. We review the relevant literature in Sect. 6.2 to better understand the studies on technology-driven sustainable supply chain management and green marketing. We then conduct a case study to illustrate the technologies that are adopted by the fashion manufacturer to better understand the real-world practice in Sect. 6.3. In Sect. 6.4, we develop a stylized model to explore the optimal decisions of the retailer and supplier and discuss the managerial insights. Finally, we draw the concluding remark in Sect. 6.5. All proofs are placed in Appendix.

6.2 Literature Review

The study of this article is related to two streams of research scopes: technology-driven sustainable supply chain management and green marketing.

6.2.1 Technology-Driven Sustainable Supply Chain Management

Advance technology is playing an important role in supporting the sustainability development and even facilitating the circular supply chain (Choi et al. 2021). It helps to reduce the garment waste in the fashion industry and hence it plays an important role in facilitating the circular supply chain. Existing literature has widely discussed the adoption of cleaner technology over the past few years. For example, Krass et al. (2013) explore how the imposed environmental taxes affect the firm decision on cleaner technology selection when demand is price-dependent. They uncover that policymaker should provide subsidy to the firm adopting cleaner technology such that the social welfare can be improved. Drake et al. (2016) study the optimal decision of the cleaner technology selection and production quantity under the two commonly observed policies, namely, carbon tax and cap-and-trade regulation. They show that it may not help to reduce the pollution level when the policymaker provides subsidy for cleaner technology adoption as it will motivate the supplier to increase the production scale. Interestingly, Wang et al. (2016) incorporate price competition in the model and examine the optimal technology choice and pricing decision in the presence of the carbon tariff policy. They show that the global social welfare will be improved when there is carbon tariff. Dong et al. (2016) consider the air pollution problem generated from the production process and the firm can implement technology to mitigate the carbon emission. They study how the cap-and-trade regulation affects the optimal order size of the retailer and examines the optimal technology investment level of the supplier in the decentralized and centralized supply chain, respectively. They find that the sustainable technology investment cost rate is a crucial factor in the optimal solutions. Similarly, Xu et al. (2017) consider the consumers are environmentally conscious. They analytically prove that wholesale pricing contract and cost-sharing contract can help to achieve supply chain coordination. Besides, they also propose to use two-part tariff to obtain Pareto improvement. Cohen et al. (2016) explore how the demand uncertainty affects the production and pricing decision of the manufacturer, along with the consumer surplus when subsides are provided to the end customers from the government for the cleaner technology execution. By modeling a price-setting newsvendor problem, they show that consumers are not always benefited in presence of demand uncertainty and the government cannot meet the desired adoption target level if demand uncertainty is not carefully addressed in the policy. Chan et al. (2018a) consider a situation that the fashion retailer adopts the quick response strategy with demand update while the manufacturer implements cleaner technology for production. They find that both the supply chain members are better off for selling fast fashion product with high stockout rate. In addition, they also propose to use minimum order quantity contract and minimum order quantity with buyback contract to achieve supply chain coordination. Shi et al. (2020b) focuses on the pricing and sustainability efforts decision and determine the value of bargaining contract in facilitating supply chain coordination when the consumer is environmentally sensitive. Besides, the authors also study the condition to achieve

Pareto improvement when either the retailer or the supplier is the investor of the cleaner technology. Similar to this stream of this study, we consider the optimal pricing and technology investment level for sustainable commitment. Differently, we further consider that the fashion retailer advertises the sustainability practices which will affect the consumer purchasing decision.

6.2.2 Green Advertising in a Circular Supply Chain

On the other hand, this article is also related to the green advertising which is used to promote the sustainability practice of the supply chain members. Green advertising can be used as a tool to attract environmental awareness consumers to purchase the sustainable products (Leonidou et al. 2011; Rahbar and Wahid 2011). Existing literature specifies to examine the advertising effort for the recycled product in a closed-loop or circular supply chain. For example, De Giovanni (2014) study the collaboration mechanism of a closed-loop supply chain in which both the retailer and supplier pay green advertising efforts to develop goodwill dynamics with the consideration of the reverse revenue sharing contract. They show that decision of such kind of collaboration should depend on the residual value of the recycled product. Hong et al. (2015) adopt game theory to discuss the pricing, advertising level and collection rate of recycled product in a closed-loop supply chain. They show that they play an important role in the optimal solutions and supply chain profit. De Giovanni et al. (2016) examine a dynamic closed-loop supply chain with different ways to enhance the product return rate. Xie et al. (2017) develop a dual supply chain system and study the supply chain coordination mechanism. They show that the effect of advertisement is an important factor that will affect the used product collection rate and the profitability of the supply chain members. To be specific, in terms of the optimal profitability, decentralized system outperforms centralized system if the effect of advertisement is small. Li et al. (2020) focus on the design and advertising investment decisions in a closed-loop supply chain that includes one remanufacturer and two advertisers.

On the other hand, literature has considered the optimal decisions for both the green product pricing and green advertisement effort simultaneously for new and remanufacturing products. Choi (2017) constructs a deterministic model and reveals the condition that the pricing of the remanufactured items should be lower than that of the new items. Gan et al. (2017) found that the retailer should set a lower retail price there is a higher customer acceptance of getting the remanufactured products. Abbey et al. (2017) show that the retailer should set a higher price for the new product when the remanufactured product is introduced in the market. Jamali and Rasti-Barzoki (2018) conclude that the centralized supply chain setting can result in a higher sustainability level than that of the decentralized one. Shen et al. (2019) consider the non-green product can substitute the green products and indicate that the sequential pricing method can generate a higher supply chain profit than the simultaneous pricing method.

Recently, existing literature has also explored the resource allocation with the consideration of cleaner technology and green advertising. Liu et al. (2017) examine the pricing decisions of a sustainable supply chain in the big data environment. They analytically prove that the optimal pricings have a negative relationship with the green investment and targeted advertising level. Hong and Guo (2019) investigate the supply chain coordination mechanism under wholesale pricing, cost-sharing, and two-part tariff contracts when the supplier invests in the technology to produce sustainable product whereas the retailer has green advertisement. This article is closely related to Hong and Guo (2019) with the consideration of optimal pricing, advertising level, and technology commitment level when the consumers are environmentally conscious. Different from Hong and Guo (2019), we further consider that consumers will not know about the sustainable practice if the retailer does not promote it. In other words, the sustainability commitment along with the promotion effort will affect the consumer demand. A higher green advertising effort to promote the sustainable practice will induce a higher consumer demand as it can increase the consumer awareness and they have more information about the sustainability practices of the manufacturer.

6.3 Crystal International Group Limited

In this section, we conduct a case study to illustrate how a fashion manufacturer, Crystal International Group Limited, adopts advanced technologies to commit sustainability. All the information is collected from public sources, such as website, sustainability report, and annual report of Crystal International Group Limited, as well as news report.

Crystal International Group Limited (Crystal Group) was established in Hong Kong in 1970 which is a garment manufacturer producing a wide range of fashion items such as denim, sweater, and functional product. It operates about 20 manufacturing plants in five different countries, including Sri Lanka, Cambodia, Bangladesh, Vietnam, and China, and has more than 80,000 employees in 2019.[1] Crystal Group supplies fashion products to the world-class retailers such as H&M, Levi's, Uniqlo. It targets to have a high degree of sustainability and has been listed as one of the "60 companies that are changing the world" in Fortune. Over the past years, Crystal Group has implemented different technologies driven projects to become a sustainable fashion manufacturer. See Fig. 6.1 for the technologies adopted by Crystal Group.

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[1] https://doc.irasia.com/listco/hk/crystal/annual/2019/ar2019.pdf.

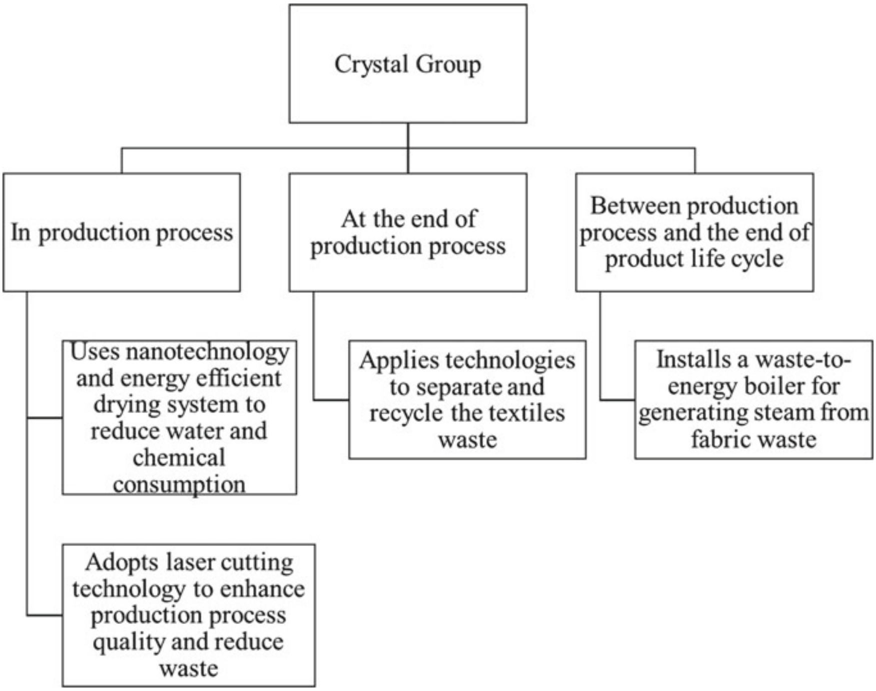

Fig. 6.1 Advanced technologies adopted by Crystal Group

6.3.1 Advanced Washing and Laser Technologies

The laser cutting technology is used in the sample producing process. It can improve the accuracy and process quality, and hence, it can also reduce the waste. Besides, Crystal Group is a pioneer in applying nanotechnology and energy efficient drying system in the washing machines. With the use of the innovated washing machines, it can reduce 90% of water and chemical usage when comparing with the traditional ones.[2]

6.3.2 Waste Recycling Technologies

Recently, Crystal Group has focused on the fabric waste recycling. The fabric waste can be synthetic materials or non-biodegradable polyester. To reduce the fabric waste, its Sri Lanka factory has partnered with a US-based technology company called PurFi to make the fabric waste generated from the apparel production process to become useful raw material for yarn production. The recycling process involves fabric waste

[2] https://www.crystalgroup.com//static/media/1569577442056_VPVENcPY0g.pdf.

collection, fabric classification, putting in the bags, labeling and weighing, and then transporting to the recycling facility for raw fabric conversion (Barrie 2019). On the other hand, the PurFi constructs algorithms to generate fabric data for each pack of fabric waste. All the data are captured in the database and the most suitable input streams will be identified and picked to separate and recycle the fibers (Ecotextile 2019). In addition, the China factory of Crystal Group also plans to exercise a sustainable project called "second lift" which aims to convert the cutting table scraps to cotton for producing denim. The recycled fabric can mitigate the negative environmental impact on the water consumption in the fabric production process.

6.3.3 Energy Saving Technologies

Crystal Group also aims to apply technologies to save energy. For example, it has implemented steam heat exchange devices on dryers to reduce the steam heat. On the other hand, it has used a non-invasive electromagnetic scale control system to avoid limescale which can help to improve the heat transfer of the steam boilers. In its Vietnam factory, it has installed a waste-to-energy boiler for generating steam. It is believed that 40% of fabric waste can be converted to become energy. All these technologies can help to reduce the natural resources consumption and greenhouse gas emissions significantly.

6.4 Model Development

In Sect. 6.3, it is known that fashion supplier has launched different advanced technologies to be sustainable. In this section, we build a stylized analytical model to study the optimal operations decisions of both the fashion retailer and supplier in which the supplier invests in advanced technology to produce sustainable fabric while the fashion retailer advertises the supply chain sustainability commitment.

To be specific, we consider a simple two echelons fashion supply chain consisting of one supplier and one fashion retailer. The supplier produces fashion product at a unit production cost m and sell it to the retailer at a unit wholesale price. To mitigate the disposal waste of the unwanted fashion product, the supplier invests in technology to develop sustainable fabric (e.g., recycled fabric) for fashion product production. The technology can help to develop the sustainable fabric and hence the supplier will incur a technology investment cost of $\frac{1}{2}\theta t^2$, where θ is the technology cost rate for sustainable fabric development, and t is the sustainability level of the sustainable fabric and $0 < t < 1$. This form of technology investment cost is commonly modeled in the literature such as Dong et al (2016). On the other hand, the retailer gets the sustainable product from the supplier and sells it to the end-customer at a unit retail price p. The end customers are environmentally conscious that their purchasing decision is affected by not only the product's retail price but also the product's sustainability level. Similar to the real-world industrial practice, we consider that the fashion retailer has put promotion effort to increase the transparency to the public about the sustainability commitment of its supply chain. We denote the promotion effort of the retailer about his supplier's sustainability commitment as e, and $0 < e < 1$. If the customers can get the information about the supplier's sustainability commitment, it can induce them to purchase the fashion product. The higher the promotion effort of the retailer, the easier the consumers gather the information about the sustainable activity of the supplier. Thus, et is the perceived sustainability level of the consumers toward a fashion brand. However, the promotion effort of the retailer is not cost-free, he will incur a cost of $\frac{1}{2}\varepsilon e^2$, where ε is the cost rate of retailer's promotion effort. For the simplicity, we normalize the market size to 1 and the market demand becomes $D(p, e, t) = 1 - p + aet$, where a is the coefficient of perceived sustainability level of the consumers. See the supply chain structure in Fig. 6.2.

The profit functions of the retailer (Π_R) and supplier (Πs) are as follows:

$$\begin{aligned}\Pi_R(p, e) &= (p - w)D(p, e, t) - \frac{1}{2}\varepsilon e^2, \\ &= (p - w)(1 - p + aet) - \frac{1}{2}\varepsilon e^2\end{aligned} \tag{6.1}$$

$$\begin{aligned}\Pi s(w, t) &= (w - m)D(p, e, t) - \frac{1}{2}\theta t^2. \\ &= (w - m)(1 - p + aet) - \frac{1}{2}\theta t^2\end{aligned} \tag{6.2}$$

The game sequence is as follows. First, the supplier decides the sustainability commitment level and the wholesale price. Second, the retailer decides the promotion effort of his supplier's sustainable commitment and the retail price. We analyze the optimal decisions of the supplier and retailers based on the wholesale pricing contract and use backward induction to obtain the optimal solutions. All the notations are summarized in Table 6.1.

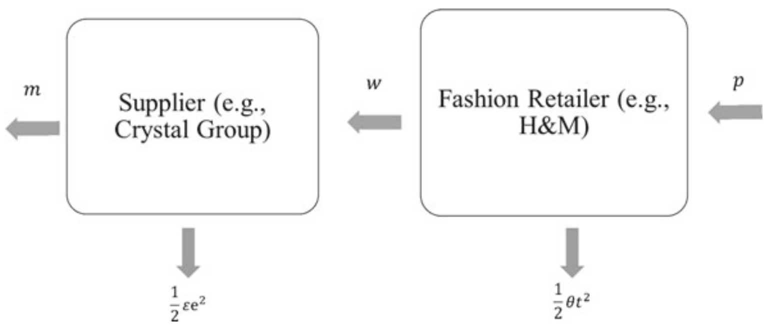

Fig. 6.2 Supply chain structure of this study

Table 6.1 Summary table of notations

Notation	Description
m	Unit production cost
w	Unit wholesale price
θ	Cost rate of technology investment for sustainable fabric development
t	Sustainable level of the sustainable fabric
$\frac{1}{2}\theta t^2$	Technology investment cost
p	Unit retail price
ε	Cost rate of retailer's promotion effort cost
e	Promotion effort of the retailer about his supplier's sustainability commitment
$\frac{1}{2}\varepsilon e^2$	Promotion effort cost of the retailer about his supplier's sustainability commitment
$D(p, e, t)$	Market demand
a	Coefficient of perceived sustainability level of the consumers
Π_R	Profit function of retailer
Πs	Profit function of supplier

From Eqs. (6.1) and (6.2), we have Proposition 1.

Proposition 1 (a) $\Pi_R(p, e)$ is a jointly concave function in p and e if and only if $\varepsilon > \frac{(at)^2}{2}$. (b) $\Pi s(w, t)$ is a jointly concave function if and only if $\theta < \frac{2a^2[(w-m)(1-w)\left(2\varepsilon+3a^2t^2\right)+a^2t^2(1-2w+m)^2}{\left(2\varepsilon-a^2t^2\right)^3}$.

Proposition 1 (a) shows that $\Pi_R(p, e)$ is a jointly concave function in p and e if and only if the cost rate of promotion effort of the supplier's sustainability commitment is sufficiently large ($i.e.$, $\varepsilon > \frac{(at)^2}{2}$), then we can derive the optimal solutions for the retail price and promotion effort from the retailer's perspective. Besides, Proposition 1(b) indicates that $\Pi s(w, t)$ is a jointly concave function if and only if cost rate of technology investment cost for sustainable fabric development is sufficiently small (i.e., $\theta < \frac{2a^2[(w-m)(1-w)\left(2\varepsilon+3a^2t^2\right)+a^2t^2(1-2w+m)^2]}{\left(2\varepsilon-a^2t^2\right)^3}$), then we can also derive the optimal solutions for the wholesale price and sustainability commitment level from the supplier's perspective. In order to generate managerial insights, we consider that these two conditions are always held throughout this article.

Denote $= a\sqrt{\frac{2\varepsilon}{\theta}}$, we have Proposition 2.

Proposition 2 (a) The optimal retail price and optimal promotion effort of the retailer are $p^* = \frac{2\varepsilon+(1+m)\Omega}{2\Omega}$ and $e^* = \frac{1}{\Omega}\sqrt{\frac{4\varepsilon-(1-m)\Omega}{2}}$, respectively. (b) The optimal wholesale price and optimal sustainability commitment level of the supplier are $w^* = \frac{1+m}{2}$ and $t^* = \frac{1}{a}\sqrt{\frac{4\varepsilon-(1-m)\Omega}{2}}$, respectively.

From Proposition 2(a) and (b), it is obvious that optimal retail price, optimal promotion effort, and optimal sustainability commitment level are dependent on all

Table 6.2 Relationship between decision variables and cost parameters

	p^*	e^*	w^*	t^*
$m \uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$
$\theta \uparrow$	$\uparrow$	$\uparrow$ iff $\varepsilon > \frac{9a^2(1-m)^2}{32\theta}$	–	$\uparrow$
$\varepsilon \uparrow$	$\uparrow$	$\uparrow$ iff $\theta > \frac{1}{16\varepsilon}\left(\frac{a(1-m)\left(1-2\varepsilon^{\frac{1}{2}}\right)}{1-\varepsilon^{\frac{1}{2}}}\right)^2$	–	$\uparrow$ iff $\theta > \frac{a^2(1-m)^2}{32\varepsilon}$

the cost parameters (i.e., ε, θ, a, and m). Interestingly, the optimal wholesale price of the supplier is dependent on the production cost only but independent of other cost parameters. In other words, no matter how expensive the technology investment cost is or how hard the retailer promotes her sustainability commitment, it will not affect the decision of the supplier to determine the optimal wholesale price.

Proposition 3 The relationships between decision variables and cost parameters are summarized in Table 6.2.

Remarks: "–" represents "no effect", "↑" represents positive relationship.

Impact of supplier's production cost m. (i) When m increases, the supplier will charge a higher wholesale price w^*. The retailer will respond by setting a higher retail price p^* and shifting the cost to the customers. (ii) When m increases, the supplier will also commit a higher sustainable level t^* and the retailer will also increase his promotion effort e^* to stimulate a higher demand.

Impact of supplier's technology investment cost rate θ. (i) When θ increases, the additional investment for the sustainable commitment will increase the corresponding costs to the supplier, the supplier will enhance her sustainability commitment level t^* to generate more profit from demand rather than increase the wholesale price in order to cover the additional cost. (ii) When θ increases, it is profitable to charge a premium retail price as the fashion product is more sustainable. In addition, retailer will also react by putting more effort e^* to promote the supplier's sustainable commitment to the public to increase demand if the promotion is very costly (i.e., $\varepsilon > \frac{9a^2(1-m)^2}{32\theta}$). This is because the retailer will incur a promotion cost to enhance the sustainable information transparency to the public which can stimulate a significant demand to compensate the expensive additional promotion cost.

Impact of retailer's promotion cost rate ε. (i) When ε increases, the supplier will take this opportunity to compensate the extra technology investment cost by having a higher sustainable commitment level t^* to induce a higher demand if the technology investment cost rate is significantly large (i.e., $\theta > \frac{a^2(1-m)^2}{32\varepsilon}$). (ii) When ε increases, intuitively, the retailer will shift the additional cost to the customers by setting a higher retail price p^*. In addition, the retailer will also increase its promotion effort e^* to trigger a higher customer demand if the supplier's technology investment cost rate is large enough too (i.e., $\theta > \frac{1}{16\varepsilon}\left(\frac{a(1-m)\left(1-2\varepsilon^{\frac{1}{2}}\right)}{1-\varepsilon^{\frac{1}{2}}}\right)^2$). This is because, with a large technology investment cost rate, similar to (i), the supplier will increase the sustainable commitment level and hence the retailer can capture the benefits of the increased demand.

6.5 Conclusion

In this article, we develop a stylized game theory model to explore the operations decision in a sustainable supply chain. We consider a two-echelon fashion supply chain in which a supplier implements advanced technology to commit sustainability practice while the retailer utilizes green advertising to promote the sustainability commitment of its supplier to attract the environmental conscious customers. To be specific, a Stackelberg game is applied to analyze the optimal decisions of the retailer and supplier under a wholesale pricing contract and derive the optimal pricing, advertising level, and sustainable technology investment for a supply chain with environmentally conscious consumers. We uncover that the optimal wholesale price is dependent on the supplier's production cost but independent of technology investment cost rate and promotion cost rate. There are three situations that the supplier will commit a higher sustainability level. Specifically, the supplier has either a higher production cost or a higher technology cost rate will result in a higher sustainability level of the supplier. In addition, when the retailer's promotion cost rate increases, the supplier will react by having a higher sustainable commitment level if her technology cost rate is significantly large.

This study can be extended to consider the following issues. First, we can consider how blockchain technology can support the sustainable supply chain management in fashion industry. Blockchain is one of the technologies that can enhance the information transparency and product traceability along the supply chain. Second, we can study how different risk attitudes of the supply chain members affect the optimal decisions in sustainable fashion supply chain management. Finally, we can also investigate the effect of competition.

Appendix—All Proofs

Proof of Proposition 1a : From (6.1), the profit function of the retailer is $\Pi_R(p, e) = (p - w)(1 - p + aet) - \frac{1}{2}\varepsilon e^2$. The Hessian Matrix of $\Pi_R(p, e)$ is $|H| = \begin{vmatrix} -2at \\ at - \varepsilon \end{vmatrix}$ and $\Pi_R(p, e)$ is a concave function in p and e if and only if $\varepsilon > \frac{(at)^2}{2}$. (Q.E.D.)

Proof of Proposition 1b : From (6.2), the profit function of the supplier is $\Pi s(w, t) = (w - m)(1 - p + aet) - \frac{1}{2}\theta t^2$. The Hessian Matrix of $\Pi s(w, t)$ is

$|H| = \begin{vmatrix} \frac{-2\varepsilon}{2\varepsilon - a^2t^2} & \frac{2a^2t\varepsilon(1-2w+m)}{(2\varepsilon-a^2t^2)^2} \\ \frac{2a^2t\varepsilon(1-2w+m)}{(2\varepsilon-a^2t^2)^2} & \frac{2a^2\varepsilon(1-w)(w-m)(2\varepsilon+3a^2t^2)-\theta(2\varepsilon-a^2t^2)^3}{(2\varepsilon-a^2t^2)^3} \end{vmatrix}$ and $\Pi s(w, t)$ is a jointly concave function if and only if $\theta < \frac{2a^2[(w-m)(1-w)(2\varepsilon+3a^2t^2)+a^2t^2(1-2w+m)^2}{(2\varepsilon-a^2t^2)^3}$. (Q.E.D.)

Proof of Proposition 2b : From (6.2), the first-order derivations of $\Pi s(w, t)$ with respect to w is $\frac{\varepsilon(1-2n+m)}{2\varepsilon-a^2t^2}$, therefore, the optimal wholesale price of the supplier is $w^* = \frac{1+m}{2}$. On the other hand, the first-order derivations of $\Pi s(w, t)$ with respect to t is $\frac{(w-m)(1-w)(2a^2t^2\varepsilon)}{(2\varepsilon-a^2t^2)^2} - \theta t$, therefore, the optimal sustainability commitment level of the supplier is $t^* = \frac{1}{a}\sqrt{\frac{4\varepsilon-(1-m)\Omega}{2}}$. (Q.E.D.)

Proof of Proposition 2a : From Proposition 2b, we have $w^* = \frac{1+m}{2}$ and $t^* = \frac{1}{a}\sqrt{\frac{4\varepsilon-(1-m)\Omega}{2}}$. On the other hand, from (6.1), we have $e^*|_w = \frac{at(1-w)}{2\varepsilon-a^2t^2}$ and $p^*|_w = \frac{\varepsilon+w(\varepsilon-a^2t^2)}{2\varepsilon-a^2t^2}$. By substituting w^* and t^* into $e^*|_w$ and $p^*|_w$, and denote $\Omega = a\left(\frac{2\varepsilon}{\theta}\right)^{\frac{1}{2}}$, we can obtain optimal retail price of retailer $p^* = \frac{2\varepsilon+(1+m)\Omega}{2\Omega}$ and optimal promotion effort of the retailer $e^* = \frac{1}{\Omega}\sqrt{\frac{4\varepsilon-(1-m)\Omega}{2}}$.
(Q.E.D.)

Proof of Proposition 3 : By taking the first-order derivations of the optimal solutions with respect to m, θ, and ε, we can obtain the results shown in Table 6.2. (Q.E.D.)

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Chapter 7
The Multi-Methodological Approach for Sustainable Operations Management in Fashion

Tsan-Ming Choi

Abstract Sustainable operations management (SOM) is a well-established field, which is crucially important to fashion business nowadays. Traditional SOM studies employ methods such as theoretical modeling (e.g., mathematical analyses), quantitative empirical (e.g., surveys), and qualitative empirical (e.g., interviews, case studies). In recent years, to enhance research rigor, more and more SOM studies employ a multi-methodological approach to explore research problems related to the fashion industry. In this paper, we discuss applications of the multi-methodological approach for fashion SOM. We examine how the multi-methodological approach has been applied in the related literature. We propose new methods as well as new areas for future fashion SOM research in which the multi-methodological approach can be applied. Important insights are derived.

Keywords Research methods · Multi-methodological research · Sustainable fashion operations management · Theoretical modelling · Quantitative empirical · Qualitative empirical

7.1 Introduction

Sustainability, which puts a strong emphasis on "environment" as well as the economics and society, is a critical part of the fashion apparel industry. According to BBC.com, the fashion industry "accounts for around 10% of greenhouse gas emissions from human activity".[1] The serious impacts that the fashion industry have on

[1] https://www.bbc.com/future/article/20200310-sustainable-fashion-how-to-buy-clothes-good-for-the-climate (accessed 8 June 2020).

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T.-M. Choi (✉)
Department and Graduate Institute of Business Administration, College of Management, National Taiwan University, Roosevelt Road, Taipei 10617, Taiwan
e-mail: tmjchoi@gmail.com; jasonchoi@ntu.edu.tw

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our planet has created many arguments over the past years and many fashion brands are launching new programs to become more and more sustainable. For instance, the well-established fashion brand Adidas is working with Allbirds to develop the greenest sports shoes in the world.[2] Despite the general public awareness of the importance of having an environmentally and socially sustainable fashion industry, as of today, it is commonly believed that more has to be done. One dimension for improvement is on having a transparent and "tractable" fashion supply chain. However, this is exactly an area that the fashion industry is falling behind.[3] Luckily, fast fashion brands like H&M and Zara and luxury fashion brands like LV are all considering to implement blockchain technologies (Choi 2019; Choi et al. 2020) to enhance supply chain transparency and show more product provenance information.

As sustainability is so important to the fashion industry (Wen et al. 2019), it is indeed crucial for researchers in operations management to explore it by a scientifically sound approach. In fact, in the literature, sustainable operations management (SOM) is a well-developed domain. Studies on green product development (Guo et al. 2020), sustainable supply chain management (Choi et al. 2020), etc. have been widely published.

Traditionally, researchers in OM (including SOM) focus on studying the problems using various approaches. The typical approaches (called "methodologies") include theoretical modeling (e.g., by mathematics; Choi 2016, 2018; Chan et al. 2020a; Choi and Luo 2019; Wen and Siqin 2020; Zhang et al. 2020), quantitative empirical (e.g., surveys; Flynn et al. 1990; Malhotra and Grover 1998; Choi et al. 2010; Li et al. 2016), and qualitative empirical (e.g., interviews, case studies; Barratt et al. 2011; Ketokivi and Choi 2014; Chen et al. 2020; Fung et al. 2020). Despite being well-established, prior OM (and SOM) related studies are being criticized. To be specific, Sodhi and Tang (2014) study the prior research in OM. The authors uncover two pertinent issues on "isolation of methodology" and "disconnection from practice", and call for changes.

Over the past decade, a number of OM researchers have proposed the adoption of a multi-methodological approach to enhance research rigor of OM studies[4] (Boyer and Swink 2008; Carter et al. 2008; Singhal et al. 2008, 2014; Tang 2015; Choi et al. 2016). For example, Singhal and Singhal (2012a) propose to include the detailed steps (e.g., including "exploratory study, theory development, validity checking, model testing, and real-world verification") in science to conduct OM research. Singhal and Singhal (2012b) further propose and explore the way, which is basically a multi-methodological approach, to implement the proposed scientific approach to explore OM problems. Choi et al. (2016) formalize different scenarios to conduct

[2] https://www.businessoffashion.com/articles/tags/topics/sustainability (accessed 8 June 2020).

[3] https://www.businessoffashion.com/articles/news-analysis/when-it-comes-to-social-and-environmental-transparency-fashion-continues-to-fall-short (accessed 8 June 2020).

[4] According to Choi et al. (2016), "multi-methodological OM research is an approach for OM research in which at least two distinct OM research methods are employed non-trivially to meet the research goals.".

multi-methodological research in OM. The authors also discuss the pros and cons of adopting the multi-methodological research approach.

The paper is organized as follows. Section 7.2 discusses the different research methods, which are widely applied to explore fashion business operations. Section 7.3 explains why it is important to conduct multi-methodological SOM research in fashion. Section 7.4 reviews the literature and shows some examples of multi-methodological SOM research. Section 7.5 discusses future multi-methodological SOM research. Finally, Sect. 7.6 shows the concluding remarks of this study.

7.2 Different Research Methods

Following the prior studies by Sodhi and Tang (2014) and Choi et al. (2016), we can see that the three major research methodologies in OM, which are naturally applicable to studying SOM, are listed below: (1) theoretical (analytical) modeling (TAM) method, (2) quantitative empirical (QTE) method, and (3) qualitative empirical (QLE) method. We discuss each research method as follows.

The QLE method: This approach refers to the qualitative research, which focuses on exploring some observed scenarios or business operations in practices. The research nature is mainly exploratory and real-world practice-oriented. Interviews with managers and case studies of companies are typical examples of the QLE method.

The QTE method: In order to have some quantitative performance measures as well as evidence towards some operational issues, the QTE method can be employed. Surveys, private, and public empirical data analyses, etc. are commonly seen examples related to the QTE method. Usually, the goals of the QTE method are to uncover the relationships among variables, highlight the importance of different factors, etc. The major concern is, results based on the QTE method usually depend on the specific data sets and even the choice of statistical methods employed.

The TAM method: It mainly includes the use of mathematics to construct analytical models and derive results. Standard methods include optimization and game-theoretical analyses.

Table 7.1 shows a summary of the above three commonly seen research methodologies, which can be applied for exploring SOM problems.

The multi-methodological approach for SOM problems means applying two or more of these distinct methods together for a single SOM study in a significant way. Figure 7.1 shows the three main methods and the probable interactions.

7.3 Why Multi-methodological Research for Fashion SOM?

The use of multi-methodological OM approach has been seen in the literature (P.S.: The examples will be presented in Sect. 7.4). Why is it especially important for

Table 7.1 Common SOM research methodologies

Methodology	Examples	Remarks
Qualitative empirical (QLE)	Interviews, single or multi-case studies.	Exploratory in nature.
Quantitative empirical (QTE)	Surveys, event studies, sales, and inventory analyses with real data, etc.	Mainly helpful in revealing relationships and highlighting factors that are important.
Theoretical (Analytical) modeling (TAM)	Optimization modeling, game-theoretic analyses, simulation studies.	Using mathematics to derive solid theoretical results. Standard in economical sciences.

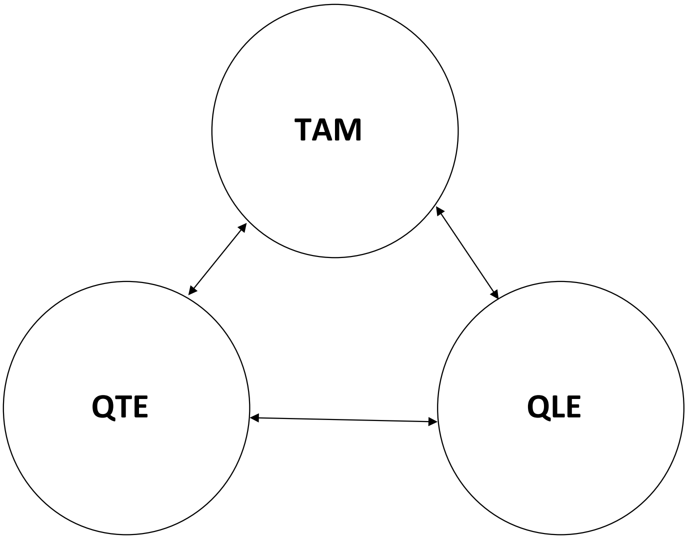

Fig. 7.1 Multi-methodological SOM research

SOM research in fashion? The following points illustrate some key features of SOM research in fashion which call for the use of multi-methodological OM approach.

Emerging area: As sustainability in fashion is an area that is still evolving and developing, the rules, regulations, and practices are highly dynamic. Different from many matured OM areas such as production planning and scheduling, before we can theoretically examine the related problems, we first have to conduct related exploratory studies as well as collect more qualitative and quantitative data to provide the needed grounds and support. As such, the use of multi-methodological approach for fashion SOM with strong emphasis on having qualitative empirical and quantitative empirical research is pertinent.

Importance of real-world validation: Sustainable operations in fashion should be real-world relevant. Good research in fashion SOM should also be based on scientific methods with sufficient evidence. It is, hence, critical to combine both theoretical modeling with empirical evidence in the study. An important aspect is the real-world validation of the theoretically derived results using qualitative and quantitative empirical data. This is crucial for SOM because of the presence of different practices and rules. As a matter of fact, even the ways of estimating emissions and pollutants are different under different schemes in different countries. Thus, it is important to know when and where the derived theoretical results are valid with respect to the real world.

More innovative ideas: Different approaches have their different functions and can help uncover different results. For a research area such as SOM in fashion, applying multi-methods together would help to develop more innovative ideas. This is super important in supporting the development of the field and generating fruitful results.

7.4 Examples of Multi-methodological SOM Research

After introducing the multi-methodological approach as well as why it is especially prominent for SOM in fashion, in this section, we give some specific examples for different types of published multi-methodological SOM research in the literature. Note that the way we organize and introduce these papers follows Choi et al. (2016)'s framework. Moreover, we do not aim to have a comprehensive review or examination of the literature. We only try to highlight some key features of each type of multi-methodological SOM research, especially those relevant to fashion business operations.

7.4.1 The TAM-QLE Approach

The QLE approach is exploratory in nature. It also helps to highlight some key features of the observed industrial practices. Using the QLE approach together with the TAM approach, one key aspect on "relevance to real-world practices" can be clearly shown. In OM, the TAM-QLE approach is rather commonly seen (e.g., Iyer and Bergen 1997; Caro and Gallien 2010; Boada-Collado and Martinez-de-Albeniz 2020; Chiu et al. 2020). Note that the use of QLE in the TAM-QLE approach can serve as both motivation, model support as well as validation of theoretical findings.

In the SOM literature, Choi et al. (2019) adopt the TAM-QLE approach to study sustainable operations in fashion apparel supply chains. The authors first discuss the fact that a fashion supply chain of a well-established international brand is commonly qualified as a system of systems. Then, they apply the system of systems management theory to propose various principles, which can be used to improve sustainable fashion supply chain management. After that, a TAM-based analysis is conducted to theoretically quantify the values of the system of systems principles. A two-stage framework and a managerial action matrix are developed. A real-world case study on H&M, which is in the form of QLE approach, is conducted to validate the theoretical research findings. Managerial insights and real-world managerial applications are generated.

Guo et al. (2020) employ the TAM-QLE approach in investigating the green product development problem in fashion apparel. The authors first conduct industrial practice examinations and interviews to motivate the problem. The authors mathematically build game theoretical models (i.e., using the TAM approach) and derive the equilibrium decisions in the fashion apparel supply chain. They conduct mathematical as well as numerical analyses to derive managerial insights. As real-world validation, industrial interviews are conducted to generate real-world inputs and comments to test and verify if the theoretical findings are solid. The authors finalize the core recommendations and uncover the key managerial insights after having both the TAM and QLE-based analyses.

More recently, Chan et al. (2020b) conduct a TAM-QLE study on corporate social responsibility of fashion companies. The authors examine qualitative data of fashion brands from public data sources. They then conduct a TAM study by building formal mathematical models. Insights are derived based on both TAM and QLE approaches.

Table 7.2 shows the details of the TAM-QLE examples that we have reviewed above. Please note the detailed methods adopted, the roles played by each method as well as the relationship between the methods.

7.4.2 The QLE-QTE Approach

The use of QTE approach helps to provide quantitative data to help show the relationships among variables in a statistical manner. It also facilitates the investigation of other approaches (e.g., QLE and TAM) by showing specific numbers.

In the literature, the pure QLE approach is usually viewed as "not scientific" enough. Despite being controversial, the adoption of both the QLE approach and QTE approach together can lift the research rigor of the related studies. Essentially, the QLE-QTE approach supports the "triangulation of data (with different research approaches)" (Bag et al. 2021) to substantially reduce the bias issues that may arise if only one research method is adopted (Choi et al. 2016).

As an example in SOM, Li et al. (2020) conduct an empirical study in which green supply chain operations are examined. The authors collect data via a survey in mainland China. They aim to uncover the moderating role played by quick response technologies in the supply chain. They also propose novel measures to help facilitate the development of green supply chain management. After collecting quantitative data, conducting the statistical analyses, and reporting the findings, the authors further conduct two real company case studies to verify the validity of the results derived from statistics. Additional managerial insights are also revealed by the two case studies.

Table 7.2 Details of the TAM-QLE examples

Paper	Detailed methods adopted	The role played by each method	Relationship between the methods
Choi et al. (2019)	TAM: Newsvendor inventory models, Bayesian analyses QLE: Validation of results	The TAM analysis derives theoretical solutions, findings, and insights based on the system of systems management principles. Public report-based case study (QLE) provides the needed real-world validation and checking.	TAM derives theoretical results and managerial insights to quantify the system of systems managerial principles. QLE is employed to help validate the applicability of the system of system management principles.
Guo et al. (2020)	TAM: Game theoretical analyses QLE: Industrial interviews, public reports	Industrial interviews and public reports (QLE) both motivate the study as well as support real-world validation and checking. The TAM analysis derives theoretical solutions, findings, and insights.	TAM derives theoretical results and managerial insights. QLE is employed to help motivate the TAM analyses and validate the mathematically proven results.
Chan et al. (2020b)	TAM: Analytical closed-form analyses QLE: Public data sources	Annual reports are examined to generate QLE insights on companies' CSR practices. The TAM analysis derives theoretical solutions, findings, and insights.	QLE is employed to generate insights. TAM is employed to derive more theoretically solid results.

In another study, Chan et al. (2016) employ the QLE-QTE approach to empirically study green service operations in two phases. In the first phase, interviews are conducted. In the second phase, qualitative analyses on industrial reports are made. Finally, surveys are also conducted to collect quantitative data for further analysis. Managerial insights regarding green service operations are then generated.

Table 7.3 summarizes details of the above review paper, which adopts the QLE-QTE approach. From the table, we observe that the CS-QE approach, which usually combines the use of qualitative and quantitative data, can improve the research rigor of the empirical research method in OM. It is also commonly called the data triangulation approach.

Table 7.3 Details of the QLE-QTE examples

Papers	Detailed methods adopted	The role played by each method	Relationship between the methods
Li et al. (2020)	QLE: Interviews and secondary data case studies QTE: Survey-based statistical analyses	QTE is employed to help test the hypotheses and generate statistical proven research findings. QLE helps verify and validate if the statistical findings from the survey data-based QTE method are correct or not. Additional insights are also developed.	QTE is the key method while QLE is very useful in lifting the scientific rigor and validate the survey results.
Chan et al. (2016)	QLE: Interviews and secondary data content analyses QTE: Survey-based statistical analyses	QLE is adopted in the first two phases, which helps to uncover real-world practices. QTE is employed to complement the QLE analyses.	QLE helps to build a valid construct. QTE helps with "data triangulation".

7.4.3 The TAM-QTE Approach

SOM research, as a part of OM research, has its roots in operations research (OR). As a well-established scientific field, OR focuses mainly on generating insights and solving problems via quantitative and mathematically based analyses. As such, the TAM-QTE approach is very commonly seen. For example, Choi et al. (2018a) conduct a study on service operations in fashion boutiques. The authors conduct both questionnaire data-based QTE analysis and game theoretical modeling exploration.

In SOM, Sheu and Choi (2019) study the extended consumer responsibility (ECR) policy via the TAM-QTE approach. The authors investigate the trade-in-for-upgrade business operations. They explore the pricing decisions in the presence of market competition. The authors establish a theoretical "consumer choice behavior" model. Then, they develop a behavior-grounded analytical model. They make use of multiple empirical data sources to support the study. They analytically derive the "syncretic value-oriented prices and trade-in rebates" for the trade-in-for-upgrade program. Table 7.4 shows a summary of the above-reviewed study.

From Table 7.4, it is crystal clear that the QTE method and TAM method are excellent complements and they support one another.

As a remark, to generate analytically tractable managerial insights, most TAM studies are conducted with respect to a non-trivial "set of restrictive assumptions". As a consequence, the derived insights are usually being criticized as "being solely theoretical and not practical enough" (Choi et al. 2016). The presence of QTE method, hence, provides the needed real-world support to overcome this problem.

Table 7.4 Details of the TAM-QTE example

Paper	Detailed methods adopted	The role played by each method	Relationships between the methods
Sheu and Choi (2019)	QTE: Survey-based statistical analyses TAM: Closed-form theoretical analysis	QLE is used to identify the key factors of the syncretic value. The TAM analysis derives theoretical optimal solutions and findings.	The results of the statistical analyses act as a theoretical fundamental for model development. TAM is used to reveal the characteristics of syncretic value creation and generate insights on the strategy adoption.

7.5 What's Next? Future Multi-methodological SOM Research

After discussing different methods and their combinations to form some commonly seen multi-methodological SOM studies, we now examine "what's next" in this section. To be specific, we discuss "where and how" the multi-methodological SOM research in fashion can be conducted. New methods are also proposed.

7.5.1 New Methods

From the above discussion, we note that the three commonly seen methods for SOM are TAM, QLE, and QTE. However, with the advance of technologies, many data-driven methods (Simchi-Levi 2014; Ferreira et al. 2016; Choi et al. 2018b; Boada-Collado and Martinez-de-Albeniz 2020) such as artificial intelligence (AI)-based methods are in the spotlight (Ren et al. 2020).

To be specific, in traditional QTE studies, the mainstream tool is "statistics". In other words, to derive findings and provide insights using the QTE approach, statistical methods are employed. In traditional TAM research, mathematical models, such as optimization models and game-theoretic models, are constructed. Deep TAM studies in SOM commonly require the explorations of structural properties of the mathematical models. An efficient way to obtain globally optimal solutions is critically important for analytically tractable problems. Alternatively, efficient heuristics with proven bounds are proposed to help find satisficing solutions.

However, the emergence of AI in real-world operations has changed the way researchers conduct TAM studies. AI methods commonly treat the solution details as a black box and solutions are not globally optimal. However, AI methods can be very quick in finding the "solutions" even for very complex optimization problems. They can also incorporate lots of data into the analyses and decision-making framework.

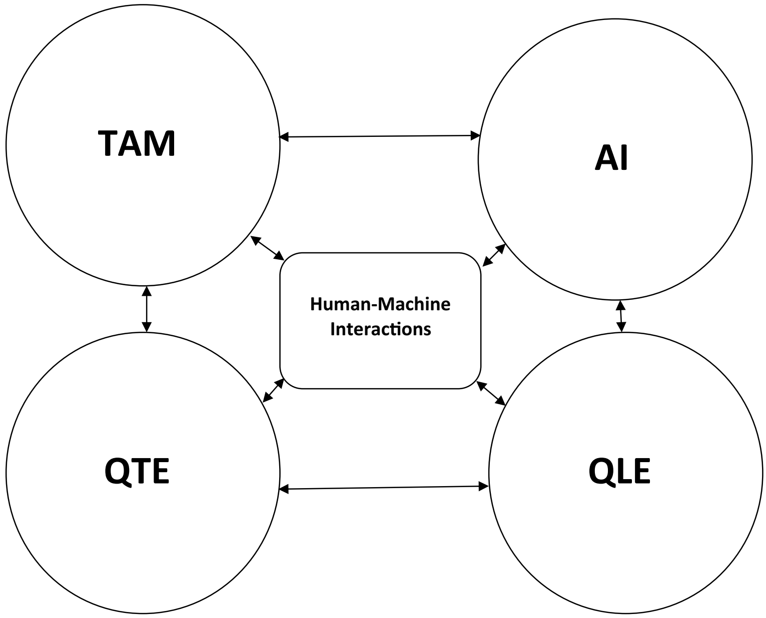

Fig. 7.2 New multi-methodological SOM research

As a consequence, the AI-based method will be a growing star that can be well combined with other research methods to help conduct SOM research in fashion.

In fashion SOM, humans usually play the central theme as the fashion industry is very “human-oriented”. However, nowadays, robotics are replacing humans and automated systems are getting more and more popular. Real-world operations related to fashion SOM may then be largely changed with the use of these robots. The way to study fashion SOM in the presence of robots will expectedly be very different from the traditional way of operations. Many new methods, probably related to a combination of AI and human intelligence, would hence be needed. This will appear in the future in the “human–machine interactions”-related studies.

Figure 7.2 depicts the new multi-methodological approach for SOM studies in fashion. Note that the human–machine interactions are more than just a method and hence it is placed in the middle. It may actually mean a totally new central part for future SOM research in both research methodology and the whole discipline.

7.5.2 New Areas

Several important areas of SOM in fashion, in which the multi-methodological approach can be adopted, are discussed one by one in the following.

Luxury fashion: The luxury fashion sector (Chiu et al. 2018; Choi and Liu 2019; Shen et al. 2020; Wang et al. 2020) is very important to the fashion industry. Consumers are willing to pay a premium for the luxury fashion goods because of their conspicuous consumption behaviors. However, nowadays, being sustainable and ethical is also pertinent. In the SOM literature, the luxury sector, especially in fashion, is still under-explored. A lot of research, especially combining multiple methods, should be conducted to provide the needed support to the area.

Fast fashion: Among all kinds of fashion brands, SOM is probably most essential to fast fashion brands (Choi et al. 2010) because they have to "green-wash" their brand names to let consumers feel they are truly sustainable and ethical. Adopting the multi-methodological approach can make use of real data to help establish theoretical frameworks and derive solid managerial insights for the fast fashion sector of the fashion industry.

Functional apparel: Industrial giants such as Nike and Adidas are known to be committed to SOM, especially in product development and technologies related investments. In order to optimize the use of resources for SOM, functional apparel companies need to optimize their supply chains with a comprehensive approach of combining multiple methods together. This may even go beyond traditional SOM analyses because the related analyses will cover all operations and related procedures of many related companies and stakeholders.

7.6 Concluding Remarks

In SOM, it is known that the multi-methodological approach can provide a way to increase research rigor. This not only contributes to the literature in deriving more robust research findings but also provides more scientifically sound research guidance to practitioners and fashion companies in the real world.

In this paper, we have concisely discussed some commonly seen combinations of standard research methods in SOM. For each one of them (i.e., TAM-QLE, QLE-QTE, TAM-QTE), prior journal publications as examples have been discussed and the important roles played by different methods have been highlighted. New methods, such as AI, and new areas for future research in fashion SOM have also been proposed.

It will be great to see a wider adoption of the multi-methodological approach in conducting SOM research in fashion in the future.

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Chapter 8
Overview and Research Agenda for Sustainable Operations Management in Fast-Fashion Era

Hau-Ling Chan, Shuyun Ren, and Na Liu

Abstract We first give an introduction to the evolution of the fashion supply chain structure from linear to circular. Next, we review and discuss the important elements that should be considered and analyzed in sustainable operations in a fast-fashion era, namely, advanced technology, customer involvement, collaborative strategy, and government support. Finally, we draw our conclusion and propose future research directions.

Keywords Research Agenda · Sustainable operation management · Fast fashion

8.1 Fast-Fashion Industry—From Linear to Circular

Fashion industry is an important sector that contributed $1.9 trillion in retail sales in 2019 (Intrado 2020). However, it is also perceived as the second dirtiest industry severely affecting our planet and generating a massive amount of air pollution, solid waste, and water pollution. It is reported that the fashion industry produces 10% of greenhouse gases emission globally (e.g., from generating electricity in the production process) and 20% of water pollution (e.g., from dying and bleaching the fabric) (Ro 2020). Besides, more than 90 million tonnes of textile and clothing waste are sent to the landfill annually and the amount is predicted to increase dramatically by 50%

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H.-L. Chan (✉)
Division of Business and Hospitality Management, College of Professional and Continuing Education, The Hong Kong Polytechnic University, Kowloon, Hong Kong
e-mail: ling.chan@cpce-polyu.edu.hk

S. Ren
School of Art and Design, Guangdong University of Technology, Guangzhou, China
e-mail: Shuyun_shara@live.cn

N. Liu
Business School, Beijing Institute of Fashion Technology, Beijing, China
e-mail: sxyln@bift.edu.cn

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by 2030 (May 2020). Fast fashion has been blamed for its negative impact brought to the environment when compared with luxury fashion. It is due to the nature of fast fashion.

Fast fashion is characterized by having reduced lead time (such as using a quick response strategy to postpone the inventory ordering decision such that the fashion brands can observe the market trends to satisfy customer demand) and introducing the new fashionable items to the market quickly (Choi 2014a, b) at an affordable price. The life-cycle of the fast-fashion product is very short and the design of it changes frequently to capture the current fashion trend (Cachon and Swinney 2011). To produce the highly fashionable items, the fast-fashion supply chains have to consume a massive amount of non-renewable resources, water, and chemical to produce the trendy fashionable items to cope with customer's needs on the trendy elements. However, making a piece of cotton shirt and a pair of jeans requires 700 and 2000 gallons of water, respectively (McFall-Johnsen 2019). Besides, customers are lured by the low retail price which results in impulse purchase, unnecessary consumption, and negatively affects our planet eventually. See Fig. 8.1 about a linear structure in a traditional fashion supply chain. On the other hand, to sell fashion products at an affordable price, fast-fashion brands have to control the production costs tightly. They prefer to use synthetic fabric (e.g., polyester, nylon, acrylic) to make clothing as these materials are cheaper and can be stretched easily; yet, they are non-biodegradable (Retviews 2019). Over the past decades, fast-fashion brands have implemented different sustainable practices to mitigate their waste and pollution problems, for instance, H&M uses environmentally friendly materials (e.g., organic cotton and lyocell) for making clothing and implements "fashion garment recycling programs" from end-customers, while Zara uses renewables sources of energy for production and adopts artificial intelligence to improve demand forecasting to reduce the chance of having overproduction.

Recently, a new sustainable business model has emerged in fast fashion by applying the concepts of circular economy (SAP 2019). A circular economy aims to reduce the use of scarce resources and waste generation. Choi et al. (2020a) define that a circular supply chain (CSC) is a supply chain system that targets to achieve environmental sustainability with a minimal level of waste and maximal use of "reuse, recycle, and remanufacturing", and generates values in a "closed-loop" system. For example, Uniqlo has applied the concepts of "reuse and remanufacturing" by collecting the down jackets from end-customers, and then extracting the feathers and reusing them as materials for making the new down jackets for the new collection (see Fig. 8.2 for details). Nike gathers the plastic bottles from the ocean and recycles them as rubber for making shoes. As a remark, the terms "circular

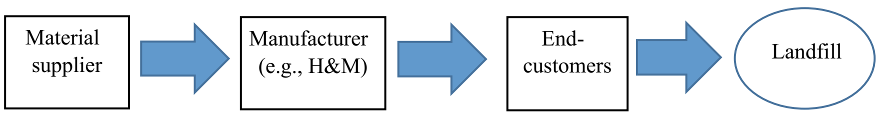

Fig. 8.1 Traditional linear supply chain structure in fashion industry

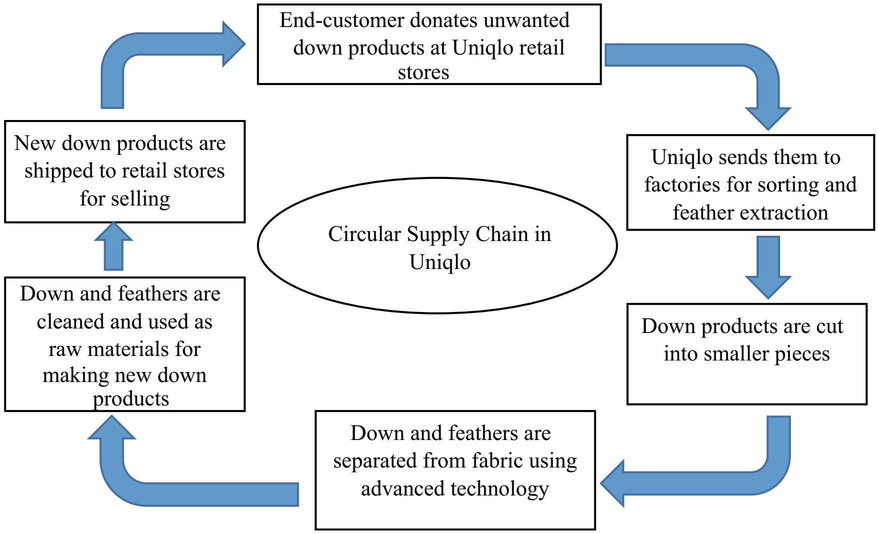

Fig. 8.2 Circular supply chain in Uniqlo

supply chain", "sustainable operations", and "closed-loop supply chain" are related to having sustainable practices. However, "circular supply chain" focuses more on "reuse", "recycle", and "remanufacturing" to result in zero solid waste ideally. See Fig. 8.3 about a circular structure in a fashion supply chain.

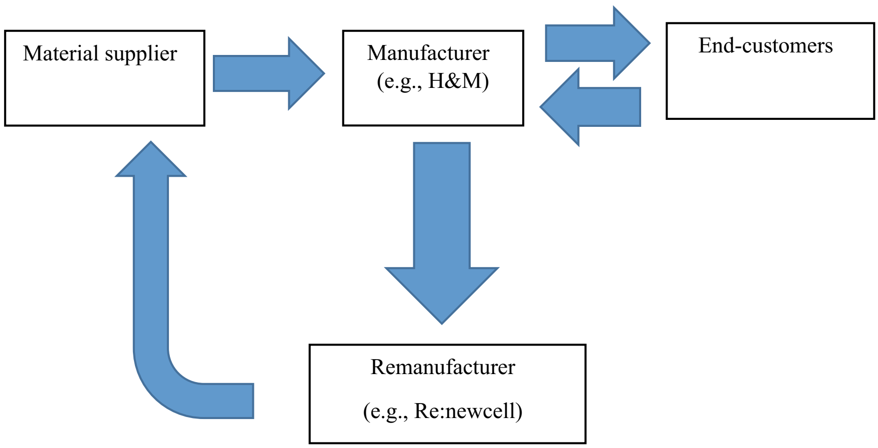

Fig. 8.3 Circular supply chain structure in fashion industry

8.2 Circular Supply Chain Management

Developing a circular supply chain requires the application of advanced technology, customer involvement, collaborative strategy, and government support. We review the recent related literature and discuss the details as follows.

8.2.1 Advanced Technology

Advanced technology is important in the production, recycling processes, and inventory planning and forecasting in circular supply chain management. For example, Sandvik and Stubbs (2019) conducted interviews with stakeholders to understand the enablers and barriers of having "textile-to-textile" recycling systems in the apparel industry. They recommend applying technology to enhance sorting and recycling which could enhance the transparency and traceability in the supply chain management. Jia et al. (2020) conducted a literature review on the circular economy in the fashion industry. They proposed that future research can adopt multiple cases to reflect the circular economy situation, analyze the relationship between the social aspect and circular economy, conduct financial assessment when technology is used for facilitating circular economy, and adopt the network concepts to evaluate the ecological innovation outputs. Maranesi and De Giovanni (2020) conducted four case studies to illustrate how the circular economy concept is aligned with the corporate strategy and how to achieve industrial symbiosis and the corresponding performance. They found that the application of the circular economy concept in the company should be well supported by the shareholders and the top management. Besides, technologies and "eco-innovations" are the major components of circular supply chain management and the collaboration mechanism. Tedesco and Montacchini (2020) conducted company auditing on the environmental performance in small and medium enterprises (SMEs), and did experiments and prototyping to highlight the opportunities and difficulties of using textile waste as a building material for new product development. Besides, the authors also applied the life-cycle approach to evaluate the environmental performance by using recycled materials. To support sustainable operations, we can implement cleaner technology, 3D printing technology, and artificial intelligence to help.

- ***Cleaner Technology***. Producing fashion products is energy-intensive which significantly generates greenhouse gases and pollutes our environment. Fashion brands (e.g., Patagonia, H&M, and Nike) have started using renewable energy. For example, Nike adopts 100% renewable energy in its facilities in North America. The consideration of adopting cleaner technology to reduce carbon emissions has been examined in the literature for fashion supply chain management. In the analytical literature, Shen et al. (2017) conducted case studies to reveal the clean technologies adoption in Chinese textile suppliers and then develop an analytical model to derive the optimal decision in the clean technology selection. Chan et al. (2018) examined the effect of using a quick response strategy of the fashion industry when the supplier invests in clean technology while the retailer improves the inventory forecasting estimation by Bayesian theory. Besides, they proposed to use minimum ordering quantity (MOQ) and MOQ with buyback (MOQ-BB) to coordinate the supply chain. Shen et al. (2020) explored the spillover effect when clean technology is adopted in the fashion industry. They found that the spillover effect can enhance the greenness level of the product. Guo et al. (2020) considered the use of advantage technology to increase the greenness level of the product and study the effect of market competition. The above studies consider that the supplier is the one who should invest in clean technology.

- ***3D Printing Technology***. 3D printing, also called additive manufacturing, is perceived as a tool to drive sustainability. This technology builds an object layer by layer and it can reduce the amount of waste generated in the production process and the residual materials can be recycled for a new round of printing (Despeisse et al. 2017; Kerdlap et al. 2019). The 3D printing technology can use to support the circular supply chain. First, it does not require a mold prior to manufacturing the object in any shape when compared with transformative traditional manufacturing (Song and Zhang 2020; Sun et al. 2020). Second, it supports the mass customization project in which the object can be personalized according to the customer's requirement and it results in "on-demand" manufacturing (Pasricha and Greeninger 2018). Therefore, with 3D printing, it is able to meet the unique needs of customers which can reduce the chance of having overproduction. For example, Adidas uses 3D printing technology to make a customized midsole of sports shoes. Existing literature on the 3D printing application investigates the management of the "spare parts" (Song and Zhang 2020), optimal pricings decisions (Sun et al. 2020), and the impact of competition intensity (Kleer and Piller 2019). However, the applications of 3D printing of the above studies do not specifically focus on the fashion supply chain.
- ***Artificial Intelligence***. In nowadays fashion industry, the applications of artificial intelligence (AI) play a crucial role in different management categories, from fashion demand forecasting to decision-making in supply chain management (Thomassey and Zeng 2018). AI-based forecasting methods and techniques are explored and applied more and more in both academic and industries due to the precise and effective performance in fashion demand forecasting (Lim and Zohren 2021). Loureiro et al. (2018) investigated the use of AI methods in fashion demand forecasting for new products and suggested that AI forecasting methods perform better than other traditional regression methods in the fashion retail market. Hofmann and Rutschmann (2018) examined the performance of big data analysis and AI techniques on fashion demand forecasting and revealed that big data analysis with AI technique can benefit fashion companies and supply chain management. With the use of information technology, fashion companies can gather information about customers' preferences, and then they can improve their inventory policy for matching supply and demand. With this practice, the fashion companies are able to satisfy customers with a reduced chance of having unsold fashionable items and the wastage of scarce resources. In real-life situations, by

exploring big data and AI techniques, H&M has eliminated stocking stores and replaced them with an assortment of products worldwide (Chaudhuri 2018). Zara uses artificial intelligence to improve the forecasting of the "best-selling" fashion items for inventory management (Heuritech 2020).

8.2.2 Customer Involvement

A circular supply chain cannot be successfully implemented without customer involvement. It is well agreed that the amount of solid waste going to the landfill can be reduced if the end-customers are willing to donate or "bring back" the unwanted fashionable items for recycling. Customer acceptance of using recycled materials for making new fashionable items is critical to the success of circular economy. Kim et al. (2021) found that the emotional value will positively affect the attitude of sustainable fashion products and the statistical results also support that a consumer with environmental awareness will have a higher tendency to purchase the sustainable fashion product. Pal et al. (2019) discussed the obstacles to forming a circular supply chain and the critical issues in future research directions. They highlight the effectiveness of the reverse supply chain, acceptance of the recycled products, technology support, and strategic alignment in the circular economy.

On the other hand, the clothing donation behavior has been widely examined using an empirical approach. For example, Ha-Brookshire and Hodges (2009) conducted interviews, questionnaires, and observations to study the clothing donation behavior of the consumers. They found that the major reason driving clothing donation is due to the closet cleaning. Bianchi and Birtwistle (2012) showed that the recycling behavior of the consumer will partially associate with clothing reselling to gain economic benefit. Bianchi and Birtwistle (2012) further found that consumer environmental awareness and consumer age will influence donation behavior. Joung (2014) suggests that fast-fashion consumers may simply discard the fashionable items because the perceived quality of the fast-fashion items is lower. Park et al. (2017) applied the behavioral reasoning theory and revealed that consumer environmental attitude will drive their intention to donate clothing to charity. Recently, empirical studies have considered the apparel resale attitude of consumers. Lai and Chang (2020) statistically showed that prosocial behavior is associated with apparel resale behavior, and both the environmental and prosocial behaviors are not related to apparel reuse intention.

However, there are very few analytical studies examining the customer involvement in clothing recycling. Choi et al. (2018) explored the used intimate apparel collection (UIAC) programs and studied the optimal level on the coupons value, collection investment, and the number of donors between charity collector and commercial collector. In the model, the authors considered that the donation rate of the end-customers is dependent on the coupon value. They also investigated how retail competition affects the levels of social, environmental, and economic sustainability in UIAC programs.

8.2.3 Collaborative Strategy

Being sustainable is the responsibility of every single firm, including suppliers, manufacturers, and retailers. Even though the fast-fashion products are sold at a lower retail price and hence the fast-fashion brands should have a lower sustainability commitment than the luxury brands (Chan et al. 2020b), they have also begun to collaborate with its supplier to implement various sustainable practices. It witnessed that business firms have collaborated with their supply chain members to achieve this goal. For example, H&M collaborates with recycling company I:CO which gets the donated clothing from H&M and performs sorting to determine whether to reuse, re-wear, or recycled. The most widely applied organizational theories to address the collaboration with suppliers for environmental sustainability are the stakeholder theory and resource-based theory. The majority of relevant literature uses "survey" and "case study" as the research methodologies. Readers can refer to Chen et al. (2017) for details. For example, Fischer and Pascucci (2017) conducted case studies in the fashion industry in The Netherlands. The authors define two ways for circular economy transition, namely status quo arrangement and product as service arrangement, and find that channel coordination, contracting, and financial performance are key elements for developing circular material flows. In other words, it is crucial to have a win–win situation when developing a circular economy. Fehrer and Wieland (2021) addressed the importance of social and ecological systems in the transformation process toward circular economy and emphasizes that the social, economic, and environmental goals should be balanced. They proposed a new circular business model and discussed future research directions. The concept of mutual benefit and the social, economic, and environmental performance in sustainable operations management has been considered in the analytical studies.

Regarding the analytical literature, a limited study specifically focuses on fashion supply chain management. For example, existing literature considers using the revenue-sharing contract as a kind of collaboration to improve the sustainability performance (Hsueh 2014; Govindan and Popiuc 2014; Zou et al. 2018; Li et al. 2019; Yu et al. 2020) or sharing of the used product collection responsibility (Wang et al. 2019). Regarding fashion supply chain management, Adhikari and Bisi (2020) considered a collaborative strategy in a sustainable fashion supply chain with a green cost-sharing contract. They studied how the fairness concern affects the greenness level and pricing decisions.

8.2.4 Government Policy and Support

Governments are also crucial in sustainable development and circular supply chain formation. Governments including Australia, China, and Singapore, have already imposed regulations and have issued carbon-related tax policies (e.g., carbon tax, cap-and-trade) for environmental protection (Chow 2020). Apart from taxes, it is also reported that governments, including British and Australian governments, motivate the circular supply chain formation through recycling by offering financial subsidies (Ukft 2019). The carbon-related tax registration and financial subsidy will induce fashion companies to adopt a sustainable practice. Virta and Räisänen (2021) revealed three cases for sustainable production and consumption in the apparel industry according to the data collected from the Finnish news media. They predict that there will be a stronger need for the policy instruments to be sustainable, such as legislation, environmental tax, and eco-label.

Regarding the analytical studies, Choi (2013) investigated how the carbon tax affects the sourcing decision of the retailer. Shi et al. (2017) constructed an analytical model to explore the sustainability investment level and pricing decision in manufacturer Stackelberg, vertical Nash, and retailer Stackelberg models in a fashion supply chain with the consideration of carbon tax. Shen and Li (2019) derived the optimal pricing and product greenness level in the presence of retail competition and carbon tax. Choi and Luo (2019) examined how the quality of the market data affects the fashion supply chain profitability and social welfare when the carbon tax is imposed by the government. Shen et al. (2020) found that a higher carbon tax price will motivate the manufacturer to adopt the clean technology in the monopoly situation and the optimal product greenness level will increase in the carbon tax if and only if the market share of the retailer is sufficiently large. Chan et al. (2020a) analytically examined the effect of carbon taxes and consumer returns on the optimal inventory policy of the retailer when she is risk-neutral and risk-averse, respectively. Apart from the taxation, the government can also provide financial subsidies to motivate sustainable operations in the fashion industry. However, the related literature in this area is minimal. In the literature, Wang et al. (2014) addressed the government subsidy for remanufacturing activities. They found that the extreme value of subsidy will intensify the competition between the remanufacturer, while a moderate value of subsidy will result in cooperation between the supply chain partners in a fashion supply chain.

8.3 Conclusion Remarks and Future Research Directions

In this chapter, we first give an introduction to the evolution of the fashion supply chain structure from linear to circular. Next, we review and discuss the important elements that should be considered and analyzed in sustainable operations in a fast-fashion era, namely, advanced technology, customer involvement, collaborative strategy, and government support. Overall, the success of the circular economy formation involves support from the stakeholders, including top management, fashion brand, supplier, government, and even customers. After reviewing the literature, we have realized the following research directions:

- Nowadays, customers are not only concerned about the greenness level of the fashion product but also the sustainable actions of the fashion brands and their suppliers. Having transparent supply chains is essential in future circular supply chain management. To support this functionality, blockchain is one of the possible technologies. Wang et al. (2020) illustrate how blockchain technology can support circular supply chain management in the fast-fashion industry. Blockchain adoption is still in the infant stage and it requires our effort to evaluate the impact and risk of using blockchain technology for circular supply chain management in terms of environmental, social, and economic performance. Dutta et al. (2020) and Choi et al. (2020b) provide good references in this area.

- Adopting cleaner technology is a commonly seen approach to enhance sustainability, and the majority of literature considers that the supplier is the one who invests in this technology. In the future, it is also interesting to investigate the situation in which the manufacturer also has the capability to invest in clean technology (such as the study by Guo et al. 2020), or both the supplier and manufacturer co-invest in the technology.
- Studies on the fashion circular supply chain management related to the real-world practice are still underexplored. It is suggested to conduct interviews, case studies, and observations to strengthen our knowledge of the supply chain context. The findings will become fundamental for building different supply chain structures in the circular economy for analytical modeling studies. Therefore, a multi-methodology approach is highly recommended to analyze the value and impact of the real-world situation. For example, we can consider that the supplier (e.g., Nike) rather than the remanufacturer collected the used apparel from the end-customers directly for remanufacturing. In addition, it is interesting to examine the possible form of sustainability collaboration between the supplier and retailer in real-world practice and then analyze the pareto/win–win mechanism for such kind of collaboration.
- 3D printing technology can facilitate the "on-demand" production nature which can significantly reduce the amount of unsold fashionable items going to landfills. To our best knowledge, there is a research gap on the 3D printing technology adoption for sustainability operations in the fashion industry which deserves our further investigation. For example, in the competitive market, how does the 3D printing technology affect the pricing and quality decisions? Are the environment, social and economic performance always better off when 3D printing is used for making customized products? If the lead-time is also considered, how does it affect our operational decisions as well?
- From the literature, it is observed that the majority of literature studies on sustainable fashion supply chain management consider the carbon tax, and limited studies focus on the cap-and-trade policy and financial subsidy. In the future, it is worth our effort to examine the different sustainable operations in the fashion industry with the consideration of cap-and-trade government policy and financial subsidy. Dong et al. (2016) provide a good reference in this area. Besides, it is also interesting to compare and analyze whether a taxation scheme is better than a financial subsidy to motivate the fashion firms to be sustainable and whether it is also good for the society.

- As we all know, it is often a challenging task to combine inventory management and demand forecasting to perform the quick response strategy in the fashion supply chain management. Different from general products, fashion products have a short life-cycle with a large number of varieties, and the market demand is changeable which makes it difficult to predict accurately. Consumer changes the position from the end of the entire process to the front in the big data era (Guo et al. 2020). It is difficult for the traditional forecasting methods that are based on historical sales data and expert experience to handle the complicated influencing factors and the rapid changes in demand. How to grasp the changes in fashion trends and market demand in real time in the big data environment and respond quickly is an urgent problem in the nowadays fast-fashion industry.

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