Operations#Finance Interface in Risk Management: Research Evolution and Opportunities

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Abstract

The operations-finance interface (OFI) jointly optimizes material, monetary, and information flows under intricate sources of uncertainty. To sketch the broad landscape in this emerging and interdisciplinary field, this paper synthesizes literature across diverse themes and dispersed methodologies, screens systematically the research progression from original foundations to recent contributions in each major research stream, and thereby advocates future research innovations on prospective topics in light of the interconnections and potential reciprocity between operations and finance from risk management aspects.

Keywords: Operations-finance interface, supply chain finance, supply chain management, corporate finance

History: Received: April 2019; Accepted: August 2020 by Sridhar Seshadri, after one revision.

1. Introduction

Operations and finance are two key functions that jointly drive business success. Operations management optimizes the supply and processing of material flows to ensure the efficient and effective resource utilization in meeting customer demand, i.e., physical supply chain management. Corporate finance primarily adjusts capital structure using various instruments to allocate monetary resources over space and time, i.e., financial supply chain management. Operations management on the one hand is supported by financial activities, and on the other hand drives the financial performance of enterprises or supply chains (BAFT et al., 2016).

Firms operating in global supply chain are exposed to a sheer variety of risks, e.g., technological risks, economic risks, financial risks, performance risk and legal/regulatory risks (Triantis, 2005). The interface between operations and finance has long been examined in risk management. According to Modigliani-Miller (MM) theorem, the separation property between operations and finance holds under the assumptions of symmetric information and perfect capital markets (Modigliani & Miller, 1958). In reality, markets imperfections (e.g., tax, bankruptcy cost, information asymmetry) lead to inevitable operations-finance interactions. Hence, omitting such interactions could distort both functions and result in potential losses to a firm or a supply chain (Birge, 2015). This provides an important starting point for subsequent research on operations-finance interface (OFI) in the next decades.

In an accelerated business environment under intricate risk exposures, both researchers and practitioners believe an in-depth understanding of the trade-offs between operational and financial metrics and thereby integrating both functions if necessary can be of substantial importance

(Protopappa-Sieke & Seifert, 2010), especially after the financial crisis rippled across global markets in 2008-2009 (McShane et al., 2011). This financial crisis has been referred to as a "failure of conventional risk management in financial institutions" (Fraser & Simkins, 2010, p.27), and thus brought risk management to the forefront once again, not only among top executives within firms but also among members of congress and government regulators.

Recently, the pandemic of COVID-19 and global trade conflicts have significantly affected global supply chains, from upstream supply, inbound and outbound logistics, to demand planning and forecasting (Kapadia, 2020), and consequently casts a dark shadow on the global economy. The former IMF chief economists believe the pandemic outbreak and the global actions to limit its spread are leading the world economy into the next recession (Financial Times, 2020). Driven by the intense flurry of government and stock exchange activities related to risk management within corporations, trade and business publications directed at top management are full of articles related to risk management.

Moreover, small and medium-sized enterprises (SMEs) might face tremendous working capital pressure under credit risk (especially in economic downturns) with regard to the exploitation issue owing to powerful supply chain partners and the credit rating issue arising from information asymmetry between SMEs and financial institutions (Paul & Boden, 2014; de Korte, 2016). This could lead to underinvestment in capital budgeting and thereby negative repercussions along a supply chain. To mitigate the impact of financial frictions on SMEs, innovative supply chain finance (SCF) schemes—service clusters relying on the collaboration between operations and finance functions among supply chain players (Gelsomino et al., 2016)—have prospered with the maturing of technology in recent years (BAFT et al., 2016). According to 2018 World Supply Chain Finance Report, global SCF market size has reached $447.8bn in 2016—an increment of 36% over 2015. Besides, more than half of the corresponding firms have plans or are investigating options to improve supply chain finance techniques (Bickers, 2018).

In sum, there is growing recognition that risk management should be conducted in a broader scope of financial assets and operational activities. On the one hand, CFOs across industries are going through liquidity exercises to ensure their organizations have cash to survive the downturn, while they're also modeling scenarios of when stay-in-place restrictions start to lift (Freedman, 2020). On the other hand, the COVID-19 pandemic brings more supply chain executives into the C-suite as sourcing diversification becomes a key supply chain strategy according to a recent PwC report (Cosgrove, 2020).

Relative to the prevalence of risk management on operations-finance interface in practice, academic research in this field is emerging rapidly yet still features great unleashed potential. For instance, Seshadri & Subrahmanyam (2005) first introduce a special issue of *Production & Operation Management* to bridge the gap between the worlds of finance and operations by combining and modifying concepts from finance to model risk in operations. Moreover, Birge et al. (2007) call for papers at the interface of finance and operations management in a special issue of *Management Science*. Similarly, Babich & Kouvelis (2015) make another call for paper in a special issue of *Manufacturing & Service Operations Management* to disseminate novel, insightful, and relevant research that unifies concepts from finance, operations, and risk management. Given the wide range of topics and methodologies in the vast literature on operations-finance interface, it might be challenging for scholars to develop a grasp of various research streams. Despite the high visibility of several frequently cited articles, the overall research landscape may

remain ambiguous. Hence, we attempt to provide a holistic view of the existing research on operations-finance interface as a navigation for researchers and practitioners.

Table 1 Overview of research syntheses on operations-finance interface and new contributions

References	Research scope	Review methods	Focal methodology of reviewed papers			Concentration
			Analytical	Conceptual	Empirical	
Seifert et al. (2013)	Trade credit	Qualitative review	√		√	Trade credit motives, order quantity decisions, credit term decisions, and settlement period decisions
Paul & Boden (2014)	Trade credit	Qualitative review	√		√	Strategic advantages to well-managed trade credit and its impact on the wider economy & market failures in trade credit supply chains & improving the operation of trade credit
Birge (2015)	Operations-finance interface	Analytical examples and empirical evidence	√		√	The interactions between operations and finance w.r.t. the implications of the absence of arbitrage, the differences between systematic and idiosyncratic risk, the valuation of limited production resources, and the inclusion of imperfect market assumptions
Zhao & Huchzermeier (2015)	Operations-finance interface	Qualitative review	√			Integrated risk management framework for multidimensional integration of operations-finance interface models by introducing a "closed-loop" view
Gelsomino et al. (2016)	Supply chain finance	Qualitative review	√	√	√	Concept and definitions of SCF & expected benefits & SCF initiatives
Babich & Kouvelis (2017)	Operations-finance interface	Qualitative review	√			Main research themes of the recent iFORM research, e.g., supply chain finance, integrated risk management, start-ups, entrepreneurship and financing, asset pricing with supply chains
Drover et al. (2017)	Entrepreneurial equity financing	Qualitative review	√	√	√	Integration of the large and disparate literature on venture financing, and identify key considerations relevant for the domain of venture financing moving forward
Bals (2018)	Supply chain finance	Deductive and inductive data analysis		√	√	SCF ecosystem with seven dimensions and one contextual perspective
Xu et al. (2018b)	Supply chain finance	Bibliometric/ network analysis & qualitative review	√	√		Research topics on deteriorating inventory models under trade credit policy based on the EOQ/EPQ model & inventory decisions with trade credit policy under more complex situations & interaction between replenishment decisions and delay payment strategies in the supply chain & roles of financing service in the supply chain
This paper	Operations-finance interface	Qualitative review	√	√	√	Research evolution and opportunities in currency risk management & commodity risk management & supply chain finance & integrated operations and finance in non-supply chain settings

Literature overviews on operations-finance interface are related to our research, as summa-

rized in Table 1. While Seifert et al. (2013) and Paul & Boden (2014) concentrate on trade credit, Drover et al. (2017) review the literature on entrepreneurial equity financing with emphases on venture capital, corporate venture capital, and angel investment. Furthermore, Gelsomino et al. (2016), Xu et al. (2018b) and Bals (2018) focus on supply chain finance in various scopes. Closest to our paper are three research syntheses on operations-finance interface. Birge (2015) provides an overview on the interactions between operations and finance adopting both analytical and empirical approaches without reviewing the literature. Zhao & Huchzermeier (2015) introduce a "closed-loop" view and propose a framework for integrated risk management on operations-finance interface by primarily reviewing analytical models in this field. Moreover, Babich & Kouvelis (2017) summarize the papers in a special issue on interface of finance, operations, and risk management and propose future research directions mainly for analytical explorations.

The primary contributions of this paper incorporate the following aspects. First, we review a *broader* scope of research themes adopting multiple methodologies on operations-finance interface in risk management. Owing to the vast and relatively divergent research streams, most previous reviews either envelop a subset of research topics in this field or focus disparately on literature streams primarily employing analytical, conceptual, or empirical methods, as shown in Table 1. Therefore, synthesizing research streams spanning across various topics and dispersed methodologies could not only provide a more comprehensive overview of this field, but also help in revealing potential research opportunities through a synopsis of topical mapping, data- or evidence-driven modeling, and the testing of extant theoretical framework. Second, a systematic review with an in-depth screening to draw the research evolution from original foundations to recent developments of each research stream on operations-finance interface in risk management is presented to navigate through the extensive landscape of research articles and to unveil disparity in literature as future directions. Third, this paper concentrates on the risk management perspectives of the interactions between operations and finance, and thereby categorize literature and identify research gaps from sources of uncertainty, the linkage between operational and financial risks, and the approaches to synchronize and explore the relationships among innovative operational strategies and financial instruments in diverse settings.

The remainder of this paper is organized as follows. In Section 2, we present the fundamentals to comprehend the evolution of operations-finance interface in risk management. Sections 3–6 paint the natural progression of research in this field through an detailed overview of four major research streams with respect to focal underlying sources of uncertainty, research evolvement, and future research opportunities in (i) currency risk management, (ii) commodity risk management, (iii) supply chain finance, and (iv) integrated operations and financing in non-supply chain settings. While research streams (i) and (ii) address respectively integrated risk management via operational strategies and financial instruments to mitigate exogenous financial risks (i.e., exchange rate risk and commodity price volatility), research streams (iii) and (iv) examine the management of endogenous financial risks (i.e., capital market imperfections) through joint operations and financing optimization in supply chain and non-supply chain settings, respectively. Section 7 concludes with a summary and an overview of potential research directions on operations-finance interface in risk management.

2. Evolution of operations-finance interface in risk management

According to the MM theorem, financial risk management could be independent from operational decisions under strong assumptions of perfect capital markets and information symmetry (Modigliani & Miller, 1958). In the capital asset pricing model (CAPM), firms should not engage in any effort to manage firm-specific risk because investors can eliminate firm idiosyncratic risks through diversification. Early research provides implications for the design of capital structure and financial hedging strategies and explores the reasons why firms hedge risk as justifications for the link between risk management and firm value. The relationship between optimal hedging and capital structure is studied in light of tax advantage of debt financing (Modigliani & Miller, 1958, 1963) and agency costs of asset substitution (Jensen & Meckling, 1976). The benefit of hedging could be greater when agency costs are low (Leland, 1998).

However, managers have become increasingly aware of how their organizations can be buffeted by risks beyond their control in practice. In many cases, fluctuations in economic and financial variables have destabilizing effects on corporate strategies and performance, causing financial distress or making a firm unable to carry out its investment strategy. Therefore, a value-maximizing firm can hedge for taxes, cost of financial distress, managerial risk aversion, the internal supply of fund to ensure value-enhancing investments, or the elimination of costly lower-tail outcomes (Smith & Stulz, 1985; Froot et al., 1994; Stulz, 1996). Meanwhile, shareholders and other stakeholders start to realize they may need to manage significant risks for firms to be successful. Therefore, there have been a dramatic change in the role of risk management in the past decades. To overcome the limitations of traditional silo-based risk management (i.e., risk management is compartmentalized and uncoordinated in autonomous units of an enterprise), managing risks across operational and financial functions in a firm and across supply chain partners leads to integrated risk management (Zhao & Huchzermeier, 2015). Thereafter, risk management has commanded a great deal of attention from researchers in OM and finance, and a series of seminal papers laid down the foundations of integrated risk management on operations-finance interface. While operational hedging utilizes real (compound) options that can be exercised contingent on demand, price and exchange rates in global supply chain networks (Huchzermeier & Cohen, 1996), financial flexibility provides "the ability of a firm to access and restructure its financing at a low cost" (Gamba & Triantis, 2013). When both real options and financial flexibility are adopted (Trigeorgis, 1993b), their interactions highlight the importance of coordinating financial and real risk management to build a well-integrated risk management strategy (Triantis, 2005). For instance, financial hedging can mitigate inventory risk for a seasonal product through market instruments when its demand is correlated with the price of a financial asset (Gaur & Seshadri, 2005). A risk-averse firm can dynamically hedge the profit by simultaneously optimizing operating policy and hedging strategy when the profits are correlated with returns in financial markets (Caldentey & Haugh, 2006). Flexible contracts can be adopted with or without hedging in a supply chain of a producer and a budget-constrained retailer facing stochastic clearance price (Caldentey & Haugh, 2009). Moreover, product flexibility and financial hedging can be complements (or substitutes) depending on whether product demands are positively (or negatively) correlated, while postponement flexibility and financial hedging are substitutes (Chod et al., 2010).

3. Currency risk management

In a risk management survey of 500 global company executives (The Economist Team, 2009), exchange rate uncertainty was ranked as the second most important risk factor next to demand uncertainty due to the economic recession in 2009. Besides, the executives ranked foreign exchange risk as their number one concern for the subsequent year. While the majority of multinational firms employ financial hedging instruments to mitigate the exchange rate risk, many global companies have adopted operational hedging strategies by diversification in more than one low-cost country (Chen et al., 2014). In this section, we first examine operational hedging and flexibility strategies to manage exchange rate uncertainty, and then move forward to the interaction between financial hedging and operational flexibility.

3.1. Operational flexibility and hedging

3.1.1. Capacity investment and facility location

Exchange rate uncertainty is first incorporated into an uncapacitated plant-location problem in a mean-variance framework by Jucker & Carlson (1976), in which currency risk is embedded in price uncertainty and random demands are independent. A series of subsequent papers extend this model using a mean-variance framework in quantity setting firms (Hodder & Jucker, 1985a,b; Hodder & Dincer, 1986). In particular, Hodder & Jucker (1985a) study international plant location under correlated exchange rate and price risks. Analogously, Hodder & Jucker (1985b) examine a plant-location problem for quantity-setting firms under correlated price risks across markets, where the mixed-integer quadratic programming problem can be solved using existing branch-and-bound techniques. Moreover, Hodder & Dincer (1986) analyze simultaneous international plant location and financing decisions in a mean-variance model for quantity setting firms, which can be readily solved using a multifactor approach. Hodder (1984) presents substantial computation advantages of a CAPM approach that measures risk by covariance as an alternative for a mean-variance objective for facility location models.

The valuation of "operating flexibility" to to mitigate currency risk in global manufacturing network configuration has been well studied. For instance, Kogut & Kulatilaka (1994) present a stylized model to show the option value of production shifting in a multinational network under exchange rate fluctuations. Huchzermeier & Cohen (1996) study global supply chain network configuration options with switching costs under correlated exchange rates adopting a compound option valuation approach. Overall, the firm trades off switching and fixed operating costs with benefit from exploiting differentials in factor costs and corporate tax rates. In addition, Lowe et al. (2002) propose a two-phase approach to evaluate alternatives in sourcing/production network design using multiple criteria in the presence of uncertain exchange rates. It is shown that a firm should evaluate various supply chain network designs in light of environmental uncertainties across multiple time periods. Please refer to Schwartz & Trigeorgis (2004) for a neatly bound collection of novel research on real options and capital investment under uncertainty.

3.1.2. Global production and distribution network

The variety of operational strategies in global production and distribution provides rich soil for the exploitation on currency risk mitigation. Rosenfield (1996) presents structural results on global manufacturing and distribution polices and focuses on how to tradeoff extra capacity and

flexibility to handle the uncertainties. Dasu & Li (1997) optimize production quantities for a cost-minimizing firm operating plants in different countries under exchange rate variability and switch-over costs. It is shown that the optimal strategy is a barrier policy when switch-over costs are linear or step functions. Moreover, Kouvelis et al. (2001) study both analytically and empirically the effects of exchange rates on the long-term ownership strategies (i.e., exporting, joint venture, or owned subsidiary) of production facilities for firms entering foreign markets in the presence of strategy switch-over costs. Kamrad & Siddique (2004) consider suppliers' reactions in the valuation of flexible supply contracts in the presence of exchange rate uncertainty, order quantity flexibility, supplier-switching options, and profit sharing. Incentives for the producer and suppliers to adopt flexibility are analyzed and its impact on contract value is presented. Kazaz et al. (2005) examine the impact of exchange-rate uncertainty on the optimal production strategies when the allocation decisions can be deferred until the realization of exchange rates.

The optimal production hedging (i.e., producing strategically less than total demand) and allocation hedging strategies are complementary as integral and robust parts of an optimal global production-planning strategy. Kouvelis & Gutierrez (1997) consider the production management of "style goods" sold in primary and secondary markets with nonoverlapping selling seasons when demand and exchange rates are uncertain. The centralized production control policies are more (or much more) profitable than the decentralized ones for any transfer price. Park et al. (2016a) study the pricing and manufacturing decisions for a firm selling one product in one domestic and one foreign market under exchange rate risk. Stochastic exchange rate leads to a new rationale for a monopoly to set a price below its cost under various conditions.

3.2. Interactions between operational flexibility and financial hedging

In practice, many multinational enterprises (MNEs) employ both financial hedging and operational flexibility to manage exchange rate volatility. Hence, established on the aforementioned operational flexibility and hedging literature, this research substream focuses on the interaction between operational strategies in capacity investment, production sourcing, and allocation options with financial hedging in currency derivatives market.

This research stream analyzes operational flexibility starting from stylized two-country sourcing model to sophisticated network design of global supply chains and financial hedging instruments from linear contracts of futures/forwards to non-linear options in a comprehensive portfolio, while the risk measurement has evolved from symmetric risk metric e.g., variance to downside risk measure e.g., conditional value-at-risk (CVaR). For instance, Mello et al. (1995) show that the optimality of a multinational firm's production sourcing flexibility is dependent on the extent to which it is aligned with financial hedging and liability structure. Chowdhry & Howe (1999) argue that a risk-averse global firm could mainly adopt financial hedging to manage short term exposure while utilize operational hedging to a greater extent in mitigating long term exposure to currency risk. Ding et al. (2007) study the impact of a global firm's financial hedging strategy on optimal capacity, postponed allocation option, and thereby global supply chain structure in a mean-variance model. Chen et al. (2014) examine how operational and financial hedging interact strategically in maximizing the mean-variance utility in a multi-country-supplier model. When two exchange rates are positively correlated and risk-aversion level is very high, financial hedging could dominate operational hedging. Park et al. (2017) find that production hedging could be both a complement and a substitute to financial hedging in

a global manufacturing firm that maximizes expected profit under a value-at-risk (VaR) constraint, where production hedging may cause the firm to decrease the optimal price below riskless price to benefit from exchange rate fluctuations. Zhao & Huchzermeier (2017) demonstrate that operational flexibility (capacity reshoring and production switching) maximizes expected profit subject to a CVaR constraint whereas financial hedging minimizes CVaR subject to a minimum expected profit, and therefore efficient financial hedging interacts with capacity portfolio to minimize their substitution effects in risk reduction.

In empirical investigations, the effectiveness of operational and financial hedging in currency risk mitigation has likewise been tested. In this context, operational hedging features geographic dispersion of multinational corporations' global subsidiary network (Allayannis et al., 2001; Kim et al., 2006), expected changes in operational volatility due to acquisitions (Hankins, 2011), and real options; the latter include market entry and exit, production and sourcing switches, and the acquisition and sale of a subsidiary (Aabo & Simkins, 2005). Financial hedging has been measured by the magnitude of foreign currency derivatives or foreign debt, where this hedging is used to manage exposure to factors such as the interest rate, price, and currency risks (Allayannis et al., 2001; Aabo & Simkins, 2005; Kim et al., 2006; Hankins, 2011; Aabo et al., 2012). The complementary relationship between operational and financial hedging has been supported by the finding that operational hedging does not effectively substitute financial hedging (Allayannis et al., 2001). Hence firms that engage in relatively more operational hedging are likely to adopt financial derivatives, and such joint operational and financial hedging is associated with reduced risk exposure and enhanced firm value. Operational hedging is typically used to mitigate long-term economic exposure, whereas financial hedging is more often employed to manage short-term transaction exposure (Kim et al., 2006). The claim that operational and financial risk management can be substitutes is supported by evidence that the use of real options (resp., financial hedging) increases (resp., decreases) with the length of the time horizon (Aabo & Simkins, 2005). Moreover, operational hedging by acquisitions (that reduce operational volatility) is a viable substitute for financial hedging by derivatives (Hankins, 2011). Besides, a positive relationship is evident between the extent of cross-functional integration in risk management and foreign exchange speculation, and active speculation and selective hedging are positively related to firm size and internationalization (Aabo et al., 2012).

3.3. Future research directions

In light of the recent coronavirus outbreak and global trade conflicts, various factors in capacity investment and facility location under currency risk can be exploited in future research. For instance, the measurement technique of currency risk exposure and the relationship among exchange-rate stabilization policies, capacity utilization, taxation, location decision (e.g., reshoring), and return rates can be revisited in global supply chain settings. The relative effectiveness of extant solution methodologies in managing exchange rate risk, e.g., financial market approach, mean-variance utility, real options theory can be assessed by further analysis and field study, while additional innovative approaches to capacity optimization and valuation could be proposed. Moreover, capacity location and financing decisions could be considered simultaneously to test and enhance the efficiency of the existing findings (Hodder & Dincer, 1986). Besides, how capacity strategies in global manufacturing network influence firms' competitive advantage could be validated empirically (Huchzermeier & Cohen, 1996).

As COVID-19 pandemic has exposed the potential vulnerabilities of global production, firms could adopt Industry 4.0 technologies and partially reshoring for security and cost considerations. Therefore, the implications of automation and reshoring on supply-demand matching and the mitigation of currency risk in both the foreign outsourcing and the interaction between robots and labour are worth further explorations (Seric & Winkler, 2020). In global production under exchange rate uncertainty, many issues such as cost structure analysis, pricing, product differentiation, market uncertainty, competitive advantage, and coopetition strategy could be explored further. Moreover, various utility formulations and risk attitudes can be employed to examine the effectiveness of operational strategies. Besides production hedging, switching options, and firm ownership strategies (Kouvelis et al., 2001; Park et al., 2016a; Zhao & Huchzermeier, 2017), other operational strategies such as modularization, product line expansion, price-setting strategies, and long-term contracting (inter alia) could likewise be analyzed in global production networks under currency risk. In addition, it would be interesting to study the impact of the aforementioned operational strategies on the value of firm's global production network, while competing and innovative approaches e.g., CAPM and real options theory could be further explored in real asset (production network) valuation models.

The complexity of global supply chain network and the evolving variety of operational risks leads to a sustained research interest in currency risk management. First, identification of major operational risks in global supply chains could vary over time. For instance, as the recent major source of uncertainty, coronavirus outbreak could lead to interrelated disruption risks and currency fluctuations in multi-tier supply chains. Empirical explorations by testing the relationship among sources of uncertainty, as well as the relationship among financial, operational and strategic currency risk management in global supply chains. In terms of risk measurement, the implementation of downside risk measures (e.g., VaR and CVaR) features a higher computational complexity (Park et al., 2017; Zhao & Huchzermeier, 2017), thus simplification methodology (analogous to the approximation between mean-variance approach and an exponential expected utility coupled with a normal distribution) can be proposed in application. To further explore the interactions between operational flexibility and financial hedging under exchange rate uncertainty, existing models could be extended from objective formulation, operational, and financial perspectives. To start with, more general utility functions could be adopted, while risk aversion could be considered through constraints (instead of risk-return objective formulations). Besides, macroeconomic variables could be incorporated as demand signals, various risk-sharing contracts, price-setting, and payment timing scenarios could be examined, and more securities from derivative market in financial hedging could be employed. Moreover, to capture real-world settings, the analyses could be expanded (respectively) to more complex settings e.g., multi-product, multi-currency, multi-stage, or continuous-time models. Additional sources of uncertainty (including interest rate risk, credit risk, commodity price risk) and correlations among them could be considered besides currency and demand risks, and the effectiveness of operational and financial hedging can be analyzed and tested when mitigating competitive exposure to exchange rate risk in global supply chains.

In addition, the adoption of various risk metrics in global operations and financial hedging under exchange rate uncertainty advocates further empirical investigation. Field study on the operations-finance interactions in multinational firms under exchange rate uncertainty could be conducted adopting alternative measures of operational and financial hedging (with a higher

precision) and extended to a broader scope of geographic regions and sectors; while the relationship between speculation and hedging of currency risk could be explored in future research. The COVID-19 pandemic and tariff uncertainty has accelerated the trend of production reshoring (Seric & Winkler, 2020), thus global supply chain restructuring and financial hedging as joint effort to mitigate the impact of disruption and currency risks necessitates further analysis and investigation. More research attention could be devoted to global firms' risk appetite and assessment, the drivers and conditions of integrated operations-finance in currency risk management, case study of best practices examining the success factors and effectiveness of currency risk management, a comprehensive implementation plan for currency risk management tailored to specific settings, e.g., industry-specific currency hedging strategies in COVID-19 pandemic.

4. Commodity risk management

Commodities represent a large building block of global economy (Martínez-de-Albéniz & Vendrell, 2017). In general, commodities can be divided into three major categories: agriculture commodities, energy commodities, and metal-based commodities. Specifically, agriculture commodities include food crops such as corn, rice, wheat, soybeans, sugar, cocoa and coffee, livestock such as cattle, hogs and pork bellies, and industrial crops such as lumber, cotton, rubber and wool. Energy commodities incorporate petroleum products such as crude oil and gasoline, natural gas, heating oil, coal, ethanol (used as a gasoline additive) as well as electricity. While metal-based commodities include mined precious metals such as gold, copper, silver and platinum, and base metals such as aluminum, nickel, steel, iron ore, tin and zinc. Besides, intermediary or manufactured products such as chemicals or generic drugs (Martínez-de-Albéniz & Vendrell, 2017) and products such as carbon emissions, renewable energy certificates and white certificates could also be commodities. Typically, commodities are traded in very active markets, such as Chicago Board of Trade (CBOT), New York Mercantile Exchange (NYMEX), or London Metal Exchange (LME), to cite a few (Martínez-de-Albéniz & Vendrell, 2017).

As the most salient feature of commodities, price volatility has a multifold impact on commodity operations. From the perspective of commodity buyers, price fluctuation would directly influence the procurement costs, and thus creates uncertainty in margins. It might further affect the demand when pricing is cost-sensitive and demand is price-sensitive (Goel & Tanrisever, 2017). For commodity sellers, price fluctuation is likewise a great risk with regard to its potential impact on demand. For intermediary commodity traders, the impact can be more severe since both input costs and output prices are uncertain. Hence, commodity price fluctuations create great challenges in making operational decisions for all the parties involved; and moreover, if handled improperly, they might even cause significant negative cash flows and expose firms to financial distress (Devalkar et al., 2017).

Commodity operations naturally involve financial considerations in integrated risk management. To start with, financial hedging can play a pivotal role in mitigating commodity price risk, smoothening the distribution of cash flows across periods, and helping the firm avoid significant negative cash flows and costs via financial derivatives on commodity prices (Kouvelis et al., 2013; Turcic et al., 2015; Devalkar et al., 2017). These hedging strategies typically do not affect the day-to-day procurement of raw materials, which must take the current price as well as its expected evolution into account. Hence, an optimal procurement strategy could be derived

by combining traditional inventory theory with financial price modeling (Berling & Martínez-de Albéniz, 2011; Berling & Xie, 2014). Second, operational strategies such as forward contracting is frequently adopted by firms to mitigate price variation in spot market (Anderson & Philpott, 2019); while the existence of spot market offers certain flexibility in procurement (Kleindorfer & Wu, 2003; Inderfurth et al., 2018). Meanwhile, futures contracts can provide important price information not available for conventional goods (Goel & Gutierrez, 2011). Furthermore, in addition to price risk, commodity processors face demand risk (Goel & Tanrisever, 2017), and operational constraints such as limited procurement, storage and processing capacities (Devalkar et al., 2017). Since price and demand for various commodities are typically correlated and storage capacity and inventory decisions are crucial in matching a commodity's supply with its demand, this could result in an interaction between hedging and operating policies (Goel & Tanrisever, 2017). Besides, for commodities (e.g., agricultural goods) whose local spot prices might be affected by both firm-specific local market specific factors such as quality, timing, and location of production (Devalkar et al., 2017) and other market factors, financial hedging alone may reduce, yet not eliminate, the risk. The above practices advocate research on the integrated optimization of financial hedging with operational decisions to mitigate commodity price risks, as detailed in the following subsections by various types of commodities.

4.1. Agricultural commodities

Processors in agricultural sector face potential challenges inherent from unique characteristics. First, there is typically uncertainty in production yield and quality due to weather, floods, drought and a number of hazards, as well as storage, handling, and processing parameters, which production managers must deal with to ensure a regular flow of output products. Second, the input and output spot prices are closely linked and exhibit considerable variability. Third, unlike manufacturing products, agricultural products such as olives are typically perishable and therefore producers cannot carry inventory from one selling season to another. Hence, the research on agricultural commodities typically address a single-period model (Kazaz, 2004). Moreover, while airlines, for example, are able to hedge against the risk of fluctuating fuel prices by investing in call options, such hedging instruments are far less prevalent for agricultural commodities, due to the limited liquidity of the option markets (Federgruen et al., 2017). As a result, there is limited research on financial hedging in this field, except for cases where soybean and corn are involved.

Primarily, there are four methods agricultural firms can adopt to manage the uncertainty in purchasing cost and supply quantity. First, forward market (typically called contract farming in agricultural industry) is frequently used by buyers and sellers to lock the price for a fixed amount of products that will be delivered in the future (Boyabatlı et al., 2011). Depending on terms and conditions, there are different types of forward contracts, e.g., fixed price contract and a contract with a specified pricing formula. Second, firms can mitigate supply uncertainty by trading the agricultural commodity in the spot market after yield uncertainty is realized. As both forward contracting and spot market transaction can be utilized for sourcing, it is thus important to optimize decisions when choosing between them or combining both (Inderfurth et al., 2018). Besides, leasing farm space to grow crops or fruits in anticipation of reducing the future purchasing costs is another strategy specific in agricultural sector. Compared with purchasing cost under supply uncertainty, the expected cost of growing by the firm is typically

less expensive due to factors such as scale economy. Finally, firms can counter the supply and price uncertainty by changing the price of the final product in response to the realized yield (Kazaz & Webster, 2015).

Research in this substream could adopt multiple methods simultaneously, while production decisions and the unique characteristics of agricultural commodities are taken into consideration. For instance, Kazaz (2004) studies the leasing, spot market purchasing and production planning under yield and demand uncertainty in the olive oil industry and further investigates the value of leasing and having a second chance to obtain olives in the spot market. Boyabatlı et al. (2011) analyzes the optimal procurement, processing, and production decisions of a meat-packer in a beef supply chain, where the packer can source fed cattle from both a contract market and a spot market and then produce two substitutable beef products. It is demonstrated the value of using a window contract instead of a fixed forward contract, and the value of long-term contracting as a complement to spot sourcing. In addition to leasing and trading in the open market that are explored in Kazaz (2004), Kazaz & Webster (2011) study the pricing strategy for a firm that operates under supply uncertainty from both a risk-neutral and a risk-averse perspective. It is found that pricing is effective only when the firm is not trading in the market, and in the meantime, although the risk-neutral firm does not benefit from fruit futures, a sufficiently risk-averse firm can under yield-dependent trading costs. Moreover, Kazaz & Webster (2015) further investigate a generalized price-setting newsvendor problem where the firm cannot trade after the yield uncertainty is realized, and reveal that, besides risk aversion, the source of uncertainty—demand and/or supply—are quite important in making the quantity and price decisions.

Analogously, for agricultural-related firms whose output product is subject to commodity price uncertainty, risk management is crucial. As frequently adopted in practice, a good portion of research considers advance selling/forward contract. For example, Devalkar et al. (2011) consider the integrated optimization problem of procurement, processing, and trade of commodities for a firm that procures input commodity, e.g., soybeans from the spot market, and then sells the processed commodity by using forward contracts (with the forward prices being equal to the futures prices) and trades the input at the end of the horizon, under the constraints of storage and operational capacity. They find that the optimal procurement and processing decisions are governed by price-dependent inventory thresholds, and it is optimal for the firm to postpone the output trade to the last possible period. Furthermore, Devalkar et al. (2017) incorporate financial distress costs and partially complete market where there are firm-specific factors that affect the spot price of the input commodity and the firm's objective is to maximize the market-based value of cash flows. It is shown that the firm's risk management objective has a significant impact on the parameters of the optimal policy; and in the meantime, financial hedging can provide significant benefit. Moreover, Goel & Tanrisever (2017) examine the optimal procurement (inventory) and hedging policies for a firm who procures an input commodity, i.e., corn, from the spot market to produce an output commodity, i.e., ethanol, to sell to the end retailer, through either a spot, forward, or an index-based contract (the price and volume of the commodities is determined as a function of spot and futures prices, thus is different from that in Devalkar et al. (2011) and Devalkar et al. (2017)), when input price, output price, and demand are correlated and the yield is uncertain. In particular, they demonstrate that selling through an index price, i.e., partial hedging, is optimal. Besides, Shao & Wu (2018) further take competition into account and study the effects of yield risk and yield correlation on firm's

selling strategies, spot price volatility, and profit, as well as the role of the forward market in the equilibrium outcomes, and reveals that firms tend to allocate more sales via forward contracts as the correlation increases.

By incorporating the unique characteristics of agricultural commodities and examining several operational decisions, these papers underline the significant benefit of coupling input through sourcing decisions and output risk management via pricing, production, and product substitution decisions (Boyabatlı et al., 2011) and the importance of understanding the relationship between procurement, processing, and trade decisions for multiple commodities as well as coordinating decisions across commodities and periods (Devalkar et al., 2011). Kazaz & Webster (2011) show that incorporating the yield-dependent cost structure into the problem has a profound impact on the optimal amount of the initial investment in the farm space and on expected profit as well as the value of fruit futures. The correlation between input and output prices provides a natural hedge, resulting in a decrease in reliance on financial hedging in contrast to the classic economics literature optimizing only the output end of the supply chain and concluding the optimal hedge ratio is one in the absence of yield uncertainty (Goel & Tanrisever, 2017). Therefore, firms should understand the dynamics between input and output prices across the supply chain when developing hedging policies (Goel & Tanrisever, 2017). Besides, by obtaining advanced demand information through the forward sale, firms can have a better operational planning by reducing holding and backlog costs (Goel & Tanrisever, 2017).

4.2. Energy commodities

Energy commodities can be divided into two categories: renewable energy that can be easily replenished, and non-renewable energy that can't be reproduced. Almost 90% of the energy consumed worldwide derives from five non-renewable sources: petroleum products, hydrocarbon gas liquids, natural gas, coal, and nuclear energy. The five main renewable energy sources are: solar, geothermal, wind, biomass, hydropower, which account for the remaining 10% of overall energy consumption. Since the most developed commodity trading markets are in non-renewable energy resources, with the exception of ethanol and some electricity generation, we next review the papers on non-renewable energy commodities and then present those on electricity.

Different from agriculture commodities, most of the energy commodities are storable; thus firms have the option to purchase and inject, store, and withdraw and sell commodities during a predetermined finite time horizon (Nadarajah et al., 2015). In the meantime, the financial market for energy commodities is quite mature. Hence, most of the problems on energy commodities are studied in a multi-period time setting considering the significance of intertemporal linkages, and financial hedging is of great importance.

Typically, the value chain for energy commodities entails physical conversions through refineries, storage facilities, transportation and other capital-intensive infrastructures (Secomandi et al., 2014). There are many types of operating flexibility embedded in contracts, e.g., "swing" or "take-or-pay" options in natural gas and electricity markets , which permit the option holder to repeatedly exercise the right to receive greater or smaller amounts of energy, subject to daily as well as periodic constraints (Jaillet et al., 2004; Sripad K. Devalkar, 2011). Meanwhile, pipeline capacity contracts give merchants the option to ship natural gas contingent on price realization at the two ends of the pipeline (Secomandi, 2010a).

An important issue that has received significant attention within the energy trading community is the valuation of these options/contracts. For example, Jaillet et al. (2004) present and test a general valuation (or pricing) framework for swing options; Secomandi (2010a) study the value of pipeline capacity by using location spread options in the natural gas industry. Besides, great research attention has been devoted to the valuation of storage assets (Secomandi, 2010b; Lai et al., 2010; Nadarajah et al., 2015). However, compared with the valuation of financial options, valuing such an option is difficult since it requires dynamic optimization of inventory trading decisions with capacity constraints in the face of uncertain energy commodity price dynamics to achieve the maximum time market value (Lai et al., 2010; Secomandi et al., 2014). Hence, research in this field typically focus on the determination of trading policy, which nevertheless generally gives rise to intractable Markov decision processes (MDPs) owing to the need to include the high dimensional exogenous commodity forward curve information (Secomandi, 2015; Nadarajah et al., 2015).

Since approximations are typically adopted to heuristically solve such MDPs (Nadarajah et al., 2015), there are numerous papers on the development of heuristics and further improve their performances. For instance, Secomandi (2010b) finds that a reoptimized deterministic model can perform well for natural gas storage valuation, but restricts to a one-factor mean-reverting spot price model. Using a multifactor forward curve model, Lai et al. (2010) develop a novel and tractable approximate dynamic programming (ADP) method that, coupled with Monte Carlo simulation, computes lower and upper bounds on the value of storage to benchmark a set of heuristics used by practitioners. They show that these heuristics are not only very fast to compute but also are significantly suboptimal compared to the upper and lower bounds. Nadarajah et al. (2015) further develop a novel ADP approach to derive approximate linear programming (ALP) relaxations for the real option management of commodity storage. By applying to existing natural gas storage instances, it is demonstrated that the ALP relaxations significantly outperform their corresponding approximate linear programs, with the best ALP relaxation matching or improving on the best lower and upper bounds available in the literature for these instances. In line with Lai et al. (2010), Secomandi (2015) provide additional theoretical basis for the observed benefit of reoptimization with various heuristics such as rolling intrinsic (RI, based on the sequential reoptimization) policy and rolling basket of spread options (RSO, based on a deterministic dynamic program) policies that are used to value leasing contracts on storage facilities, and offer additional numerical evidence for the near optimal performance of the RI and RSO policies in several practical cases. Different from Lai et al. (2010) and Nadarajah et al. (2015) in which dual penalties are obtained from the value functions of approximate dynamic programs (ADPs) and thereby necessitates solving auxiliary ADPs, the estimation of dual penalties are obtained from the optimal value function of a simplified version of the problem, i.e., when there are no frictions. It is shown that the RI policy significantly outperforms the RSO policy in some cases. These results are important to energy commodity traders because they provide scientific validation, support, and guidance for the use of heuristic valuation models in practice and therefore support the trading activity (Lai et al., 2010; Secomandi, 2015).

Overall, by investigating the valuation of these options, these papers suggest how the merchant's operational and trading decisions are linked and the significant value in adapting the trading policy to the stochastic price evolution. For example, Secomandi (2010b) reveal that the optimal inventory trading policy at each decision time depends on both the realized spot price

and inventory available for a price-taking commodity merchant facing both space and capacity limits. A computational analysis based on natural gas data further shows that mismanaging the interplay of the operational and trading decisions can yield significant value losses. Moreover, when the firm has market power, i.e., when the trading decisions may have an impact on future prices, Martínez-de-Albéniz & Vendrell (2017) find that the optimal trading policy is similar to the classical case without market power by taking kerosene as an example. In addition, by studying the optimal multiechelon procurement and distribution policies for a firm in the gasoline supply chain, Goel & Gutierrez (2011) indicate that the presence of the commodity market may lead to significant reductions in inventory-related costs; therefore, it is important to incorporate the spot procurement flexibility and price information available on commodity markets in designing operating policies.

Besides, for most nonrenewable energy commodities, refining is indispensable in the supply chain to transforms inputs with a wide range of quality characteristics into refined derivative products of precise specifications for feedstocks(Dong et al., 2014). Refineries vary greatly in input and capacity efficiency (Plambeck & Taylor, 2013); in their abilities to convert heavy fractions to light fractions, i.e., conversion flexibility; and in the range of raw materials they are capable of processing, i.e., range flexibility (Dong et al., 2014). Since commodity industries such as petroleum oil refining face tremendous price uncertainties in both input and output markets, the ability to maximally utilize the process flexibility of refining facilities and to make prudent procurement decisions thereby is of critical importance for refiners' survival and profitability in volatile marketplaces (Dong et al., 2014). In particular, Plambeck & Taylor (2013) show that variability in the market prices for a manufacturer's input and output has substantial implications for whether the manufacturer should focus on improving input efficiency or capacity efficiency. Furthermore, Dong et al. (2014) consider the value drivers of conversion flexibility for a refinery who purchases inputs from a spot market and sells outputs to a spot market.

In addition, there is one research substream on how to mitigate the risk of volatile energy commodity prices by employing financial hedging strategy. For instance, Connors et al. (2011) investigate the optimal static fuel surcharge financial hedging strategy and the potential benefit for a manufacturer shipping finished goods at different locations world-wide when faced with both uncertain total transportation volumes and fuel prices as well as budget constraint. However, when markets are incomplete, eliminating such risk is impossible. Quadratic hedging, which is based on forming a self financing approximate replicating portfolio that is dynamically adjusted to minimize the expected quadratic hedging error, is an attractive approach in this case. Interested readers can refer to Secomandi et al. (2019) for a more detailed formulation and derivation of quadratic hedging in incomplete markets.

Moreover, electricity and other types of environmental friendly energy can be crucial with the increasing concern of sustainability. In addition to net metering and peak pricing policies, governments have provided various direct (e.g., tax credit) and indirect subsidies (e.g., carbon tax) to increase renewable energy investments (Kök et al., 2016). Correspondingly, different from the papers on conventional energy commodities reviewed above, the research in this field is mostly on the impact of pricing and subsidy policies on investment, production decisions and carbon emission as well. For example, Murphy & Smeers (2010) examine the impact of long-term forward contracts on investments in an electricity market subject to market power, and find that it depends on whether the demand is known at the time the investment and forward positions are

taken. Alizamir et al. (2016) study the dynamic control of remuneration rates (prices) of feed-in tariff policies, and demonstrate that the current practice of maintaining constant profitability is theoretically rarely optimal, which is quite interesting. Kök et al. (2016) investigate the impact of pricing policies (either flat or peak pricing) on the capacity investment levels and carbon emission, and reveals that the same pricing policy may lead to distinct outcomes for different renewable energy sources (renewable and conventional) due to their generation patterns. Meanwhile, both direct and indirect subsidies can lead to a lower emission level, yet indirect subsidies may result in lower renewable energy investments. Besides, Zhou et al. (2016) and Zhou et al. (2019) explore the impact of negative prices. In particular, Zhou et al. (2016) show that the impact of the presence of negative prices on the storage policy structure depends on whether it is fast or more typical slow grid-level electricity storage; and moreover, ignoring negative prices could result in a considerable loss of value when negative prices occur more than 5% of the time. Zhou et al. (2019) further examine the effect of such negative prices on the value added by and environmental benefit of storage in a wind-energy-production system. Moreover, Sunar & Birge (2018) study how each renewable firm commits and sets its production strategy when there are multiple competing renewable firms and inflexible conventional firms. It is shown that in equilibrium, imposing or increasing a market-based undersupply penalty rate in a period can result in a strictly larger renewable energy commitment at all prices in the associated day-ahead market. The above research demonstrates that increasing renewable energy investments and further reducing carbon emissions require careful attention to the pricing policy and market characteristics. In addition, Anderson & Philpott (2019) consider how a buyer and a seller of a commodity can agree on a forward contract, either through direct negotiation or through a nonstrategic broker, and further the difference between these two mechanisms when both have private information on the future spot price.

4.3. Metal-based commodities

Metals paly important roles in various industries inlcuding power, construction, and manufacturing sectors. For instance, they are important components in battery production and even play a vital role in the creation of nuclear energy. Besides, coins and bars made out of precious metals are collected by investors as an investment vehicle. Price volatility is the most prevalent economic risk faced by both precious metal miners and firms involved with base metals such as steel. Similar to energy commodities, financial hedging is frequently adopted to manage price risk. Different from other commodities, there are typically various grades for the same metal, which adds both complexity and flexibility to operations management. For instance, gold miners can manage risk financially by committing to sell gold through forward contracts and options, and operationally by varying the grade of gold they process. Markou et al. (2017) thus empirically explore how these two risk management strategies affect inventory operations. It is found that gold commitments and variable grading have clear effects on gold inventory, and moreover, they could be viewed as complementary risk management strategies: the operational side of the strategy allows firms to remain profitable, and the financial side counteracts the unfavorable increase in inventory.

Integrated risk management for steel by incorporating both operational and financial hedging has likewise been explored. For instance, Kouvelis et al. (2013) study how to manage commodity risks (price and consumption volume) via physical inventory and financial hedge in a multiperiod

problem (with an interperiod utility function) for a risk-averse firm procuring a storable commodity, such as steel, from both a spot market and a long-term supplier. It is found that, as long as futures are used in each period, alone or not, the optimal inventory policy is myopic; however, the optimal hedging policy, is never myopic, yet depends on future optimal decisions. Turcic et al. (2015) examine the merits of hedging stochastic input costs by considering a generalized version of newsvendor model in which both the upstream and the downstream firms face stochastic input (e.g., steel) costs. It is shown that if left unmanaged, the stochastic costs could reverberate through the supply chain; and moreover, the equilibrium hedging policy will in general be a partial hedging policy. Kouvelis et al. (2018b) further explore both stochastic costs and working capital constraints. In the presence of capital constraints, it is demonstrated that besides index prices and index penalties that has to be pegged to the prices commodities that the supply chain members purchase for production in the absence of capital constraints, the terms of the coordinating contract must include capital commitments, which would be challenging to implement in practice.

4.4. General industrial commodities

Provided the absence of financial derivative markets for industrial commodities, financial hedging is thus infeasible and the only alternative is to focus on operational risk management. This means that, for firms dealing with industrial commodities, they can on the one hand mitigate the risk by considering procurement and selling both in spot market and by using option/forward contracts, just like that for the firms dealing with agricultural commodities; and on the other hand, they should not simply maximize expected profits, but instead sign contracts taking risk into account. For instance, as for the former, Martínez-de Albéniz & Simchi-Levi (2005) develop a general framework for the design of effective portfolio contracts and replenishment policy so as to maximize the buyer's expected profit when there are both inventory and price risks. It is demonstrated that portfolio contracts not only increase the expected profit, but also reduce financial risk. Martínez-de Albéniz & Simchi-Levi (2006) further take the risk into account, which is measured by the variance of profit and is considered together with expected profit. This thus extends portfolio analysis to the area of operations management. Besides, Mendelson & Tunca (2007) explore how the procurement of industrial commodities is allocated between spot trading and the fixed-price market that precedes it, when there is a single supplier and multiple manufacturers and more importantly, all of them have private information. It is found that although strategic spot trading improves supply chain profits and consumer surplus, it cannot eliminate fixed-price contracts entirely. This is because depending on the information structure of the supply chain, spot trading may make either the supplier or the manufacturers worse off. Similarly, Pei et al. (2011) analyze the structure and pricing of option contracts for an industrial good in the presence of spot trading and asymmetric information about the buyer's valuation premium for the supplier's product. In addition, Popescu & Seshadri (2013) examine how different characteristics of product demand and market affect the relative sales volume in the forward and spot markets for a commodity such as flash memory. Once again, it is demonstrated that a combination of factors will determine whether a commodity will be sold mainly through forward contracts or in the spot market.

4.5. Future research directions

Derivative markets for commodities enable financial hedging, bring liquidity to the markets, and thereby mitigate price volatility. First of all, the research on commodity risk management with financial derivatives is still limited, especially in the agricultural sector. Second, while futures prices historically have served as benchmark prices for forward contracting in research and practice, the futures contract price might fail to converge with the cash price towards the expiration date of the futures contract (nearby futures price) according to the U.S. Institute for Agriculture & Trade Policy (Suppan, 2019a). Hence, how to manage these risks in an inefficient derivative market is a challenging issue worth more investigation. Third, while excessive speculation and extreme price volatility have undermined the ability of processors and producers to manage their price risks (Suppan, 2019a), most papers suggest that the fundamentals of demand and supply are the dominant drivers of commodities prices. It is shown that excessive speculation and extreme price volatility can be attributed to the absence of well-calibrated and enforced position limits. Therefore, more research is needed in order to assess the true impact of speculation and position limits on the trading of commodity contracts by financial entities.

In the meantime, more operational strategies could be introduced to manage the commodity price fluctuations, e.g., Park et al. (2016b) study the value of inventory sharing between two firms in the presence of spot and forward markets in a multi-period setting, where the two firms process a common commodity to meet stochastic demands. While inventory sharing is more frequently adopted in retailing sector, it has received relatively less attention in commodity operations. Hence, another future research direction could be the effectiveness of inventory sharing in mitigating the commodity price risk and further introducing other innovative risk management strategies. This is of great importance in the context of the current economic downturn where cooperation is almost a necessity for firms to survive (Frangoul, 2020).

Furthermore, most of the aforementioned papers assume that capacity levels for processing and storage resources are given exogenously. The uncertainty in spot prices and production yield may affect capacity investment decisions because the profits from processing depend on the yield and price. For instance, Boyabatlı et al. (2017) examine the optimal processing and output storage capacity investment decisions—in addition to the periodic processing and inventory decisions—of a processor that uses a commodity input to produce both a commodity output and a by-product in the context of palm industry, where the input and output spot prices are correlated and the production yield is uncertain. In the meantime, insufficient capacity and infrastructure could have an impact on the futures price and spot market price of a commodity as well as the operations. For instance, the scarcity of available pipeline and storage has worsened the situation of the oil market during the outbreak of coronavirus (Clifford, 2020; Lahiff, 2020; Stevens, 2020). Moreover, since the derivative markets for commodity products could encourage long-term investment in capacity, infrastructure and technology, it would be interesting to incorporate financial hedging.

Besides, the shocks of one firm in global supply chains can be easily transmitted to its suppliers and customers through operational decisions such as transfer prices and order quantities, which might lead to significant financial losses, and even a supply chain disruption (Turcic et al., 2015). Moreover, the operational and financial interdependencies between supply chain members could ease the transmission of risks along the chain. Thus, each firm must consider not only its own direct risk exposures, but also the cash-flow risks of its supply chain partners and

how their strategic interactions through operational decisions, which might create indirect risks for the firm's cash flows, as well as the other parties' hedging strategy. For example, Kouvelis et al. (2018a) and Kouvelis et al. (2019) examine how cash-flow risks and supply chain characteristics such as market size, cash-flow volatility, and correlation affect firms' hedging decisions via vertical interaction (i.e., its supply chain partners' decision). Hence, more research can be conducted along this line, i.e., both empirically and analytically studying the operational and financial decisions of a firm dealing with commodities from a supply chain perspective by taking its partners' price risk and decisions into account.

Moreover, the strong linkages among various commodity markets could attract more research attention. On the one hand, agricultural commodities could serve as both a source of food and an industrial ingredient. For instance, both humans and animals consume corn, yet the commodity is an important ingredient in fuel production such as ethanol; humans eat the beef of cows, while a variety of industries use beef hide, fats and bones to create products. On the other hand, there is typically an economic link between oil prices and agricultural and industrial commodity prices. For example, lower energy prices could help farmers on the input expenses side of the balance sheet. Meanwhile, falling ethanol demand could hurt corn usage, and lower energy prices could lead to a lower production cost. Therefore, spikes in one commodity market could inevitably trigger subsequent "spill-over" changes in other commodity markets. Investigating how these correlations across different commodity markets affect firms' operational and financial decisions in risk management could be another important research direction.

In addition, most of the aforementioned papers (except Kouvelis et al. (2018b)) assume that commodity firms have sufficient capital. In reality, however, farmers in U.S. have been managing low incomes, rising costs, increasing debt and bankruptcy, volatile export markets and a series of extreme weather events tied to climate change (Lilliston, 2020). In the meantime, many U.S. oil companies are already paring back spending and closing wells (Domm, 2020b). It is shown that probably 25 or 30% of the U.S. shale firms are going to be restructured or go bankrupt in the next 9 to 12 months (Domm, 2020a). Besides, the trade war between U.S. and China, and the COVID-19 are imposing new disruptive challenges for firms dealing with commodities. On the one hand, these global events have introduced greater price volatility in the commodity markets as traders built positions on growing concerns, e.g., the plunge of crude oil price during the COVID-19 crisis (Garber, 2020; Lahiff, 2020; Clifford, 2020). On the other hand, supply chain disruption results in far less revenue than before yet with the same expenditures or more to alter operations strategy. Hence, it would be of great importance to study the impact of financial constraints on commodity risk management and the effectiveness of financing mechanisms.

4.5.1. Agricultural commodities

Analogous to that for energy commodities, conversion is an important form of operational flexibility in agricultural oil refining, such as the oil extracted from soybeans, sunflower, canola, and safflower seeds. Although great similarity exists between the oil refining processes in these two sectors, the agribusiness has limited, often illiquid spot markets for the end products, and refineries face different challenges (Dong et al., 2014). Therefore, investigating operational flexibility strategies in dealing with these challenges can be a fruitful direction for future research.

Second, many countries have set a number of policies to support their agricultural sectors. For instance, United States Department of Agriculture (USDA) has provided an unprecedented

$26 billion trade aid to farmers through the Commodity Credit Corporation (CCC) prior to the COVID-19 outbreak. Family farm groups and Institute for Agriculture & Trade Policy (IATP) have adopted a different approach to aid including measures that help farmers to manage debt, facilitate access to credit and create a distinct program for farmers selling in local markets (Lilliston, 2020). Besides, apart from the current system of subsidies and massive trade aid payments, a set of policies known as "supply management" is starting to gain attention, under which the government could directly manage agricultural supply through a variety of measures (Holmberg, 2019). These initiatives—setting marginal farmland aside, storing grain as reserves, implementing price floors and ceilings, and controlling the volume of imports—could work together to ensure a fair price for farmers that covers their costs. Hence, it would be meaningful to study how these subsidies and trade aid payments as well as the supply management measures can benefit the producers and further revamp the operations of the agricultural commodity related firms, especially with the advent of the new coronavirus.

4.5.2. Energy commodities

Most above papers on valuation for energy commodities are conducted from the asset value maximization perspective. For firms that can adapt production, suspension, and in particular shutdown decisions over time to the evolution of uncertain market factors, this asset value perspective is obviously not appropriate despite its popularity. Because the cost of a permanent plant shutdown is hard to assess as it may impact societal entities outside the specific plant being shut down, which could include the parent company owning the plant and the local community (Trivella et al., 2017). Therefore, societal impact has to be considered when managing the permanent shutdown decisions in merchant commodity and energy production assets and calculating the value. More research could be conducted on production suspension that is frequently used in the energy industry, e.g., in response to changes of energy prices or government policy (Seay, 2012; Plambeck & Taylor, 2013).

In addition, how to achieve the goal of a low-carbon energy future is one fundamental issue. Environmental friendly and renewable energies only account for a small portion of the overall energy consumption and there are still many challenges ahead. For instance, as a clean and energy-efficient fuel, hydrogen has to be generated from compounds, e.g., natural gas. The cost could be expensive if cleaner sources like biomass are used. Meanwhile, a tax on greenhouse gas emissions (or any other policy that increases the cost of fossil fuels) could backfire by reducing investment in improving energy efficiency in manufacturing (Plambeck & Taylor, 2013). Consequently, even as fossil fuel companies claim to be pivoting toward clean energy, they are planning to invest trillions of dollars in new oil and gas projects that are inconsistent with global commitments to limit climate change (Reich, 2020). Therefore, another important future research direction could be studying how to incentivize the energy related firms to turn to renewable energy considering the environmental impact.

4.5.3. Metal-based commodities

Analogously, the mining industry faces intense global scrutiny for the environmental footprint. For example, crackdowns on environmental pollution have caused the shutdowns of more than half of the lead and zinc mines in China. While the mining sector starts to adopt cleaner ways of doing business, restrictions on mining activity might limit supplies and raise prices. In

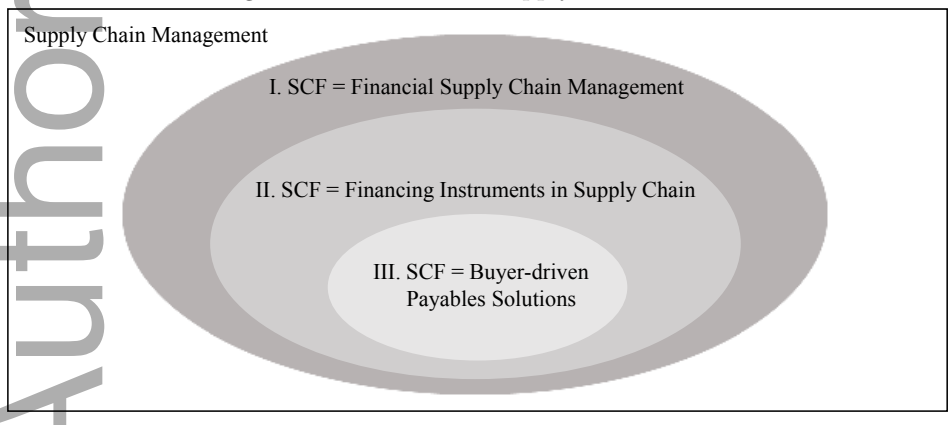
the meantime, the BRICs countries have great impact on metals markets and pricing, which depends critically on the government's fiscal and monetary policy. In general, stimulating measures can stoke demand for metals, while tighter monetary policies can depress demand. Besides, one U.S. trade policy expression of discontent toward China are tariffs on steel and aluminum imports (Suppan, 2019b). Most steel and metal commodities have been affected by the escalating coronavirus crisis. Therefore, there are many important factors besides price volatility deserve further investigation for the operational and financial decisions of metal commodity-related firms.

5. Supply chain finance

5.1. Foundational research on supply chain finance

Supply chain finance jointly optimizes operations and finance under capital constraint in various supply chain settings. There are typically three scopes of SCF (Liebl et al., 2016; Templar et al., 2016), as shown in Figure 1. First, supply chain finance generally denotes the management of monetary flows or financial processes in supply chains, which is also referred to as financial supply chain management, i.e., "optimized planning, managing, and controlling of supply chain cash flows to facilitate efficient supply chain material flows" (Wuttke et al. 2013a). Second, SCF can be viewed as the application of financing schemes to enhance the efficiency of monetary flows in supply chain, i.e., "the inter-firm optimization of financing as well as the integration of financing processes with customers, suppliers, and service providers in order to increase the value of all participating firms" (Pfohl & Gomm, 2009). Third, SCF may merely refer to supplier financing as a buyer-driven payables solution, i.e., reverse factoring, where "the lender purchases accounts receivables (of suppliers)... from specific informationally transparent, high-quality buyers." (Klapper, 2006). In this paper, we adopt the first approach to view SCF in a broader scope.

Figure 1 Definitions of supply chain finance



The investigation of SCF begun with the explorations on its drivers, major benefits, potential resistance, adoption process, and overall effects on supplier-buyer relationships. Supply chain finance programs are typically initiated by established buyers (or suppliers), financial institutions (banks), or specialized service providers (such as LSPs) to provide financial assistance for SME suppliers (or buyers) in need of working capital. Thus working capital positions in

the supply chain are the primary antecedents of SCF adoption and determine the types of SCF instruments used. In the meantime, supply chain finance typically establishes a conceptual foundation—based on principal-agent theory—while assuming that firms within and outside the supply chain have asymmetric information. Firms within the supply chain can serve as intermediaries to resolve the issue of asymmetric information between capital seekers and capital markets (Pfohl & Gomm, 2009). Hence, supply chain finance aims to enhance the allocation of working capital through cross-functional coordination of operational and financial departments and inter-organizational collaboration among supply chain partners (Hofmann, 2005; Pfohl & Gomm, 2009). The mechanism of a chosen SCF instrument determines timing of the trigger event, the duration and amount of funding, and the financing rate.

The major benefits of SCF programs rely on the reduction of financing costs for suppliers (due to the interest spread between SMEs and established firms) or for buyers (because of extended payment terms). For instance, the Swiss Post Group (the LSP) offers combined logistics and financial services as a supply chain intermediary in a pilot project with Procter & Gamble (P&G), under which Swiss Post Logistics can sell goods to retailers at standard prices determined by P&G's policies plus a logistics and finance fee (Hofmann, 2009), with the capital costs for the retailers being much lower than that they would incur individually. Meanwhile, these programs have the further advantage of strengthening supply chain relationships, increasing its members' negotiating power, and improving service. The dependence between supplier and buyer—and their respective bargaining power—are determined by the buyer's order quantity, the ordered product's strategic value, and the intensity of market competition. These factors affect, in turn, the product's purchase price (Liebl et al., 2016). The SCF solutions driven by incentives to improve the adopter's own financial performance are typically implemented based on bargaining power, and SCF practices driven by incentives to secure the entire supply chain through risk mitigation efforts depend on a high level of trade process digitalization (Caniato et al., 2016).

For both the anchor buyers and suppliers, the onboarding process of involved parties is ranked as the most important success factor of a SCF program (Herath, 2015). The main costs of establishing SCF programs are (i) management costs of inter-organizational supply chain collaboration and of intra-firm cross-functional coordination and (ii) investments in digital platforms for the trade process (Wandfluh et al., 2016). Therefore, the success of supply chain finance instruments depends crucially on the alignment of incentives in supply chain collaboration and cross-functional coordination (Blackman et al., 2013; Wuttke et al., 2013b; Wandfluh et al., 2016). Buyers can categorize suppliers based on their strategic importance and creditworthiness, bringing the most crucial ones onboard first and then gradually incorporating more suppliers into the system (Wuttke et al., 2013a). In the meantime, the SCF team needs to work closely with managers from the procurement, operations, IT, legal, treasury, and finance departments. Furthermore, the extent of digitalization plays a key role in providing the real-time transparency of supplier invoice processing and other functions. Ensuring that a corporation's enterprise resource planning (ERP) system is compatible with the SCF platform typically requires both managerial effort and technical modifications. Besides, data transmission in SCF transactions must comply with the involved countries' applicable electronic security laws.

5.2. Categories of supply chain finance

The extensive variety of supply chain finance solutions can be categorized from diverse perspectives, including timing of the trigger event, focal point of credit risk, availability of collateral, and financed elements in the balance sheet (Zhao & Huchzermeier, 2018b). Please refer to Camerinelli & Bryant (2014), BAFT et al. (2016) and Babich & Kouvelis (2017) for related principles of categorization. In this section, we classify SCF instruments into four categories with regard to the timing of trigger event. (1) Post-shipment finance establishes a line of credit from a financier for a borrower based on (typically, discounted) accounts receivable. The collateral in this case is the invoice, shipping document, or bill drawn on the buyer. As a consequence, the credit risk is relatively low and the financing rate is favorable. (2) In-transit finance provides the borrower with a loan from a financial institution, where the loan is based on product or inventory (of a certain quantity and quality) that is currently being transported or enmeshed in other logistics processes. The portable collateral of in-transit finance is the product deposit in shipment, so the associated credit risk is less than in the pre-shipment finance case; hence the loan's interest rate is accordingly somewhat lower. (3) Pre-shipment finance enables a supplier to receive funding from a financier—based on a buyer's purchase order—for working capital needs (e.g., the purchase of raw materials, inventory processing, personnel and management costs) before product delivery. Because the collateral for pre-shipment finance is a purchase order instead of an invoice, the credit risk is relatively high; hence the interest rate for advancing liquidity to the supplier is typically high, though it could be reduced in light of a well-established buyer's creditworthiness. An example application of this type of SCF is the launch of a new product; here the supplier needs capital for capacity investment in new production facilities requested by a reputable buyer, which (together with the bank) then initiates financing for the supplier. (4) Miscellaneous SCF instruments that span across various time periods thus can not be categorized into one of the three types above. (5) The interactions between general financing (i.e., without specific financing instrument) and sourcing decisions in supply chain settings, as defined in Section 5.1.

5.2.1. Post-shipment financing

As a major source of short-term financing, trade credit has attracted great research attention (Seifert et al., 2013; Paul & Boden, 2014). The frequently explored topics in this substream include: (1) the motives of the existence of trade credit, (2) the setting of the optimal credit terms, and (3) the impact of trade credit on operations (mainly on inventory decisions in a newsvendor setting) and the supply chain members' profit. For detailed elaborations of literature review on credit term decisions and settlement period decisions, especially for that under deterministic demand or within one single firm, please refer to Chang et al. (2008), Bougheas et al. (2009), Seifert et al. (2013), Luo & Shang (2014) and the references therein. In this subsection, we mainly focus on the first and third topics.

The motivations for firms to provide credit has been actively researched for more than 30 years (Seifert et al., 2013), which can be classified into financial and operational motives. With regard to the financial motives, firms offering trade credit could have advantages over their smaller and less financially secure customers, in either obtaining money (Schwartz, 1974) or credit evaluation and collection over other competing lenders (Mian & Smith Jr, 1992). Trade credit can be seen as a liquid reserve held by the firm to meet its cash requirements in future; and

meanwhile, the credit provider can earn an interest rate by assuming a financial intermediary's role (Emery, 1984). Furthermore, the firm can profit from the tax effect (Brick & Fung, 1984) and the pooling effect of liquidity shocks (Hu et al., 2018). From the perspective of operational motives, Ferris (1981) first derives a transactions theory of trade credit use by considering the trading partners' exchange cost every time the goods are delivered. Trade credit can be used as a operational response to deterministic variations in demand (Emery, 1987), or to price discriminate (Brennan et al., 1988; Petersen & Rajan, 1997). Moreover, trade credit can be seen as an efficient contractual device, such as in screening the buyer's default risk (Smith, 1987), signalling the product's quality (Lee & Stowe, 1993; Long et al., 1993; Emery & Nayar, 1998), and aggregating the supplier's information with the bank's (or investors') (Freixas, 1993; Biais & Gollier, 1997; Jain, 2001; Maksimovic & Frank, 2005; Chod et al., 2016). Besides, trade credit could be effective in avoiding the borrowers' opportunistic behavior (Burkart & Ellingsen, 2004), in improving vertical supply chain relationship and therefore benefit all firms (Fisman & Raturi, 2004; Cunat, 2006; Dass et al., 2014), or in softening price competition in a horizontal supply chain (Peura et al., 2017).

There is extensive research on how a firm should make order quantity decisions under trade credit and further the relative effectiveness between trade credit and bank finance under stochastic demand, when either the retailer (buyer) or both the retailer and the supplier (manufacturer) are capital constrained. The essential research questions are: (1) What interest rate the supplier should set when offering trade credit, and should the bank finance the retailer or the supplier when both of them are capital constrained? (2) For a capital-constrained retailer or buyer, how the order quantity has changed, and further which financing method the retailer should choose and what is the relationship between bank credit and trade credit?

To address these questions, the bank credit market is generally assumed to be competitive, i.e., the bank asks for an interest rate so that it is indifferent between issuing the loan to the retailer and earning a risk-free rate. In this case, it is shown that the optimal order quantity depends on the interest rate set by the supplier; yet in general, the retailer orders a larger quantity under trade credit compared to that without financing or in bank financing (see Zhou (2009); Yang & Birge (2011); Kouvelis & Zhao (2012); Jing et al. (2012)), to take the advantage of limited liability. Based on an empirical study, Wu et al. (2018a) find that although both trade credit and bank credit help with inventory investments, trade credit requires a higher cash level, while the bank credit serves as an insurance and can reduce a firm's cash reserve requirements.

Furthermore, the research indicates that trade credit is typically preferred if the supplier finances the retailer at rates less than or equal to the risk-free rate (Kouvelis & Zhao, 2012; Cai et al., 2014). Nevertheless, trade credit might be chosen even if the supplier is at a disadvantaged position (Yang & Birge, 2017). It is demonstrated that the specific answer to both questions, on the one hand depends on whether there is only a single credit channel or both credit channels are viable, and on the other hand, varies with a lot of factors. For instance, Jing et al. (2012) show that trade credit is always less attractive than bank credit financing when there is only a single credit channel, whereas bank credit might be more preferred when both credit channels are viable (see Cai et al. (2014); Yang & Birge (2011); Chod (2016); Kouvelis & Zhao (2017) for other related papers). Furthermore, the optimal trade credit policy and the equilibrium financing choice might depend on the retailer's net wealth or cash position (Zhou, 2009; Raghavan & Mishra, 2011; Cai et al., 2014; Yang & Birge, 2013, 2017; Rene Caldentey, 2011), the demand

risk (Yang & Birge, 2011; Kouvelis & Zhao, 2012; Jing et al., 2012), the priority rules among multiple creditors in a bankruptcy (Yang & Birge, 2011), the production cost (Jing et al., 2012), the relative competitiveness of trade credit and bank credit market (Cai et al., 2014; Chod, 2016), the magnitude of the risk shifting problem (Chod, 2016), the supplier's share of the retailer's expenditures (Chod et al., 2019a; Lee et al., 2017), and the supplier's credit rating (Kouvelis & Zhao, 2017) as well. Zhou (2009) and Dada & Hu (2008) consider the problem in a setting where the bank is profit-maximizing. Besides, when both the retailer and the supplier are capital constrained, Raghavan & Mishra (2011) suggest that a lender who finances the manufacturer has a motivation to finance the retailer as well; whereas Jing et al. (2012) argue that the bank should finance the manufacturer if production cost is low and finance the retailer otherwise. In the meantime, when both bank and trade credit are viable, there is a divergence regarding the relationship between these two types of credits. Cai et al. (2014) show that it rests with the retailer's internal capital, whereas Chod (2016) conclude that a combination of bank and supplier financing is always optimal since each has their own merits. In addition, Babich et al. (2012) suggest that internal financing and trade credit loans are substitutable.

Factoring is a form of debtor finance where a firm sells accounts receivable (i.e., invoices) to a third party (i.e., a factor) at a discount. Since the receivables are sold rather than pledged, traditional research mostly focuses on the impact of moral hazard—a factor cannot contract upon a seller's ex-post level of credit management—on factoring decision and at the same time supports the finding with empirical data (Sopranzetti, 1998), or studies how factoring can mitigate under-investment problem (Sopranzetti, 1999). Compared with factoring where suppliers typically have higher credit ratings, reverse factoring is a quite novel supply chain finance solution, which mainly enables SME suppliers to obtain financing at a more favorable interest rate. Thus, the research on reverse factoring, on the one hand, typically compares reverse financing with conventional sources of financing, such as bank financing (van der Vliet, 2015; Van der Vliet et al., 2015), or with other supply chain finance solutions, such as early payment financing (Chen et al., 2017), and addresses the question of what extensions of payment terms or underlying mechanisms allow the supplier to benefit from reverse factoring (Kouvelis & Xu, 2019, Tanrisever et al., 2020a). On the other hand, from the perspective of the buyer, whether a buyer can expect to be served better from offering cheaper financing to its supplier by means of reverse factoring, and further how much extra service the buyer can contractually agree with the supplier when the supplier serves demands of two buyers with a minimum fill rate constraint are investigated (van der Vliet et al., 2015; van der Vliet, 2015). More recently, to overcome the problem that the firm must sell the whole receivable when it chooses to sell it in reverse factoring, receivables pooling has emerged. For instance, van der Vliet (2015) study how pooling receivables with other firms can mitigate the inherent cost of indivisibility, and it interacts with pooling investment (cf. van der Vliet et al. (2017) for the latest version).

Although manufacturer/supplier guarantor financing has been adopted in practice for years, relatively less research attention has been devoted to this scheme. Zhou (2009) studies how a manufacturer teams up with a bank to offer an interest-free loan program to a financially constrained retailer to sell more products. Recently, Yan et al. (2016) focus on bank financing with a partial credit guarantee (PCG) provided by the upstream firms in a setting where the bank acts as a leader. It is shown that with a suitable guarantee coefficient, the proposed PCG contract may realize coordination, even super coordination, whereas the bank loans without

guarantee could not. In addition, Jin et al. (2018b) find that overall, collaborative strategies, i.e., bank financing with supplier's guarantee (BF-with-SG) and bank financing with trade credit (BF-with-TC), dominate non-collaborative strategy, i.e., bank financing separately (BFS), for the supplier and whole supply chain, whereas the reverse holds for the retailer. The entire supply chain could perform better if one partner borrows from bank and then shares credit with another than the case in which both partners borrow separately.

5.2.2. In-transit finance

Inventory pledge credit is provided by a financial institution to a borrower while using secured inventory as collateral. This financial instrument can be used to fulfill working capital needs for capacity expansion, equipment renewal, or material supply. When other types of firm assets are already leveraged, pledged inventory can serve as collateral to secure a loan. In the meantime, it is widely used to develop agricultural markets in countries such as in Latin America and in Asia (Coulter & Shepherd, 1995). Particularly, how to set the impawn rate is of great importance in inventory financing. For instance, by using the database of spot steel and dividing the impawn periods into different risk windows, He et al. (2012) demonstrate that the key to setting the impawn rate is to predict the long-term risk, and moreover the log-returns of inventory is autocorrelative.

In warehouse receipt finance, a financial institution provides loans to a supplier based on a warehouse receipt that certifies—as portable collateral—the secured storage of product in a specified quantity and quality. Here, the transfer of a warehouse receipt from supplier to financier conveys the right to withdraw a certain amount of the commodity, at any time, from the secured warehouse. The financier provides a loan up to an agreed percentage (the discounted value) of the stored product. Like inventory pledge credit, warehouse receipt finance is frequently used in the agribusiness sector to enhance the overall efficiency of markets when producers and commercial entities can convert inventories of agricultural raw materials or intermediary or finished products into a readily tradable device (Lacroix & Varangis, 1996; Mahanta, 2012). The key aspects of warehouse receipt finance are risk assessment, provisions for performance guarantees and the establishment of systems for warehouse inspection, and the financing ratio as well as funding structures (Mahanta, 2012; Jones, 2018). In addition, a recognized basis in law so that the ownership established by the receipt is not challenged is a precondition for the viability of warehouse receipt finance (Lacroix & Varangis, 1996).

5.2.3. Pre-shipment finance

Pre-shipment financing solutions aim to alleviate capital constraint of firms (mainly of the suppliers) prior to the shipment, which can be initiated either by suppliers or by buyers. Typically, buyers facilitate the financing provided the suppliers' financial constraint has an impact on the buyers' supply and thereby expected profit.

Buying firms could provide financial support directly to their suppliers by issuing both sourcing contracts and loan directly, which is called buyer direct financing (BDF). Deng et al. (2018) explore the efficacy of buyer finance in an assembly system with multiple suppliers by comparing buyer finance with bank finance, and further show that the assembler may charge an interest rate that is even below its unit capital opportunity cost in buyer finance, to reap the benefit from enhanced inventory backup and lower component purchasing prices. Besides, analogous

to manufacturer/supplier guarantor finance, buyer intermediated financing is another approach for buyers to mitigate their suppliers' cash flow risk by collaborating with banks. In particular, Tunca & Zhu (2017) reveal that buyer intermediated financing can significantly improve channel performance, and simultaneously benefit both supply chain participants by building a game-theoretical model and comparing buyer intermediated financing with commercial loan in a setting where the supplier's product might be defective.

Furthermore, to mitigate negative externalities resulting from supply chain partners' financial constraints, subsidizing scheme is frequently adopted (Daripa & Nilsen, 2005). As one of the pre-shipment finance instruments that gain the earliest research attention, most papers conclude that subsidizing can improve the performance of a supply chain in different settings. For instance, Nagarajan & Rajagopalan (2008) demonstrate that a simple holding cost subsidy based contract can improve the performance of vendor managed inventory system. Babich (2010) indicates that subsidies could have a significant value in mitigating supply risk using a dynamic, stochastic, periodic-review model. He shows that the optimal capacity orders do not depend on the subsidy decision under certain assumptions. Chen et al. (2016b) suggest that an inventory subsidizing scheme plays a key role in coordination in a decentralized supply chain. To secure production or distribution, firms might invest in the capital-constrained supply chain partner's operations as equity and later obtain a portion of dividends in return. In this aspect, Yan et al. (2018) show that the supplier can achieve the highest profit when offering a financing portfolio of the pure supplier finance (SF)/trade credit and pure supplier investment (SI). In addition, long-term contract is another strategy that is recently explored to help suppliers prone to default. By comparing with short term contract, Swinney & Netessine (2009) reveal that dynamic long-term contracts, where the contract price is partially tied to some index, allow the buyer to coordinate the supply chain in the presence of default risk.

Manufacturers (or suppliers) can collect partial payment from retailers (or buyers) in advance to cover the production cost, with the remaining payment being collected upon delivery of the product to the retailer (Chen et al., 2017). Early payment financing is typically related to preorder/advance selling and advanced payment (discount). Since there is no interest rate imposed on the payment and it is only part of the wholesale revenue to the manufacturer, early payment is not a loan. The research in this substream mainly focuses on the scheme design, effectiveness and impact of early payment financing on operational decisions. In particular, Lai et al. (2009) study preorder, consignment and the combination of these two modes. Chen et al. (2013) examine internal financing, delayed order payment and advanced payment. It is shown that the presence of financial constraint has a significant impact on the choice of different modes. Moreover, Chen et al. (2017) investigate the efficiency of early payment financing in a pull supply chain by comparing with bank financing and in-house factor financing, which indicates that the result depends on the manufacturer's production cost and initial capital, as well as the demand variability. Besides, Jin et al. (2018a) compare advance selling and delayed payment. It is demonstrated that advance selling strategy is preferable for the retailer when she is sufficiently capital-constrained or customers are relatively price sensitive; in contrast, delayed payment strategy is preferable for the supplier and the entire supply chain when the retailer is sufficiently capital-constrained.

Besides, purchase order financing (POF) is frequently employed to fund capital-constrained suppliers, which allows financial institutions to offer loans to SME suppliers by considering the

value of purchase orders issued by reputable buyers (Tang et al., 2017). POF has been studied in connection with other pre-shipment finance solutions. For instance, Tang et al. (2017) investigate the relative efficiency of the POF and BDF in a supply chain where a financially constrained supplier can exert unobservable effort to improve delivery reliability. It is demonstrated that the manufacturer's information advantage about the operational efficiency makes BDF the more preferred financing scheme than POF if the supplier is severely financially constrained. Analogously, Wu et al. (2014) consider buyer-backed purchase order financing (BPOF) in which a creditworthy manufacturer supports its unreliable SME supplier to make POF in line with a guarantee agreement. It indicates that BPOF significantly improves the core enterprise's profitability. Reindorp et al. (2018) address another new perspective in purchase order financing: the potential of purchase commitments for mitigating capital market frictions. Specifically, a commitment brings to potentially opposing effects for the retailer: the financing effect and the risk-sharing effect. In addition, Zhao & Huchzermeier (2018a) recently investigate both BPOF and advance payment discount (APD). They show that when either APD or BPOF can be chosen, the retailer prefers APD to BPOF if her internal asset level is above a certain threshold; yet when both APD and BPOF are available, the retailer prefers APD and does not initiate BPOF unless the marginal cost of financial distress dominates the benefit of unit discount.

5.2.4. Miscellaneous SCF instruments

There is extensive research on SCF schemes that features various timing of trigger event. To start with, leasing (including equipment leasing and leaseback) is another important source of financing when acquiring equipment. Equipment leasing could be provided by banks, captives and independent financial firms. Leaseback, short for "sale-and-leaseback", is typically a financial transaction in which a firm sells an asset and leases it back for the long term. In this substream, the first managerial question is the lease-versus-purchase decision (Smith & Stulz, 1985) and whether enter into a sale-and-leaseback agreement or not (Kim et al., 1978) given certain financial frictions and various incentives. For example, Eisfeldt & Rampini (2008) study the financing role of leasing and secured lending considering that repossession of a leased asset is easier than foreclosure on the collateral of a secured loan but leasing involves agency costs due to the separation of ownership and control. They find that firms that are more credit constrained tend to lease, while firms that are less constrained tend to buy the asset. Besides, leasing is a financial mechanism frequently adopted in agribusiness for processors without capital to buy land for a certain product or for farmers/landowners without capital to maintain the land appropriately. Hence, the optimal amount of leasing along with the use of spot markets in their production planning decisions has been examined from the perspective of (supply) risk mitigation. Interested readers can refer to Section 4.1 for a comprehensive review of the related research.

With an increasingly open global economy and advanced technologies, third-party and forth-party logistics providers (3PLs/4PLs) have emerged as finance providers in addition to their traditional roles. Compared with trade credit and bank financing modes, in 3PL financing service mode, a 3PL is able to take advantage of his position to coordinate material, financial, and information flows, and thus is convenient in supervising goods and reducing financing risk (Chen & Cai, 2011; Zhou et al., 2017; Huang et al., 2018; Chen et al., 2018). The operations management literature has not paid much attention to these roles of 3PLs with a few exceptions.

The earliest work on 3PL financing is Chen & Cai (2011), which indicate that 3PL financing might yield higher profits not only for a 3PL firm but also for the supplier, the retailers, and the entire supply chain. Huang et al. (2018) investigate a similar problem. Different from Chen & Cai (2011), it is the supplier rather than the retailer that pays for the transportation fee in Huang et al. (2018) and the impact of wholesale price contract on supply chain coordination is studied. Furthermore, Chen et al. (2018) and Zhou et al. (2017) incorporate the impact of the leadership. Specifically, Chen et al. (2018) show that the supply chain profit can be higher under leadership by the 3PL than by the manufacturer. Zhou et al. (2017) compare 3PL guarantor financing (LG) and manufacturer guarantor financing (MG) in a four party supply chain under different power structures (between the manufacturer and the 3PL). It concludes that when either the manufacturer or the 3PL is the Stackelberg leader, the entire supply chain can benefit from letting the Stackelberg follower be the guarantor, whereas the follower's preference of either MG or LG depends on the upstream firms' economies of scale in operational costs. Nevertheless, there is no difference between MG and LG for the retailer and the supply chain under the Nash game, in which case both upstream firms prefer the other to be the guarantor.

As one of the recently emerging SCF schemes, crowdfunding features an alternative fund-raising solution to support innovative ideas and entrepreneurial ventures, typically by raising small amounts of money from a large number of people via internet (Chakraborty & Swinney, 2019). Depending on the form of payment/reward to the investors, it generally can be classified into four types: donation-based, reward-based, equity-based, and debt-based. The strong growth in crowdfunding has sparkled research interest. In particular, Moritz & Block (2016), Short et al. (2017), and McKenny et al. (2017) provide excellent literature reviews of the current state of research in this area. Basically, the majority of the existing research focus on predicting crowdfunding campaign outcomes and on the optimal campaign design (Babich et al., 2018). Two exceptions are Babich et al. (2018) and Xu et al. (2018a), with both studying how crowdfunding interacts with more traditional financing sources in a supply chain. To be concrete, Babich et al. (2018) compare crowdfunding with venture capital (VC) and bank financing in a double-sided moral-hazard setting. Interestingly, it is shown that the economic value of crowdfunding might harm the entrepreneur and the VC since competition from other investors reduces value to VC investors and entrepreneurs could lose valuable operational expertise of VCs. Xu et al. (2018a) investigate a firm's optimal funding choice by taking market uncertainty and word-of-mouth (WoM) communication into account. Compared with bank financing, it demonstrates that crowdfunding is preferred only when the market uncertainty is very small or relatively large.

Moreover, blockchain technology enables new levels of collaboration among supply chain partners as opportunities in SCF. On the one hand, firms have announced the creation of a blockchain platform for SCF, such as blockchain-based letters of credit, bills of lading, factoring and reverse factoring (Hofmann et al., 2017). On the other hand, a new form of financing—initial coin offering (ICO)—has emerged, whereby an entrepreneurial venture obtains funds from investors in exchange for crypto tokens ("coins") that are the sole means of payment for the venture's future products of services (Chod & Lyandres, 2018). Although it was first held by Mastercoin in July 2013, it became popular in 2017. The oft-cited advantages of ICOs over traditional financing include low transaction costs and global investor outreach, as well as the ability to combine financing with customer base building. Interested readers can refer to Cong

& He (2018) and Babich & Hilary (2018) for more details of blockchain and ICO. Given that both are quite new and still being actively developed, there is very few literature studying blockchain and ICO in the operations and finance field. In particular, Chod et al. (2018) first explore both practical and theoretical implications of blockchains for supply chain finance and operations management by comparing the efficiency of signaling a firm's operational capabilities to lenders through inventory transactions and that through loan requests. Furthermore, Chod & Lyandres (2018) investigate the choice between ICO and conventional equity-based financing for entrepreneurial ventures and identifies several determinants of optimal ICO structure. In addition, Nguyen (2018) review the literature in crowdfunding, initial coin offering, and venture capital, as well as the potential relationship among them.

5.2.5. Genaral financing and sourcing in SCF

Since both the financial and operational status of a supplier is crucial for a buyer (vice versa), the interactions between sourcing and financing (without explicit financing instrument) are frequently investigated in SCF (see Section 5.1). For instance, Wu et al. (2018b) focus on how the buyer makes sourcing and production decisions when facing a spot market and multiple suppliers under capacity constraint and correlated disruption risk. Furthermore, Chod et al. (2019b) explore whether a manufacturer facing default risk should single-source or multi-source, and demonstrate that diversification is the preferred strategy in equilibrium although there is a higher upfront signaling cost owing to the alleviation effect of holdup. Besides, Babich et al. (2012) find that a buyer is inclined to have more suppliers if the internal financing is not available, facing either an uncertain demand or an uncertain supply under capital constraint. Yang et al. (2015) indicate that a firm's potential bankruptcy can hurt its competitors and benefit its suppliers/customers. In addition, Agca et al. (2017) show that credit risk propagates through multiple supply chain tiers for both positive and negative credit shocks. Tong et al. (2018) study the inventory policy under various payment timing contracts in a multi-echelon supply chain, and demonstrate that a wholesale price contract with partial consignment timing can achieve the centralized inventory levels at both the supplier and the retailer.

Recent advances in this substream focus on the contract design for supply chain coordination under financial constraint (Lee & Rhee, 2010; Xiao et al., 2017). In this aspect, Lee & Rhee (2010) consider the impact of inventory financing costs on supply chain coordination under all-unit quantity discount, buybacks, two-part tariff, and revenue-sharing contracts. It is shown that these contracts fail to achieve joint profit maximization if each agent relies on financing from a financial institution. Nevertheless, the supply chain can be fully coordinated if trade-credit in addition to these contracts is adopted. Meanwhile, Chaharsooghi & Heydari (2010) propose a model that coordinates the reorder point and order quantities in a two-level supply chain with backorder. Kouvelis & Zhao (2015) show that buyback contracts are coordinating and equivalent to revenue sharing with only variable default costs, while would be Pareto dominated by revenue sharing contracts in the presence of fixed default costs. Hence, revenue sharing contracts are recommended for working capital coordination in supply chains under bankruptcy risks. Analogously, Xiao et al. (2017) find that all unit quantity discount contract fails to coordinate, whereas the revenue sharing and buyback contracts can coordinate when the supply chain has a sufficient total working capital.

5.3. Future research directions

In contrast to its prevalence in practice, research endeavor of supply chain finance is relatively limited in scale and thus features high potential for developing both qualitative and quantitative managerial insights. The recent economic downturn owing to COVID-19 poses corporates under a series of financial risks that could strongly affect supply chain. This advocates increasingly greater research effort on supply chain finance in the mitigation of financial risk along the supply chain. To begin with, supply chain finance is a concept that lacks coherent conceptual foundation and thorough empirical investigation. Moreover, analytics of SCF could be the next wave of research in light of the rapid growth of SCF practice in the past decade, while new developments in FinTech (Lee et al. 2020)–e.g., blockchain technology–could spur research advancement in both OM and Finance (Babich & Kouvelis, 2017).

5.3.1. Trade credit

As one of the primary sources of short-term financing, trade credit has attracted the majority of research attention in SCF. Although numerous theoretical advantages have been demonstrated in trade credit, evidence indicates that these advantages are far from always achieved (Paul & Boden, 2014). Meanwhile, how to extend the trade credit over time is another interesting topic worth investigating, considering the factors such as reputation formation (Diamond, 1989), the maturity structure of the project return stream and the durability and specificity of project assets (Wilner, 2000), the dependence between the creditor and the debtor (Wilner, 2000), the evolution of the bargaining power (Fabbri & Klapper, 2016), as well as contract incompleteness (Fabbri & Menichini, 2016).

5.3.2. Innovative SCF solutions

Besides trade credit, there are a wide range of innovative supply chain finance solutions, such as manufacturer/supplier guarantor finance, factoring and forfaiting, invoice discounting, purchase order financing, buyer direct financing, early payment financing, buyer intermediated financing, 3PL/4PL financing, equipment leasing and leaseback, crowdfunding, blockchain-based SCF such as ICO, etc. On the one hand, each of these SCF solutions is rapidly emerging in practice, yet there is relatively limited research on these innovative SCF solutions, especially the buyer-led ones. Hence, it would be interesting to study how these innovative financing mechanisms affect the supply chain profitability. On the other hand, the research on the selection among various SCF solutions in various supply chain settings and objective formulations is likewise very limited (Gelsomino et al., 2016; Bals, 2018). Therefore, it would be interesting to figure out supply chain members' preferences among SCF solutions by comparison studies.

5.3.3. Supply chain finance and coordination

The supply chain coordination under financial constraints was first studied by Dada & Hu (2008) in a non-linear loan schedule. Coordination contract design in joint financing and operational decisions including reorder point and order quantity, the pervasive use of various SCF instruments, and the competitive structure in supply chains could be examined further. For instance, the interplay between inventory policies and financing schemes in supply chain coordination deserves more research attention (Chaharsooghi & Heydari, 2010), and the impact of competition among multiple suppliers/retailers on supply chain coordination and financing could

be studied in future (Lee & Rhee, 2010). In practice, supply chain partners could renegotiate credit terms in the presence of information asymmetry and credit rating fluctuations, which can be incorporated in future explorations (Xiao et al., 2017; Kouvelis & Zhao 2018).

5.3.4. Coopetition of SCF providers

SCF features the diversity of participants including financial institutions, FinTech platforms, leading corporates, supply chain partners, logistics providers, etc. It is notable that potential competitors might team up to offer a SCF solution. On the one hand, this could be demanded by the buyers to increase the magnitude of available funding, particularly for long tail suppliers, or to utilize the competition among SCF providers to lower financing cost and secure funding by diversification (Bickers, 2018). On the other hand, the collaborating SCF providers could benefit from the synergy effect in leveraging geographic, funding, and technological strength (Herath, 2015). Nevertheless, a few potential questions might arise despite these benefits. The first question is how should financial institutions collaborate with FinTech platforms. A good portion of financial institutions might seek to consolidate their leadership with a comprehensive proprietary platform; while others would either partner with another financial institution or a third-party to pursue a combination of in-house development and external partnership (Hurtrez & Salvadori, 2010). Second, it would be interesting to explore how externalities across borrowing channels lead banks to structure their lending contracts in when multiple lending channels are available. Third, a corporate would typically pick a lead bank in a multi-bank financing to keep all banks engaged in their pool without having to manage multiple relationships. Therefore, a follow-up question is how the lead bank should share credit information with the uninformed follower banks.

5.3.5. Risk management in SCF

While SCF is highly perceived as promising in practice, the potential associated risks should be well managed to ensure its effectiveness. On the one hand, SCF might not be secured by fixed tangible collateral. On the other hand, SCF involves the commitment of multiple parties in a contract on timely fulfillment of obligations (Zhao et al., 2015). Hence, the quality of supply chain relationships and collaboration across functional units are prerequisites for SCF excellence. Although SCF platforms could have a solid grasp of the detailed operational and financial status of their clients and technically can assess the risks of potential defaults, risk management remains the name of the game (Ren, 2017): Once there is opportunistic behavior or supply chain disruption, the entire SCF system may suffer. In addition, agency issues between financial and operational stakeholders of a firm (Babich & Kouvelis, 2015), and incentive misalignment between insiders and outsiders of the firm or different classes of investors might hold back the adoption of innovative SCF solutions, and affect potential value generation (Babich & Kouvelis, 2017). Hence, it is crucial to study how to design incentive schemes to promote cross-functional collaboration within a firm and across supply chain partners and thereby mitigate the risks in SCF programs by mechanism design and game theory (Birge et al., 2007; Bals, 2018). In addition, various factors, e.g., market differences and business cycles on SCF adoption/competition, the impact of SCF programs on risk metrics, and the risk mitigation of financial institutions and solution providers of SCF could be further investigated (Gelsomino et al., 2016; Bals, 2018). Besides, mitigating risks in SCF programs through regulations and

third party guarantee providers (e.g., insurance firms) could be explored (Paul & Boden, 2014). Meanwhile, it would be interesting to examine the effectiveness of frequently adopted risk control techniques such as international factoring, funded or unfunded sub-participation, securitization, syndication, multilateral institution or export credit agency finance, intermediation platforms and services (BAFT et al., 2016).

5.3.6. Liquidity of SCF-related assets

As SCF could becoming prevalent or even a necessity for most firms in future, one issue in tandem is the liquidity of SCF-related assets. Recently, a few innovative mechanisms of liquidating SCF-related assets have been proposed. For instance, firms could issue debt secured by account receivables, and sell their receivables to a financial institution who will pool them with other firms' receivables and issue a package of securities against them, which is known as securitization (Mian & Smith, 1994). Ant Financial (operator of Alipay) launched 2 billion CNY (US $317.4 million) worth of asset-backed securities (ABS) on Shanghai Stock Exchange in 2018, and is China's first traded security backed by loans to online retailers, opening up a new financing channel in e-commerce (Ren, 2018). Nevertheless, despite the importance of the liquidation schemes in SCF, there is scant research on this topic. Hence, a deeper dive into this issue could generate more managerial insights for the robust development of SCF.

5.3.7. Supply chain finance in agribusiness

Agriculture in China and India is primarily carried out by smallholders with typically limited and poorly documented assets. Provided that these assets can rarely be used as collateral for seeking loans from financial institutions, and the policy-induced distortions in the rural financial markets (such as those caused by credit subsidies, taxes on financial services and loan wave-off) could discourage financial institutions to fund smallholder agriculture, capital constraint has therefore been one of the main challenges in the transition towards commercial agriculture (Chen et al., 2016a). Nevertheless, with increasing attention paid to social responsibility and sustainability (Xu et al., 2018b), large buyers have begun to place these issues as priorities and try to help the farmers to tackle the capital issue in upgrading and modernising their farms. For instance, Nestlé collaborates with local governments and banks to provide farmers with financial support (Gong et al., 2018). The emerging technologies such as FinTech have created opportunities for scaling up institutional finance for smallholder agriculture. In the meantime, governments can finance the farmers through rural development and poverty alleviation programmes or by providing direct financial support to the institutions linking farmers to markets. Moreover, cooperatives, joint liability groups or self-help groups (SHGs) could be important financing channels for farmers (Chen et al., 2016a). Besides, many agribusiness firms could provide inputs and services such as information and technical support to the farmers. In addition, the agricultural supply chain may suffer from risks such as weather risk, yield and quality uncertainty, market volatility, mortality risk, property risk and strategic breach of the contract, which could significantly affect the development of SCF.

Recently, a few OM scholars start to study the social responsibility and sustainability in agriculture, especially that in emerging economies. However, the existing SCF research in agricultural supply chains is fairly rudimentary. First, most papers in this field feature qualitative research such as case study, see Chen et al. (2016a) for instance. Second, in economics, Stiglitz

(1990) and Arnott & Stiglitz (1991) have quantitatively studied peer monitoring, which is mainly adopted to ensure borrowers exercising prudence of fund-in-use and therefore enhance the likelihood of repayment. Recently, de Zegher et al. (2018) show how eliminating payment delay can improve productivity and welfare for farmers by combining dynamic programming and non-cooperative game theory, and can increase profitability for processors and (if the buyer's discount rate is not too high) buyers. In comparison with the SCF practice in agricultural sector, research on SCF in agribusiness is far from sufficient, especially from risk management perspectives. On one hand, the underlying mechanisms of innovative SCF solutions in agriculture (such as internal financing, leasing of movable assets, the financing through tripartite agreements among farmers, leading firms and financial institutions, and group lending) can be explored further to show how they alleviate the farmers' capital constraints and improve social welfare. On the other hand, it would be fruitful to combine both the operational and financing decisions in agriculture and study the interactions between them.

6. Integrated operations and financing in non-supply chain settings

After reviewing the research on supply chain finance, this section mainly explores the literature on capital budgeting in operational investment in non-supply chain settings, which has recently gained significant research attention. Section 5 mainly explores the impact of capital constraint on operational decisions in supply chain settings and thereby how various supply chain finance solutions could interacts with each other and optimize chain-wide material and monetary flows. In contrast, this section focuses on the interactions between operational and financing aspects to achieve joint optimization in single-firm settings, competitive settings, or multi-player networks, respectively. In this stream, operational perspectives could include capacity investment, production planning, inventory/sourcing management, and incentive alignment; while the financial aspects incorporate capital structure, payment time, cash allocation, dividend issuing, subsidy, covenant, and capital market frictions (Tanrisever et al. 2020b) such as information asymmetry, transactions cost, liquidity shock, interest rates, taxation, and bankruptcy. Next, we adopt a process view and categorize this research stream as follows.

6.1. Capacity investment and financial leverage

This research substream primarily explores how capital budgeting, agency costs associated with the financial leverage and costly bankruptcy process affects the investment in operational flexibility for risk mitigation. Traditional research on operational flexibility (typically conducted in isolation from financial considerations) compares two counterbalancing operational effects: Investment expenses with a potential increment in unit costs versus an improved ability to match supply and demand. Nevertheless, a firm might face a capital constraint when making these investments, and therefore an external source of financing could be needed. In this case, how the financial factors would affect these operational flexibility decisions should be taken into consideration. For instance, Gaur et al. (2011) study the impact of financial innovations (i.e., securitization) on real investment decisions within the framework of an incomplete market economy consisting of firms, investors, and an intermediary. The main result indicates that pooling and tranching are valuable in reducing ambiguity surrounding the valuation of new real

investments in incomplete markets.Chod & Zhou (2013) examine how the optimal investment in the capacity of flexible and nonflexible resources is affected by financial leverage and, conversely, how a firm's resource flexibility affects its optimal capital structure in a two-product firm. It is shown that resource flexibility could not only reduce the mismatch between supply and demand but also mitigate the shareholder-debtholder agency conflict and the risk of costly default. Boyabatli et al. (2015) study how the tightening of the capital budget for financing the capacity investment and a lower financial flexibility in the production stage shape the optimal choice between flexible and dedicated technology for a multi-product firm.

Most research attention on capacity investment has been devoted to cases in single-firm settings. In particular, de Véricourt & Gromb (2017) study how a firm's capacity choice interacts with funding from investors to derive the optimal contract. It is suggested that operational managers should challenge the financial policy and check whether adjustments to financial contracts can avoid the distortions of deviating from efficient capacity investment. Ning & Sobel (2017) investigate the joint production and capacity management with internal financing and dividend issuing in a multi-period setting, and find that internal financing creates a spillover between the endogenous values of two operationally independent facilities, which thereby leads to an interdependence among the optimal policies.

Moreover, capacity investment has likewise been explored in competitive settings. For instance, Swinney et al. (2011) analyze the timing of capacity investment decisions of both established firms and start-ups in a competition of entering new markets. Ning & Babich (2017) study a R&D investment problem in the presence of knowledge spillover and debt financing. Interestingly, it is shown that even firms with unlimited internal capital may prefer external debt financing, because the incentive for risk shifting of debt financing can cure free-riding problem arising from knowledge spillover and thereby the first-best investment becomes feasible. They conclude that debt can be used by firms as commitment device in a multi-stage game.

6.2. Production and financing decisions

Analogously, the research on the interactions between production and financing decisions is mostly discussed in single-firm settings. For instance, Damon & Schramm (1972) study the interrelationships among short-run production, workforce level, investment or disinvestment in marketable securities, the additional short-term debt incurred or retired, advertising and pricing decisions by developing a simultaneous and a sequential production-finance decision model, respectively. Xu & Birge (2004) develop a single-period model where the production and financing decisions are made simultaneously, and demonstrate that the interactions between a firm's production and financing decisions is actually a trade-off between the tax benefits of debt and financial distress costs. Birge & Xu (2011) extend Xu & Birge (2004) to a multi-period setting and suggest the firm's financial and operational decisions are linked through the leveraging effect of fixed costs and the amount of risk taken in production commitments. There is a nonlinear form of the relationship among profitability, leverage, and inventory volatility. Moreover, de Korte (2016) examines how investment in production postponement affects a firm's financial and operational processes (i.e., early or delayed product differentiation) in the presence of a costly bankruptcy and salvage markets. It is found that the optimal production postponement might be reversed in contrast to the case when capital markets are perfect.

Early research on the interactions between finance and production decisions in competitive settings include Brander & Lewis (1986) and Brander & Lewis (1988), both of which consider a two-stage sequential duopoly game where the two firms decide upon financial structure in the first stage and select output levels in the second stage. However, Brander & Lewis (1986) focus on the "limited liability" effect of debt financing whereas Brander & Lewis (1988) consider the strategic bankruptcy effects of financial decisions. It is shown that limited liability may commit a leveraged firm to a more aggressive output stance, whereas the impact of bankruptcy costs varies with its form. Parsons (1997) further extends Brander & Lewis (1988) to incorporate a broader range of specifications. In contrast to the result in Brander & Lewis (1988), firms initially have an incentive to decrease output levels in certain cases if they take on more debt. Moreover, Chod & Lyandres (2011) examine the impact of the firms' incentives to go public on the product market competition. They indicate that public firms adopt riskier and more aggressive output market strategies than private firms since the capital market has a greater ability to diversify idiosyncratic risk.

6.3. Inventory and financing decisions

There is extensive literature on the interactions between inventory management and financial leverage in non-supply chain settings. For instance, Agrawal & Seshadri (2000) study the impact of risk aversion on price and order quantity in a setting similar to the newsvendor problem, in which the demand distribution is a function of the selling price and the risk-averse retailer can trade after the demand is realized. Similarly, Seshadri & Wu (2014) provides a unified approach to conduct sensitivity analysis in production and inventory planning problems when the decision maker is risk averse and faces uncertainties in future cash flows. In the meantime, how a firm should dynamically replenish its stock under cash flow constraint has been investigated (Chao et al., 2008; Luo & Shang, 2015). Alan & Gaur (2018) explore how a bank can mitigate information asymmetry by screening firms and thereby controlling each firm type's order quantity and leverage under asset-based lending. Iancu et al. (2016) examine an inventory-heavy firm facing uncertain demand that can issue competitively priced debt to fund its inventory investments and is afforded different degrees of operational flexibility to adjust inventory in response to observed sales. They demonstrate that flexibility in replenishing or liquidating inventory by providing risk-shifting incentives could lead to borrowing costs that erase more than one-third of the firm's value; nevertheless, these aforementioned agency costs and operating distortions can be fully alleviated by simple covenants widely used in practice when properly designed.

6.4. Pricing/customer behavior and financing decisions

The research on the impact of financing decisions on pricing is relatively scarce. The earliest work to our knowledge, Lam & Chen (1986) integrate pricing and credit decisions in a setting where both product demand and customers' cash flows are uncertain. More recently, Besbes et al. (2017) study dynamic pricing under debt and find that limited liability could lead to performance spiral down. However, debt amortization or financial covenants, debt relief and early repayment options could be used to mitigate these inefficiencies in a decreasing order. Besides, Chun et al. (2017) study how point valuation and cash price decisions should be made optimally in light of the inherent liabilities in a dynamic model where a firm sells one product and rewards customers purchasing in cash with points. Regarding the impact of financial distress/bankruptcy

on the operational decisions, Craig & Raman (2015) introduce the store liquidation problem to the literature and present a technique for optimizing key store liquidation decisions including markdowns, inventory transfers, and the timing of store closings. Furthermore, Birge et al. (2017) investigate how customers' strategic waiting behavior to a firm's financial distress influences the firm's probability of bankruptcy in return, the firm's operational decisions such as inventory and price, as well as its profitability. What it indicates is that deferred discounts, such as rebates and store credit, can serve as an effective mechanism to mitigate strategic waiting.

6.5. Incentive alignment and financing decisions

Traditionally, the incentive issues are examined primarily between the managerial team and shareholders of a firm. In addition to shareholders, there are other stakeholders e.g., banks and bondholders who provide financing to the firm. In this case, financing providers could play an important role in shaping the firm's operational and financial strategies. The earliest research in this substream mainly investigate how capital structure, i.e., the conflicting incentives of bondholders and stockholders, can control other incentive/conflict issues, such as the agency relationship between a firm and its customers when a firm liquidates (Titman, 1984), and the agency issue between atomistic shareholders and management on investment (Stulz, 1990). Dasgupta & Shin (1999) study the impact of capital structure on the incentive alignment in a Cournot duopoly to share information through a trade association, where the two firms are asymmetric in terms of their ability to observe demand. They find that the frequent result for all-equity firms that information will not be shared could be reversed. Moreover, Xu & Birge (2008) explore the interactions among a firm's production decisions, capital structure, and managerial compensation policy in a unified newsvendor framework, which observes that financial leverage can vary with the profit margins. Besides, de Korte (2016) studies the impact of conflicting benefits among the firm's shareholders, management and bondholders simultaneously in a three-stage newsvendor model. The results indicate that the portion of equity incentive in the optimal contract is critical and should decrease in bankruptcy costs and the leverage ratio of the firm. In addition, Lai & Xiao (2017) examine how managerial short-termism can affect a firm's inventory decision when external investors have only partial information.

6.6. Future research directions

The ongoing COVID-19 pandemic and global trade conflicts would inevitably reshape the prevalent global operations in the past deacdes that features outsourcing and global collaboration. Reshoring and relocation decisions would be dependent on the trade-offs among flexibility, security, quality, standardization, automation, labour cost, and market factors. These considerations would thereby affect the interactions between financing (of higher importance in an economic downturn) and operational processes. To begin with, as the majority of extant research on capacity investment and financial leverage focus on credit risk, future extention could incorporate additional sources of uncertainty, e.g., commodity price volatility, exchange and interest rate fluctuations. Besides, global firms' capacity investment strategies and diversification effect could be explored in various competitive settings including supplier or buyer competition, price or quantity competition, supply chain competition, or market entry and exit games. The primary findings regarding agency issues, cash reserves, dividend issuance, and capital structure from theoretical models could be tested as hypothesis in field studies. The interactions

among market changes, product portfolio, and capital structure could be explored further in capacity investment. In addition, financial hedging strategies of various risks to secure capacity investment under competition could be examined.

Moreover, the inherent connection between production and financing decisions enables future research opportunities. For instance, the impact of capital structure on product line expansion could be studied in various types of market competition (i.e., from perfectly competive, oligopolistic, to monopoly market settings). The relative effectiveness of making production and financial decisions either sequentially or simultaneously could be examined to further validate the Modigliani-Miller theorem. Besides, the interactions of more underlying factors such as information asymmetry, agency issues, competitive reactions, public offering, market share, debt structure and maturity could be analyzed and tested in joint financing and production optimization (cf. Brander & Lewis, 1986, Chod & Lyandres, 2011).

To further explore the interplay between inventory and financing strategies, dynamic decision making process in collaborative settings could be examined (Protopappa-Sieke & Seifert, 2010). The interplay between trade credit and inventory management in one-firm models (either as supplier or buyer) could be examined in scenarios where a buyer has alternative source of capital, a supplier sells multiple products, or different competitive settings. Moreover, both internal and external factors including multi-product, information asymmetry, default risk, payment timing, and upstream/downstream competition could be considered in further exploitations. The integrated inventory replenishment and cash retention policy in different settings can be further extended by incorporating external financing options.

In addition, the interactions between pricing/customer behavior and financing decisions could be enriched as follows. From operational aspects, additional product features, third-party partnerships, marketing strategies, and competitive settings could be incorporated to study customer behavior in light of financing decisions. From financial perspectives, loan maturity, interest rate, debt relief, mortgage claim, and managerial compensation could be jointly examined with pricing/revenue-related decisions. Besides, most extant papers in this substream focus on exogenous financing, thus more effort could be devoted to endogenous financing and its implications for operational decisions. Moreover, empirical research could further test hypotheses on the relationships among financial distress, loyalty program, customer behavior, and operational performance metrics (Chun et al., 2017; Besbes et al., 2017).

Meanwhile, incentive alignment could be studied further in different settings including various types of principal-agency relationship, atomistic shareholder, and Cournot/Bertrand competition. The impact of capital structure, managerial short-termism, and inventory decisions on firms' information sharing and incentive alignment could be examined further under information asymmetry (Dasgupta & Shin, 1999; Lai & Xiao, 2017). Meanwhile, empirical research on optimal capital structure and the interactions between competition and incentive alignment under uncertainty deserves future research attention (Xu & Birge, 2008).

7. Conclusion

This paper attempts to provide a comprehensive overview of research landscape and a navigation for future explorations on the interface between operations and finance in risk management. In sum, our research contributes to the extant literature in three main aspects. First, we syn-

thesize research spanning across diverse topics and divergent methodologies and unveil potential research opportunities to advocate future research attention in this dynamic and emerging field through an abridgment of topical mapping employing analytical, conceptual, or empirical approaches. Moreover, to elaborate the evolution of of each research stream, we trace the historical progression from research origins to recent contributions in detail and thereby pinpoint prospective discrepancy in literature as future research directions. Third, risk management aspects of operations-finance interactions have been emphasized in light of the interrelationships among operational and financial risks, and the potential reciprocity between operational strategies and financial instruments in extensive settings.

Nevertheless, the research to date merely represents the beginning of investigation into the interactions between operations and finance (Birge, 2015). The majority of the aforementioned research contributions in this filed has emerged in the recent two decades, which are far from sufficient to fathom the profound knowledge on operations-finance interface, especially from risk management perspectives. Therefore, an overview of major future research directions proposed in Sections 3-6 is presented in Table 2.

In addition, we propose general research directions spanning across diverse research streams on operations-finance interface in risk management as follows: (1) Extension to more complex settings, e.g., multi-product, market entry/exit, competition, collaboration, multi-currency, and multi-tier supply chain networks. (2) Incorporation of information asymmetry/incompleteness and incentive alignment issues, and thereby examine how they could affect operations and finance as well as their interactions. (3) Exploration of relevant operational decision variables including contract terms, modularization, product line expansion, and sustainability metrics. (4) Addtional financial perspectives such as default probability, capital structure, payment timing, taxation, interest and exchange rates, and credit rating. (5) Intricate sources of uncertainty from both financial and operational aspects and their correlations. (6) Extension of single-period models to multi-period settings, and thereby study, e.g., how operational and financial strategies would vary over time with growing information transparency, higher automation, and customer market changes. (7) Consideration of alternative objective formulations, risk attitudes, and decision timing. (8) Application of operations-finance interface theories in specific sectors, e.g., agricultural, automotive, electronic, and logistics sectors. (9) Investigation of extant theoretical conclusions using empirical and case study methods. (10) The impact of innovative technologies on market dimensions (e.g., multi-bank platforms fostering transparency/competition) and opportunities of applying new technologies such as blockchain. (11) Innovative varieties and combinations of operational hedging and financial flexibility strategies.

Acknowledgments

The authors thank a senior editor and two anonymous referees for their helpful comments and suggestions. Jiao Wang's research was supported by the National Natural Science Foundation of China (Grant No. 71902124), by China Postdoctoral Science Foundation (Grant No. 2019M663543), by the Soft Science Project of Sichuan Science and Technology Department (Grant No. 2020JDR0057), and by the Chengdu Philosophy and Social Science Planning Office (Grant No. 2019L10), as well as by Sichuan University (Grant No. 2018hhf-48, and Grant No. skbsh2019-37).

Table 2 Summary of future research directions on operations-finance interface in risk management

Category	Research stream	Major future research directions
Currency risk management	Capacity investment and facility location	(1) Risk measures of currency exposure; (2) relationship among exchange-rate stabilization policies, capacity utilization, and location decision; (3) innovative solution methodologies in optimization and valuation; (4) impact of capacity strategies in global manufacturing on competitive advantage.
	Global production and distribution network	(1) Implications of automation and reshoring on financial hedging in currency risk mitigation; (2) cost structure analysis, pricing, product differentiation, market uncertainty, competitive advantage, and coopetition strategy; (3) utility formulations and risk attitudes; (4) innovative operational strategies (e.g., modularization, product line expansion, price-setting strategies); (5) impact of operational strategies on valuation of global production network.
	Interactions between operational flexibility and financial hedging	(1) Interrelated disruption risks and currency fluctuations in multi-tier supply chains; (2) simplification methodology for implementation of downside risk measures under currency exposure; (3) extension to more complex settings, e.g., multi-currency and multi-stage; (4) operational and financial hedging in mitigating competitive exposure to currency risk; (5) global supply chain restructuring and financial hedging under pandemic and tariff uncertainty.
Commodity risk management	General	(1) Risk mitigation in inefficient derivative markets; (2) impact of speculation and position limits on commodity trading; (3) effectiveness of inventory sharing and innovative cooperative risk management strategies; (4) impact of insufficient capacity and infrastructure on commodity operations; (5) operational and financial strategies in light of supply chain parters' strategies.
	Agricultural commodities	(1) Innovative operational flexibility strategies in agribusiness; (2) subsidies, trade aid payments, and supply management measures to revamp agricultural operations.
	Energy commodities	(1) Social impact of permanent shutdown in merchant commodity and energy production assets and valuation; (2) how to incentivize energy firms to adopt renewable and clean energy.
	Metal-based commodities	Impact of environmental policy, stimulating measures, and monetary policies on operational and financial decisions of metal commodity.
Supply chain finance	Trade credit	(1) Field study on how to achieve theoretical advantages of trade credit in practice; (2) trade credit contact in dynamic settings considering reputation formation, project maturity structure, bargaining power evolution, etc.
	Innovative SCF solutions	(1) Impact of innovative financing on supply chain profitability; (2) selection among various SCF solutions in different supply chain settings and objective formulations.
	SCF and coordination	(1) Interplay between SCF and coordination contract desgin; (2) impact of competition among multiple suppliers/retailers on supply chain coordination and financing.
	Coopetition of SCF providers	(1) Competition and diversification effect of multiple SCF providers; (2) risk sharing and synergy effect from the collaboration of SCF providers; (3) how externalities across borrowing channels lead banks to structure lending contracts.
	Risk management in SCF	(1) Design of incentive schemes to promote cross-functional collaboration in risk mitigation of SCF programs; (2) key factors of SCF adoption and competition in risk management; (3) effectiveness of risk control techniques in SCF.
	Liquidity of SCF-related assets	Innovative mechanisms of liquidating SCF-related assets, e.g., securitization and asset-backed securities.
	SCF in agriculture sector	(1) Risk management in innovative SCF solutions for smallholders in agribusiness; (2) social and environmental aspects of SCF in agriculture.
Integrated operations and financing in non-supply chain settings	Capacity investment and financial leverage	(1) diversification effect in various competitive settings of capacity investment games; (2) field study on agency issues, cash reserves, dividend issuance, and capital structure; (3) hedging strategies to secure capacity investment under competition.
	Production and financing decisions	(1) Impact of capital structure on product line/inventory management in market competition; (2) effectiveness of making production and financial decisions either sequentially or simultaneously.
	Inventory and financing decisions	(1) Dynamic decision making in extended settings including multi-product, collaboration and competition; (2) internal and external financing in inventory replenishment.
	Incentive alignment and financing decisions	(1) Impact of capital structure, managerial short-termism, and inventory decisions on incentive alignment; (2) empirical research on capital structure and interactions between competition and incentive alignment under uncertainty.
	Pricing/customer behavior and financing decisions	(1) Extensive operational and financial aspects, e.g., product features, inventory metrics, loan maturity, and interest rate; (2) interaction of exogenous/endogenous financing and pricing/customer behavior.

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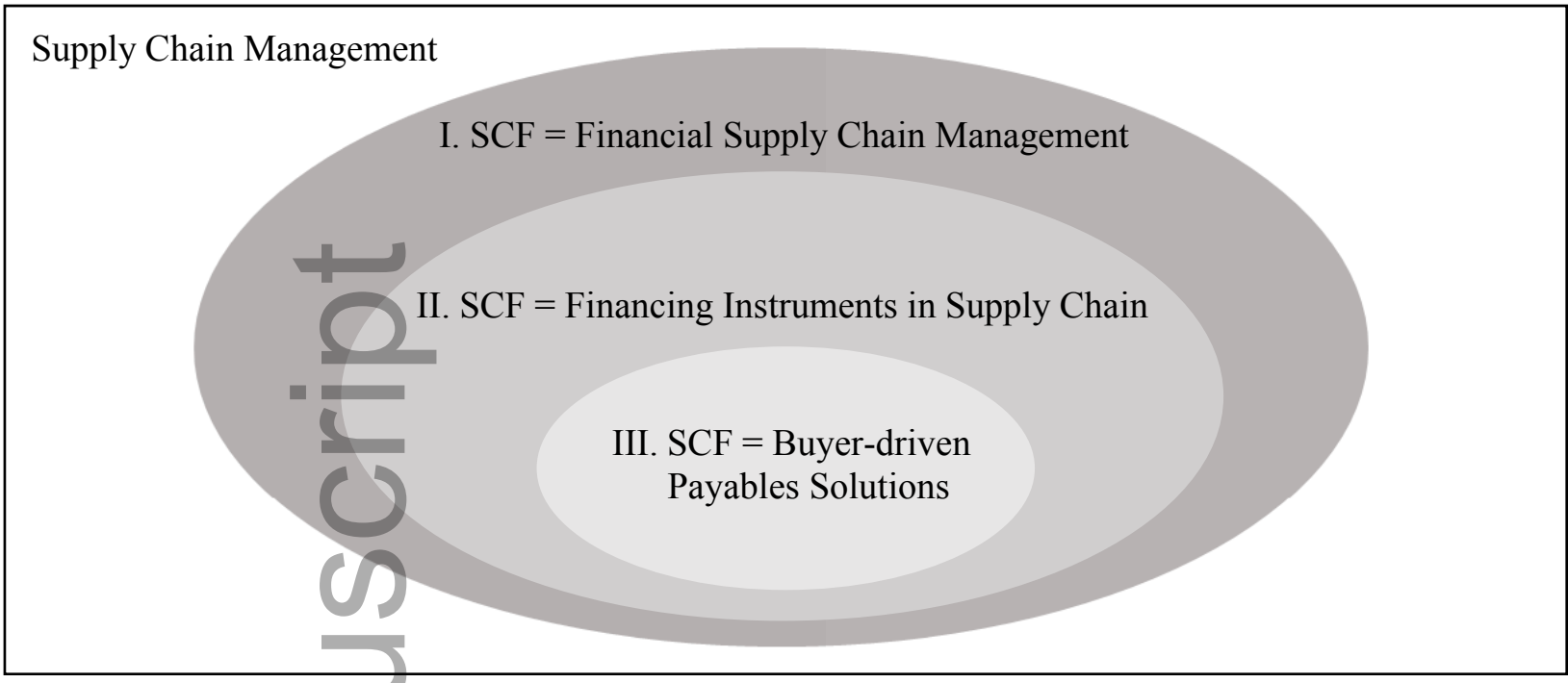

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