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The behavioural causes of bullwhip effect in supply chains: a systematic literature review

--Manuscript Draft--

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Abstract:	The bullwhip effect, also known as demand information amplification, is one of the principal obstacles in supply chains. In recent decades, extensive studies have explored its operational causes and have proposed corresponding solutions in the context of production inventory and supply chain systems. However, the underlying assumption of these studies is that human decision-making is always rational. Yet, this is not always the case, and an increasing number of recent studies have argued that behavioural and psychological factors play a key role in generating the bullwhip effect in real-world supply chains. Given the prevalence of such research, the main objective of this study is to provide a systematic literature review on the bullwhip effect from the behavioural operations perspective. Using databases, including Scopus, Wiley Online Library, Google Scholar and Science Direct, we selected, summarised and analysed 53 academic studies. We find that most studies build their models and simulations based on the 'beer distribution game' and analyse the results at the individual level. We also demonstrate the importance of studying human factors in the bullwhip effect through adapting Sterman's double-loop learning model. Based on this model, we categorise and analyse the behavioural factors that have been studied and identify the explored behavioural factors for future research. Based on our findings, we suggest that future studies could consider social and cultural influences on decision-making in studying the bullwhip effect. In addition, further aspects of human mental models that cause this effect can be explored.

Editor (highlighted in **Blue** in the revised revision)

Comments	How to address
Please ensure that the review recognises and considers related review and survey papers and ensure that this study is appropriately placed with respect to these existing studies.	We thank the editor for giving us another chance to revise this paper. This time, we have cited the related reviews and added the reviews that reviewer 3 suggested. All cited publications are shown as follow: 1) Arvan, M, Fahimnia, B, Reisi, M & Siemsen, E 2019, 'Integrating human judgement into quantitative forecasting methods: A review', *Omega*, vol. 86, 237-252. 2) Bhattacharya, R & Bandyopadhyay, S 2011, 'A review of the causes of bullwhip effect in a supply chain', *International Journal of Advanced Manufacturing Technology*, vol. 54, no. 9–12, pp. 1245–1261. 3) Fahimnia, B, Pournader, M, Siemsen, E, Bendoly, E & Wang, C 2019, 'Behavioral operations and supply chain management- A Review and Literature Mapping', *Decision Sciences*, vol. 50, no. 6, pp. 1127-1183. 4) Fahimnia, B, Sanders, N & Siemsen, E 2020, 'Human judgment in supply chain forecasting', *Omega*, 94. 5) Geary, S, Disney, SM & Towill, DR 2006, 'On bullwhip in supply chains—Historical review, present practice and expected future impact', *International Journal of Production Economics*, vol. 101, no. 1, pp. 2–18. 6) Giard, V & Sali, M 2013, 'The bullwhip effect in supply chains: A study of contingent and incomplete literature', *International Journal of Production Research*, vol. 51, no. 13, pp. 3880–3893. 7) Miragliotta, G 2006, 'Layers and mechanisms: A new taxonomy for the bullwhip effect', *International Journal of*

	Production Economics, vol. 104, pp. 365-381. 8) Perera, N, Hurley, J, Fahimnia, B & Reisi, M 2019, 'The human factor in supply chain forecasting: a systematic review', *European Journal of Operations Research,* vol. 274, no.2, pp. 574-600. 9) Perera, N, Fahimnia, B & Tokar, T 2020, 'Inventory and ordering decisions: a systematic review on research driven through behavioral experiments', *International Journal of Operations and Production Management*, vol. 40, no. 7-8, pp. 997-1039. 10) Wang, X & Disney, SM 2016, 'The bullwhip effect: Progress, trends and directions', *European Journal of Operational Research*, vol. 250, no. 3, pp. 691–701. Please see page 4-5. Moreover, how we respond to your comments is highlighted in blue, and we have highlighted all the changes in the revised version for the convenience of yours and the reviewers' to read our revised revision. We hope it would be easier to check how we respond to each of the comments and suggestions.

Reviewer 1 (highlighted in **Yellow** in the revised revision)

Comments	How to address
The revised paper is much improved. I see the value of this review to current scholars that may not be aware of the breadth of the research in this area, as well as new scholars and students that desire an introduction. I have some differences of opinion about the content and context of some of the papers in the review, but I appreciate that the authors have a different perspective.	We thank that the reviewer recognized our improvement, and considered our paper as a valuable work in this research area. How we respond to your comments is highlighted in yellow.
1. I'm satisfied with the use of Sterman's Double Loop Learning model as the framing of the review. However, the text around and between Figures 2 and 3 explaining what the authors' additions are is a bit premature and requires some explanation of why the additions are important. It might be better if the authors waited until the text around Figure 7, and talk there in more detail about what they added and why.	To address this comment, we deleted the text about our additions between Figure 2 and 3 and we also deleted Figure 3. We moved this text to the beginning of section 5 before Figure 5, and we revised this paragraph by adding more explanation of the additions' importance. Please see page 22-23.
2. A large proportion of the papers are listed as "Controlled Experiments." However, from my perspective there are some significant differences with respect to experimental procedures among these studies. I see the most important distinction as between studies where participants completed an inventory management task alone with computer-managed upstream and downstream partners versus contexts where participants know that other humans are managing those other partners, and perhaps in the same room. Given that the authors note that social factors are underexplored in this area, comparing and contrasting the results among these different types of controlled experiments might reveal some insights or research questions that remain unanswered. Alternatively, the authors might explain why my distinction isn't important.	We agreed with the reviewer that the procedures of controlled experiment involving computer agent could affect the decision-making of human participants. We compared these studies and added new insights in the paper. Specifically, three studies involved not only human participants but also computer agent (Cantor & MacDonald 2009; Croson et al. 2014; Haines, Hough, & Haines 2017). All three studies adopted Beer Game. Croson et al. (2014) and Haines, Hough and Haines (2017) mentioned that the participants were informed about the presence of computer agents and the presence of other human participants. The differences between these two studies about the setting and the procedure are that Croson et al. (2014) had one treatment with participants managed one of the positions, and the rest positions are computers; another treatment with all positions are managed by participants. In both treatments, participants were informed an optimal decision rule and others (including computers) knew this rule as well.

	The result showed that treatment with all humans manipulated all positions performed worse than treatment involving computers since participants had trust issues in their team members about applying the optimal decision rule. And we have classified the human factor of trust into social interaction, but we did not state that the experiment procedure compared these two conditions, and we have added additional information to make it clear. (Please see **Section 5.1.3**). Haines, Hough and Haines (2017) had all treatments with participants managed either wholesaler or distributor and the other positions managed by computers, however, without informing any decision rules. Based on the result from Croson et al. (2014), trust may also play a role in the decision-making under these treatments. We added this point into the conclusion as one unanswered research question of whether the participants tend to trust more in computer agents or human agents with an increase in the number of human participants (Please see **Conclusion Section** on page 44-45). Cantor and Macdonald (2009) mentioned that participants played the role of distributor, while the other three roles were manipulated by pre-programmed computers. However, they did not mention in the article about whether the participants had been told about the automated agents as their supply chain members. So it is hard to say whether or not trust influenced the performance of their participants.
3. The authors bring up that emotions have been largely unstudied, and I feel like they are spot-on. For this reason alone, emotions should at least have its own line in their model, if not its own box. I am struck that Sterman's own description of the beer game (http://web.mit.edu/jsterman/www/SDG/beergame.html) goes to great length talking about the energy and emotions that are at	To respond this comment, we have added a box of emotion in our model. Although there has no study focused on emotion, several studies have mentioned its influence on participants, behavior and decision-making. Thus, based on the information about emotion in our selected studies, we added the box of emotion in Figure 5 (please see

play when the board version of the beer game is played, but fear that many of us have boiled the emotion out of the experience. Thus, I would also like to see some analysis and perspective from the authors about how our laboratory experiment participants might differ from real life participants in supply chains with respect to how they emotionally experience and react to a bullwhip situation (e.g., the Barilla case or even the toilet paper shortages last March).	**Section 5** on page 23, and **Figure 5** on page 25). We used red dashed lines to indicate there has relationship between emotion and social interaction, or individual traits, or cognitive processes (blue dashed box). Based on our selected studies, emotion may have impact on social interaction since blame and distrust of other members in supply chain could be triggered by perceiving unexpected results (Kovacevic et al. 2013; Sterman 1989a). In addition, emotion could influence the decision strategy and behavior of participants (Nienhaus, Ziegenbein, & Schoensleben 2006; Sterman & Dogan 2015). Moreover, individual traits (e.g., personality) have been demonstrated to have impact on emotion as well based on some psychological studies (e.g. Thompson 2008). We did not used solid line to indicate the relationships between emotion and other behavioral factors because these relationships are complex and it is hard to whether there has any feedback loops, or which behavioral factor cause emotional decision-making based on our selected literature pool, or what kind of influence emotion has on which behavioral factor in our model. Nevertheless, we included this point in our conclusion to call more attention in future research. (Please see page 43 and 45-46) Moreover, we have added some analysis about toilet paper shortage from the perspective of how laboratory experiment participants might differ from the real life participants based on emotion (Please see **Section 5.7** on page 41-42).
4. The use of student participants has become controversial in this line of research. I would like the authors to provide some analysis and perspective on the breakdown of research between students versus supply chain professionals. Have we reached the point in	We have added a subsection of "professional vs. student participants" in section 4 to analyze and conclude the results we found from the studies. Also, we summarized participants information in Table 2 (students, MBA students,

this line of research where we have answered all of the questions we can by using student participants?	professionals etc.), which the selected studies recruited for their experiments. Besides, we added this point into our conclusion for future research direction. Please see **Section 4.4** on page 20-22, and page 46.

Reviewer 3 (highlighted in **Green** in the revised revision)

Comments	How to address
I was not quite positive in reconsidering this paper for possible publication in IJPE. Saying that I think the authors have done a good job in responding to the comments of all reviewers and the revised manuscript looks much better that the initial submission. My primary concerns about the small pool of papers to review are still valid, but I think the focus is primarily placed on thorough content analysis and extracting new insights. On this basis, I am happy to reconsider this paper once the following concerns are addressed.	We thank that the reviewer's positive feedback. How we respond to your comments is highlighted in green.
1. The important role of automation and supply chain digitalisation plays in managing bullwhip effect has not been discussed in any parts of this paper. The role that human decision-makers play in creating or boosting the bullwhip effect is highly influenced by the degree or automation and industry 4.0 initiatives. We may not yet have a large literature on this, but this is worthy of being discussed in some details.	We agreed with the reviewer, and we have added one aspect of automation and supply chain digitalization in our conclusion to emphasize the importance of supply chain digitalization in the area of bullwhip effect in order to draw more attention in the context of automation in future research. Please see page 47-48.
2. I am surprised to see that some of the related reviews are not cited here (e.g., Arvan et al., 2019; Fahimnia et a., 2019; Fahimnia et a., 2020; Perera et al., 2020). I encourage the authors to read these papers and find out how those reviews can inform this paper.	We have added these related reviews in our paper and indicated the differences between these reviews and our manuscript in context, objectives and methods. Please see page 4.
3. I am not sure if Figure 6 is adding much value. This information and simple statistics can be simply explained in a couple of lines.	To respond to this comment, we have deleted Figure 6 since it has already been explained in the text.
4. I suggest the authors proofread the paper one more time before resubmitting. The information flow can be improved and there are a few types in the newly added sections (e.g., in page 9, "in a single echelon in supply chains" should be "in a single echelon supply chain"?).	To address this comment, we have sent our paper to a proof-reading service to improve our writing before we resubmit it.
5. There are a number of sub-headings that are not numbered (e.g., all sub-headings under 5.1-5.6). I suggest either numbering	We have numbered all the sub-headings under section 5.1 to 5.7.

these sub-sections or to use bullet points to make them better stand out.	

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Giard, V & Sali, M 2013, 'The bullwhip effect in supply chains: a study of contingent and incomplete literature', *International Journal of Production Research*, vol. 51, no. 13, pp. 3880–93.

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Perera, HN, Fahimnia, B & Tokar, T 2020, 'Inventory and ordering decisions: a systematic review on research driven through behavioral experiments', *International Journal of Operations and Production Management,* vol. 40, no.7-8, pp. 997–1039.

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The behavioural causes of bullwhip effect in supply chains: a systematic literature review

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The behavioural causes of bullwhip effect in supply chains: a systematic literature review

Abstract

The bullwhip effect, also known as demand information amplification, is one of the principal obstacles in supply chains. In recent decades, extensive studies have explored its operational causes and have proposed corresponding solutions in the context of production inventory and supply chain systems. However, the underlying assumption of these studies is that human decision-making is always rational. Yet, this is not always the case, and an increasing number of recent studies have argued that behavioural and psychological factors play a key role in generating the bullwhip effect in real-world supply chains. Given the prevalence of such research, the main objective of this study is to provide a systematic literature review on the bullwhip effect from the behavioural operations perspective. Using databases, including Scopus, Wiley Online Library, Google Scholar and Science Direct, we selected, summarised and analysed 53 academic studies. We find that most studies build their models and simulations based on the 'beer distribution game' and analyse the results at the individual level. We also demonstrate the importance of studying human factors in the bullwhip effect through adapting Sterman's double-loop learning model. Based on this model, we categorise and analyse the behavioural factors that have been studied and identify the explored behavioural factors for future research. Based on our findings, we suggest that future studies could consider social and cultural influences on decision-making in studying the bullwhip effect. In addition, further aspects of human mental models that cause this effect can be explored.

Keywords: bullwhip effect, behavioural causes, systematic review, cognitive psychology, supply chains

1. Introduction

The bullwhip effect, also known as demand information amplification or the Forrester (1958, 1961) effect, is a phenomenon whereby a small variation in end-customer demand leads to a significant fluctuation in orders that the upstream supplier receives in the supply chain system (Lee, Padmanabhan, & Whang 1997). This phenomenon has a tremendous negative influence on supply chain performance, with associated costs, such as machine capacity and staff recruitment fluctuations and excessive inventory levels.

Traditional studies on the bullwhip effect have focused on the operational perspective, including its causes (Lee, Padmanabhan, & Whang 1997; Lin et al. 2017) and mitigation solutions, such as reducing lead time and increasing information transparency (Lee, Padmanabhan, & Whang 1997; Wang & Disney 2016). However, human factors—psychological or behavioural causes—may lead to the bullwhip effect (Sterman 2006), because irrational decisions can be produced by individual cognitive limitations (Gino & Pisano 2008; Loch & Wu 2005) and stressful environments (Sterman & Dogan 2015). Thus, even under a rational operational decision-making process (e.g. when the order decision is mathematically optimal), irrational behaviours still strongly influence the bullwhip effect level in supply chain systems (Sterman 1989a).

An increasing number of studies have explored the behavioural causes of the bullwhip effect in supply chains over the past three decades. The topics studied include inventory information sharing (e.g. Croson & Donohue 2003, 2006), training and communication (Wu & Katok 2006), reactions to reverse bullwhip effect and supply shock (Rong, Shen, & Snyder 2008), trust in collaboration (Cao, Baker, & Schniederjans 2014) and human judgement in forecasting (Baecke, De Baets, & Vanderheyden 2017). These studies integrated human behaviours into research on

operations management and formed a new research approach to the bullwhip effect in supply chains by adopting theories from cognitive and social psychology.

Given the prevalence of behavioural research on the bullwhip effect, we aimed to systematically review relevant works. The systematic review method is considered an evidence-based practice (Jones & Gatrell 2014), which has been expanding driven by topic-related questions in different disciplines, and its application and expansion have enriched and developed knowledge bases and research methods in different fields (Tranfield, Denyer, & Smart 2003). We acknowledge that several reviews have been devoted to the bullwhip effect (Bhattacharya & Bandyopadhyay 2011; Geary, Disney, & Towill 2006; Giard & Sali 2013; Miragliotta 2006; Wang & Disney 2016), which have comprehensively reviewed the methods applied for modelling and reducing bullwhip effect. For example, Wang and Disney (2016) classified methods, particular the operational research approaches applied in modelling bullwhip effect, and highlighted solutions, such as the value of information sharing across the supply chains (Giard & Sali 2013). Further, recent reviews (Arvan et al. 2019; Fahimnia, Sander, & Siemsen 2020; Perera et al. 2019) contributed to revealing the scope of human judgement in supply chain forecasting, which could be considered as one of behavioural factors driving the bullwhip effect. Within the board operations and supply chain context, Fahimnia et al. (2019) reviewed and categorised 12 operations contexts as well as emerging topic considerations, and Perera, Fahimnia and Tokar (2020) reviewed the behavioural experiments in ordering and inventory decisions.

Nevertheless, most such reviews have only considered behavioural factors for the bullwhip effect as one of the reviewed topics, or have reviewed the behavioural factors for bullwhip effect associated with operational causes (e.g. forecasting). Further, some reviews (e.g. Bhattacharya & Bandyopadhyay 2011; Geary, Disney, & Towill 2006; Miragliotta 2006) are

outdated. To the best of our knowledge, until date, no review has systematically explored the behavioural causes of the bullwhip effect within the context of supply chains. Therefore, the main objective of this study was to classify, analyse and synthesise the behavioural causes of the bullwhip effect from different aspects. To this end, we summarised the research methods, research levels and research clusters in the study of behavioural factors of the bullwhip effect, and we categorised these behavioural factors. This study offers two main contributions, as follows:

1. demonstrating that human and behavioural factors cannot be ignored in examining the bullwhip effect, which will motivate future studies to include human factors in the decision-making process of the bullwhip effect
2. identifying research gaps to indicate a future research agenda through understanding the influence of human and behavioural factors on the bullwhip effect and considering possible problems in real business scenarios.

The remainder of this paper is organised as follows. Section 2 presents the relevant background and fundamental theories of this topic. Section 3 includes the method adopted in this study, and Section 4 mainly discusses the aggregated results found in the collected studies. Section 5 presents the content classification and analysis, and Section 6 emphasises the existing research gaps based on the analysis results, proposes potential future research directions and discusses the limitations of this study.

2. Background and Fundamental Theories

2.1 Brief History of Bullwhip Effect Research

The concept of the ‘bullwhip effect’ was discovered and termed ‘demand amplification’ by Professor Jay Forrester (1958, 1961) during the development of the system dynamics discipline.

Burbidge (1961, 1984) proposed a method from the operational perspective to control inventories and asserted that the bullwhip effect was caused by using stock control ordering during the process of transmitting demand. Sterman (1989a, 1989b) used the 'beer distribution game' experiment to explore the bullwhip effect and indicated that it was caused by irrational decisions resulting from decision-makers' misperceptions of feedback. Further, Lee, Padmanabhan and Whang (1997) proposed four underlying causes for bullwhip effect based on a comprehensive systematic analysis: order batching, the shortage and rationing gaming, demand signal processing and fluctuating prices. Based on these causes, more scholars began to study the bullwhip effect—for instance, Cachon and Lariviere (1999) examined rationing gaming and order batching by using a supply chain system with N-retailers and one supplier, and Kim et al. (2006) introduced stochastic lead time.

Such studies focusing on the operational causes of the bullwhip effect have assumed that humans are always rational. However, a series of experimental studies have indicated that human rationality is bounded, and hence, individuals' decisions can deviate from the expected decision and subsequently affect performance. Thus, the behavioural operations approach has emerged and provides a new theoretical basis for exploring the bullwhip effect further.

2.2 Behavioural Operations Research

The study of the bullwhip effect from the perspective of behaviour can be traced to Forrester (1958). On this basis, Sterman (1989a) used experimental methods to explore the behavioural causes of the bullwhip effect and asserted that the behaviour of the people managing the supply chain system is key to improving its performance. Thus, it is necessary to further explore the behavioural factors of the bullwhip effect. Moreover, in recent years, scholars have proposed that operations management be examined from the behavioural operations perspective, which

provides a new research approach to the bullwhip effect. For example, Loch and Wu (2005) discussed how to consider more practical behavioural factors in theoretical analysis models and proposed that human behaviours result from individual cognitive limitations, social interactions with others and cultural evolution and transmission. Further, Bendoly, Donohue and Schultz (2006) and Bendoly et al. (2010) summarised relevant psychological theories and reviewed experimental research and knowledge to reveal the influence of human behaviour on operations management. They assumed that knowledge on behavioural operations mainly derives from system dynamics, group dynamics, social psychology and cognitive psychology. In addition, Gino and Pisano (2008) stated that in investigating behavioural operation, a new approach is to study operations management by combining cognitive and social psychology theories. This approach involves exploring the relevant attributes of cognition, the dynamics of groups and organisations that affect operations and the interactions between these attributes and operation systems.

Given that most operations occur in the context of large organisations, communication, learning and culture are crucial. However, it is also necessary to consider elements of cognitive psychology, which encompasses mental psychological processes, involving topics on decision-making, emotion, perception, memory and problem-solving (Gino & Pisano 2008). To conclude, explorations of the causes of the bullwhip effect from the behavioural perspective are significant to the supply chain management field, given that the behaviours of decision-makers who manage the supply chain have marked effects on supply chain performance. Therefore, the analysis of human cognitive and social factors from a psychological perspective is essential in investigating the bullwhip effect.

3. Methodology

This study adopted a systematic review method that has four stages, namely, the identification, selection and evaluation of sources followed by the analysis of data (e.g. Bryman 2012; Hart 1998). A systematic literature review is aimed at minimising selection bias during the process of collecting relevant articles by defining and excluding keywords to describe and discuss the search results (Saunders, Lewis, & Thornhill 2009; Spina et al. 2013). Compared with the traditional review method, its process and results are more scientific, objective and transparent (Durach, Kembro, & Wieland 2017; Tranfield, Denyer, & Smart 2003). The details of this method are discussed in the following subsections, and the literature data collection and screening process is displayed in Figure 1.

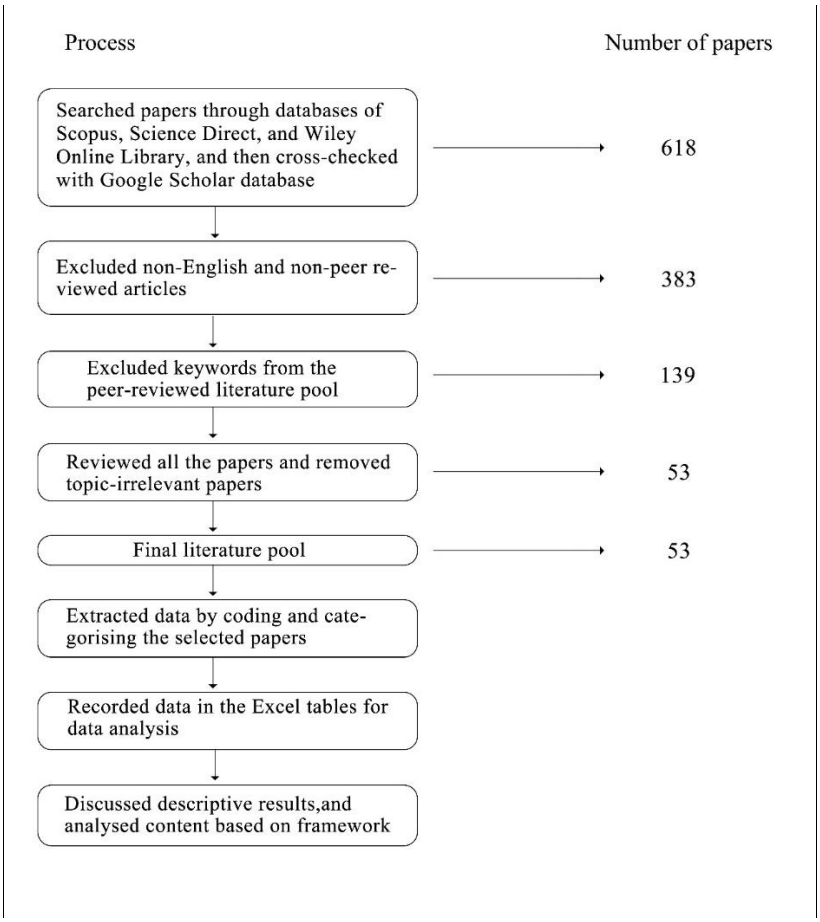


Figure 1: Literature data collection and screening process

3.1 Identification of Keywords and Sources

The keywords were determined to indicate the two main spheres that comprise this literature review—the bullwhip effect and the associated psychological factors. All the co-authors discussed and agreed on all the search terms, and the fourth author was the gatekeeper of this study. The study was based on a keyword search in the Scopus database. We accessed this database using the search field 'article title, abstract and keywords' and identified the specific search terms to ensure that we collected all relevant documents. We combined the keywords 'bullwhip effect', 'beer game' and 'beer distribution game' with each of the following search terms: 'reaction', 'preference', 'misperception', 'perception', 'individual', 'human', 'behaviour', 'cognitive', 'heuristics', 'social', 'interaction', 'learning', 'communication', 'judgement', 'psychology', 'behavioural operations', 'decision', 'rationality', 'trust', 'problem solving', 'personality' and 'overconfidence'. The keywords 'beer game' and 'beer distribution game' were also used in the search because this experimental method is widely used to study the bullwhip effect and the decision-making process in a dynamic environment. Moreover, the search results for 'bullwhip effect' were limited; thus, 'beer game' and 'beer distribution game' were added to expand the search range of this research topic.

We found a total of 586 articles from the databases of Scopus, Science Direct and Wiley Online Library. To enhance rigour, we used Google Scholar to cross-check after completing source identification and added 32 new articles after cross-checking, resulting in a list of 618 articles. To align with the scope, we limited the results to peer-reviewed articles published in all date ranges and in English, since peer-reviewed articles are the most widely used knowledge base for validating results and publishing new findings in the research community (Spina et al. 2013). We removed articles that were not published in English and grey literature, such as books, book chapters, conference papers, reviews, notes and dissertations (Bryman 2012; Eksoz,

Mansouri, & Bourlakis 2014; Perera et al. 2019). Thus, the final list had 383 journal articles published until January 2021.

3.2 Source Selection

Source selection includes investigating the data and corresponding sources based on the review aims (Spina et al. 2013). In systematic literature reviews, certain keywords are excluded to refine the search results to match the boundaries systematically (Saunders, Lewis, & Thornhill 2009). Thus, in the present study, we excluded keywords comprising terms that we considered beyond the scope of this topic and unrelated to the areas of human factors associated with the bullwhip effect. For instance, we excluded 'marketing', 'Markov processes', 'algorithms', 'genetic algorithms', 'mean square error', 'Lyapunov methods' and 'production engineering'. This method reduced the number of articles in the peer-reviewed literature pool; however, we carefully checked every article we removed to ensure that it was indeed beyond the research scope.

We checked the remaining 139 articles one by one to ensure that they were consistent with our research scope and excluded a further 86 from the list, which we considered beyond the research scope. These excluded articles treated the supply chain as a 'hard' system and used operations research–based methods to explore the dynamic behaviour of the bullwhip effect, such as studies on control engineering (e.g. Hofmann 2017; Naim et al. 2017), statistical approaches (e.g. Costantino et al. 2014; Disney, Towill, & Van De Velde 2004), hard simulation (e.g. Liu, Howley & Duggan 2012; Poornikoo & Qureshi 2019) and mathematical optimisation (e.g. Fu et al. 2014; Sadeghi et al. 2013). As a result, 53 peer-reviewed studies, published from 1988 to January 2021 were selected as the final literature pool. This literature pool was shared among, and confirmed by, all co-authors.

3.3 Source Evaluation

The purpose of source evaluation is to extract data by coding and categorising the studies selected. We designed the coding process to understand the approach, focus and findings of the selected studies on the bullwhip effect. Analysing the information these studies contained was essential to determining the directions of the literature from the aspects of the research areas considered over time in a systematic review (Snyder 2019). Table 1 displays the coding criteria we used, including the coding items, their description and the reason for using these items. The results of the coding were recorded in Microsoft Excel tables for data extraction and data analysis.

Code	Description	Reason for Use
Authors' names	Authors of the study	To identify studies by authors
Publication year	Year in which study was published	To enable a view of studies over time
Journal	Journal of final publication	To identify trends in published journal articles
Title	Title of the study	To ensure the title of each article was correct
Research methods	The methods used in reviewed studies: - modelling - simulation experiment (simulating a business scenario that involved subjects without control and experimental groups) - controlled experiment - case studies - survey/questionnaire - computer simulation (mathematical simulation)	To identify trends in methods
Research area cluster	Topic and research area on which the study focused	To identify the main areas of interest addressed in the studies
Identification number	Number assigned to each article	To ensure all articles were coded
Research analysis level	Analysis level of the study: - individual level - group and organisational level - cultural level	To identify trends in analysis level

Findings	Influence on bullwhip effect and on supply chain	To investigate the findings of each article and the effects of the findings on the research objectives
Behavioural factors	Types of behavioural factors studied in bullwhip effect research: - social interaction (communication and coordination, information sharing and trust) - information feedback (perception, ambiguity and debiasing) - mental models (judgement anchoring and adjustment, framing effect, overconfidence, underweighting and overweighting, rationality/bounded rationality, misperception of feedback, procedural rationality, problem-solving, system thinking and cognitive reflection) - strategy (decision patterns and risk aversion) - behaviour (hoarding behaviour and inaccurate behaviour) - individual traits (personality, and age and experience) - emotions (frustration and helplessness, and panic)	To identify the behavioural factors that the articles studied

Table 1: Coding criteria for the systematic review

3.4 Data Analysis

The process of data analysis in a systematic review involves extracting and synthesising the relevant information from the selected studies and analysing the results to enable the reviewer to identify future research directions (Snyder 2019). Therefore, we analysed all the data extracted from the final list and used the analysis results as the basis for determining research gaps. The aggregate results are presented in Section 4. Moreover, given that we aimed to analyse the current situation of the studies on the bullwhip effect involving human behavioural factors, we considered it necessary to classify the behavioural factors of the selected articles and discuss the results.

We adapted Sterman's (1994, 2000) double-loop learning model to categorise the content of the selected articles (Figure 2). This model includes three feedback loops in the learning and decision-making process. The first feedback loop involves 'real world', 'information feedback'

and ‘decisions’. In this loop, humans compare the perceived information about the real-world state to their desired state, and then try to make decisions to move the real state towards their expected state. The second loop indicates that humans make decisions not only based on their perceptions of the real world but also based on decision rules. These decision rules in decision-making are governed by mental models, which can be altered by information from the real world. The third feedback process links ‘information feedback’ and ‘mental models’, representing that information can change the mental models of humans, and mental models can affect the information perceived from the real world. This model indicates that the information feedback humans perceive from the complex real world will not only alter their decisions in the context of existing decision strategies, but also alter their mental models (Sterman 1994, 2000). Mental models are the internal representations of external surrounding attributes and explain perception, reasoning and decision-making in human cognition (Johnson-Laird 1983; Sterman 2000). They can guide human perceptions and help shape behaviours.

We adapted the double-loop learning model (Sterman 1994, 2000) for two reasons. First, this model includes the core of system dynamics and the basis for all decision-making in the dynamic world (Forrester 1961), that is, the cognitive process of decision-making in mental models. Thus, this model provides a base framework for categorising the human factor causes of the bullwhip effect from the perspective of behaviour operations (Bendoly, Donohue, & Schultz 2006; Bendoly et al. 2010; Gino & Pisano 2008; Loch & Wu 2005). Second, using this model enables identifying the state-of-the-art of the behavioural causes of the bullwhip effect from the perspective of the decision-making and learning feedback process in the dynamic environment. This identification is particularly important because limited cognition and information (Sterman 2000) cause non-optimal decisions; thus, the factors that can cause these

limitations in optimal decision-making must be identified. This model facilitates identification of not only the factors that have been studied but also the factors that are unexplored.

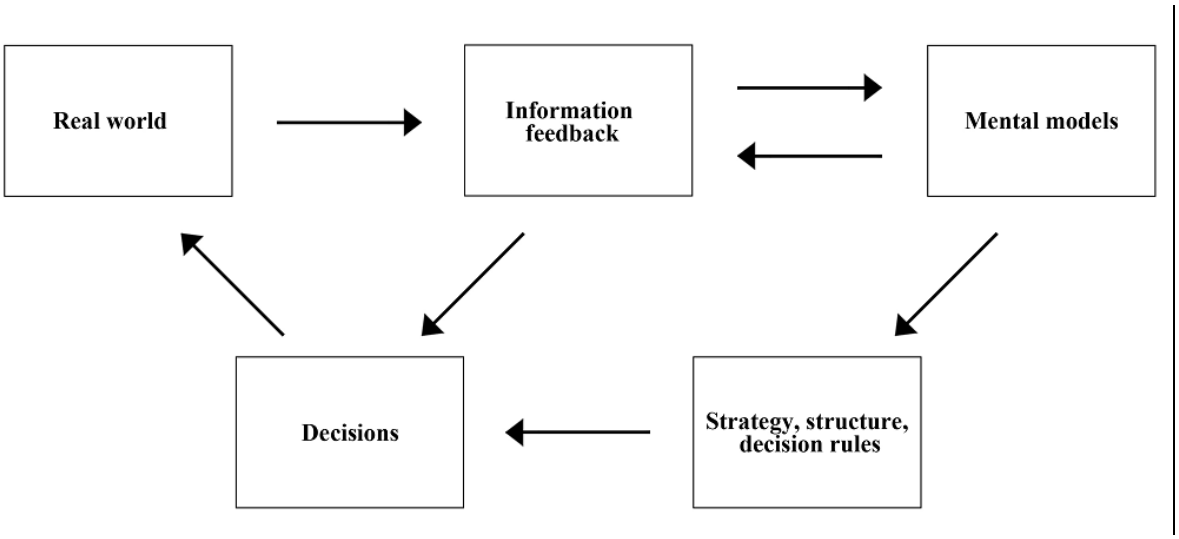


Figure 2: Double-loop learning (Sterman 1994, 2000)

4. Aggregate Results

In this section, we present the primary results from the analysis of the final article list. We discuss the aggregate results of the selected articles from the perspectives of the publication year, the journal title and quality counts, the research area cluster, the methods used and the research analysis level.

4.1 Publication Year and Journal Title

The results on analysing the publication year of the selected studies indicated that an increasing number of scholars are devoting attention to the effect of human factors on the bullwhip effect. The number of selected studies on the behavioural factors regarding the

bullwhip effect has gradually increased since 2002 and started to decline from 2015 (see Appendix A).

The final literature pool of 53 articles was derived from 32 journals. The journal title classification is presented in Appendix B, according to the Academic Journal Guide (Chartered Association of Business Schools [ABS] 2018) and the SCImago Journal and Country Rank. This classification illustrates the name of the journal and the location of the research field. The results indicated that 23 journals were listed in the ABS and nine were not. Most of the articles were from *International Journal of Production Economics* (six) and *Production and Operations Management* (five), which specialise in operations and technology management.

4.2 Major Research Cluster

We adopted a word cloud to construct and analyse the main research area clusters based on the frequency of the keywords used in the literature pool of the 53 articles (Figure 3). This word cloud showed that these keywords were indicative of the major research areas addressed in the selected articles, and all keywords were relevant to behavioural factors and the bullwhip effect. The most common keywords used included ‘bullwhip effect’, ‘supply chain management’, ‘behavioural operations’ and ‘beer game’. Among these, ‘bullwhip effect’ appeared 25 times, ‘supply chain management’ 19 times, ‘beer game’ 11 times and ‘behavioural operations’ 10 times. Other commonly used keywords that appeared fewer than 10 times were ‘inventory management’, ‘beer distribution game’, ‘supply chain’, ‘simulation’, ‘system dynamics’, ‘decision making’, ‘experimental economics’, ‘dynamic decision making’, ‘experiments’, ‘information sharing’, ‘human experiments’, ‘decision biases’, ‘supply chain coordination’, ‘inventory’, ‘inventory control’ and ‘structural equation modelling’. Overall, this analysis indicated that the most attention has been devoted to the areas of the bullwhip effect and supply

chain management, followed by the areas of resolving the bullwhip effect by using the beer game setting and from the perspective of behavioural operations. Moreover, other methods and concerns of the bullwhip effect studies were suggested by the appearance of other keywords, such as ‘decision biases’ and ‘simulation’.

Figure 3: Word cloud of most frequent keywords in reviewed articles

4.3 Analysis of Research Method and Research Level

We classified the methods used in the selected articles based on Bendoly et al.’s (2010) summary of the typical research methods used in the study of system dynamics, group dynamics, cognitive psychology and social psychology. The classification included case study, controlled experiment, survey/questionnaire, modelling and simulation. Case studies involve observations of human behaviours or direct communication with people in a real working environment to explore a real-world phenomenon (e.g. Niranjan, Wagner, & Bode 2011). Controlled experiments refer to research involving manipulation by researchers to study different treatments on different participants and groups (e.g. Croson & Donohue 2003). In a complex environment, such as a supply chain, controlled experiments allow researchers to control and

design the environment and identify causality between behavioural factors and empirical regularities (Donohue & Croson 2002). Surveys/questionnaires are a method through which researchers collect reliable data from humans, by measuring the problems under study (e.g. Moon & Kim 2005). Modelling involves establishing models to generate accurate statements about behavioural processes to explain, predict or control human behaviour in the laboratory or real business world (e.g. Bruccoleri, Cannella, & La Porta 2014; Mazur 2006). The computer simulation method involves studying a system that exists or is designed by simulating a real scenario or system, and it examines the dynamic interaction between human behaviour and complex systems (e.g. Rong, Shen, & Snyder 2008). In addition to these research methods, we considered 'simulation experiment' as a research method. Unlike controlled experiments and computer simulations, this method simulates supply chain scenarios involving subjects without controlling independent variables or having control and experimental groups (Niranjan, Metri, & Aggarwal 2009; Di Mauro et al. 2020), such as the 'beer game' introduced by Forrester (1958).

The results reflected that most studies (66%) built their simulations, models and experiments based on the 'beer game' (see Appendix C for details). Thus, this research method has been the most widely used in studies on the bullwhip effect in supply chains. However, not all the studies used the beer game simulation in their research method. For example, Delhoum and Scholz-Reiter (2009) used the 'supply net game', which is a simulation game of production in networks. Among all the methods (see Figure 4), the controlled experiment was the most widely adopted method in this sample (56.6%). The next most common method was modelling (26.4%), followed by computer simulations (20.8%), surveys/questionnaires and simulation experiments (17%) and, last, case studies (3.8%). Moreover, 39.6% of the selected studies applied more than one method.

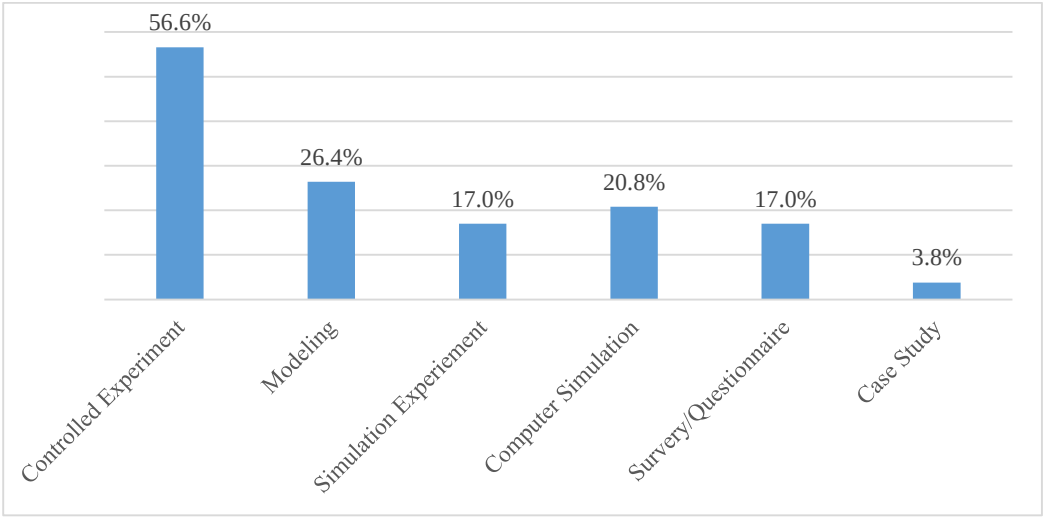


Figure 4: Research method applied in the literature pool

The research level depended on the behavioural content of the selected articles and the perspective of studying this behavioural content. The research content relates to group attributes and individual attributes, which could indicate how individual factors and social interaction factors affect operational performance and how such attributes relate to cultural (Gino & Pisano 2008; Loch & Wu 2005). Thus, we classified the research into three levels: individual; group and organisational (social); and cultural. In individual-level analyses, the behavioural content focused on the individual cognitive perspective, such as decision-makers' thinking, perceptions, reasoning and emotions related to supply chains (Gino & Pisano 2008). The group- and organisational-level analyses investigated the social interactions among all members in the supply chain, such as trust and communication (Gino & Pisano 2008). The cultural-level analyses studied likely differences in supply chain performance under certain cultural backgrounds. Overall, 77.4% studies selected were undertaken at the individual level, which means that these examined research content at the individual level of each role or each decision-maker (e.g. Cantor & Macdonald 2009). Of this 77.4%, in all, 31.7% studied individual cognition at the social level and 2.4% at the cultural level. The second most common level was

the social (group/organisational) level, with 47.2% of studies focused on interaction among other members (e.g. Wu & Katok 2006). Moreover, 8% studied social interaction at the cultural level. The least common level was the cultural level, with 3.8% of studies undertaken at this level and based on culture (e.g. Cao, Baker, & Schniederjans 2014).

4.4 Professional v. Student Participants

The use of professional participants or student participants in beer game is arguable in the research of bullwhip effect. Among 39 studies that applied a controlled experiment or a simulation experiment involving human participants, 35 studies comprised student participants, such as undergraduate, graduate and MBA students. The samples had either one type of students or a combination of two or all types. Further, these 35 studies can be classified into studies that included student participants with (10; e.g. MBA students) and without work experience (25; e.g. undergraduate students). In addition, the samples of nine studies included professional participants, among which three had only professional participants.

Table 2 summarises the studies involving participants with work experience and indicates whether these studies compared the results on participants when including more than one participant type. The results illustrated that seven articles made such comparisons of their experiment results, of which five studies indicated that the performance of students without work experience was consistent with that of professionals (Croson & Donohue 2006; Sterman 1988, 1989a; Tokar et al. 2016; Turner et al. 2020) and one found no significant difference between students with (i.e. MBA students) and without work experience (Tokar et al. 2016). However, Tokar, Aloysius and Waller (2012) and Ancarani, Di Mauro and D'Urso (2016) have observed that managers tend to perform better than student participants, since students may not

have better understanding of concepts than professionals and they tend to frequently overestimate orders in the experiment.

Overall, most studies highlighted that professional participants and students do not differ significantly in terms of their performance in the beer game experiment. However, the participants in most studies had never played the beer game before, while few studies repeatedly ran the beer game for the same group of students and professionals to compare their performance. Thus, the similar performance found between both samples may be because both were not familiar with the game rules and may have intuitively and randomly placed orders. Consequently, we argue that professionals and MBA students with rich working experience may perform differently from students without working experience, driven by some behavioural factors, such as overconfidence and emotion (Ancarani, Di Mauro, & D'Urso 2016; Sterman 1989a), although this is an area for future studies.

Authors (year)	**Participants**			
	Students without work experience (e.g. undergraduate)	Students with work experience (e.g. MBA)	Professionals	Comparison
Sterman (1988)	√	√	√	√
Sterman (1989a)	√	√	√	√
Steckel, Gupta and Banerji (2004)		√		
Croson and Donohue (2005)		√		

Croson and Donohue (2006)	√		√	√
K-T Hung and Ryu (2008)		√		
Niranjan, Metri and Aggarwal (2009)		√		
Haines, Hough and Haines (2010)		√		
Niranjan, Wagner and Bode (2011)		√		
Tokar, Aloysius and Waller (2012)	√		√	√
Narayanan and Moritz (2015)	√	√		No comparison
Tokar et al. (2016)	√	√	√	√
Ancarani, Di Mauro and D'Urso (2016)	√		√	√
Cannella et al. (2019)			√	
Di Mauro et al. (2020)			√	
Turner et al. (2020)	√	√	√	√

Table 2: Summary of studies involving participants with work experience

5. Content Analysis

We modified the double-loop learning model based on the theory of behavioural operations and the findings from the selected articles shown in Figure 5. A notable point is that we used our modified model to represent decision-making in a single echelon in supply chains involving social interaction with other individuals. We added three important behavioural factors to the original model: social interaction, individual traits and emotions. Social interaction represents the interactions between decision-makers in different echelons in a supply chain system, regarding, for example, information sharing and coordination. Since a supply chain is a social network consisting of many individual echelons, it is necessary to understand how the presence of other echelons influence the current state of the real world, and thus influence the decisions and behaviours of those in individual echelons, and the whole supply chain network. In addition, individual traits, such as personality, age, gender and cultural background, can affect cognitive processes (in Figure 5, the box within blue dashes represents the factors involved in the cognitive process). We also added the factor emotion to our modified model since it is essential in decision-making and in completing human rationality (Simon 1983). Several studies from our literature pool indicated that participants felt frustrated and helpless during the experiment. These emotions could be triggered in case of a mismatch between the perceived outcomes and participants' expectations about their last decision (Sterman 1989a). These emotions could affect social interactions since people may blame and mistrust others owing to such unexpected outcomes (Kovacevic et al. 2013; Sterman 1989a). Moreover, emotions could influence their decision strategy and behaviours (Nienhaus, Ziegenbein, & Schoensleben 2006; Sterman and Dogan 2015). Likewise, studies have demonstrated that emotions could be influenced by individual traits; for instance, those with a neurotic personality more likely tend to be anxious (Thompson 2008). However, we found it difficult to ascertain the type of relationships between

emotion and other behavioural factors based on the information from the selected articles. Therefore, we used red dashes in our modified model to indicate that there is a complex relationship between emotion and social interaction, individual traits and cognitive processes (including other behavioural factors in the box within blue dashes).

Through our modified Sterman's (1994, 2000) framework, we classified the content of all collected articles into seven major categories. The category of social interaction had the subcategories of communication and coordination, information sharing/exchange and trust. This category indicated whether the study involved interactions with other individuals that could alter the state of the environment. The other six major categories relating to cognitive psychology were emotion, individual traits, information feedback, mental models, decision strategy and decisions. In addition, the modified framework shows that each main category had subcategories that covered the content related to behavioural factors in the literature pool of the 53 articles selected (see Figure 5).

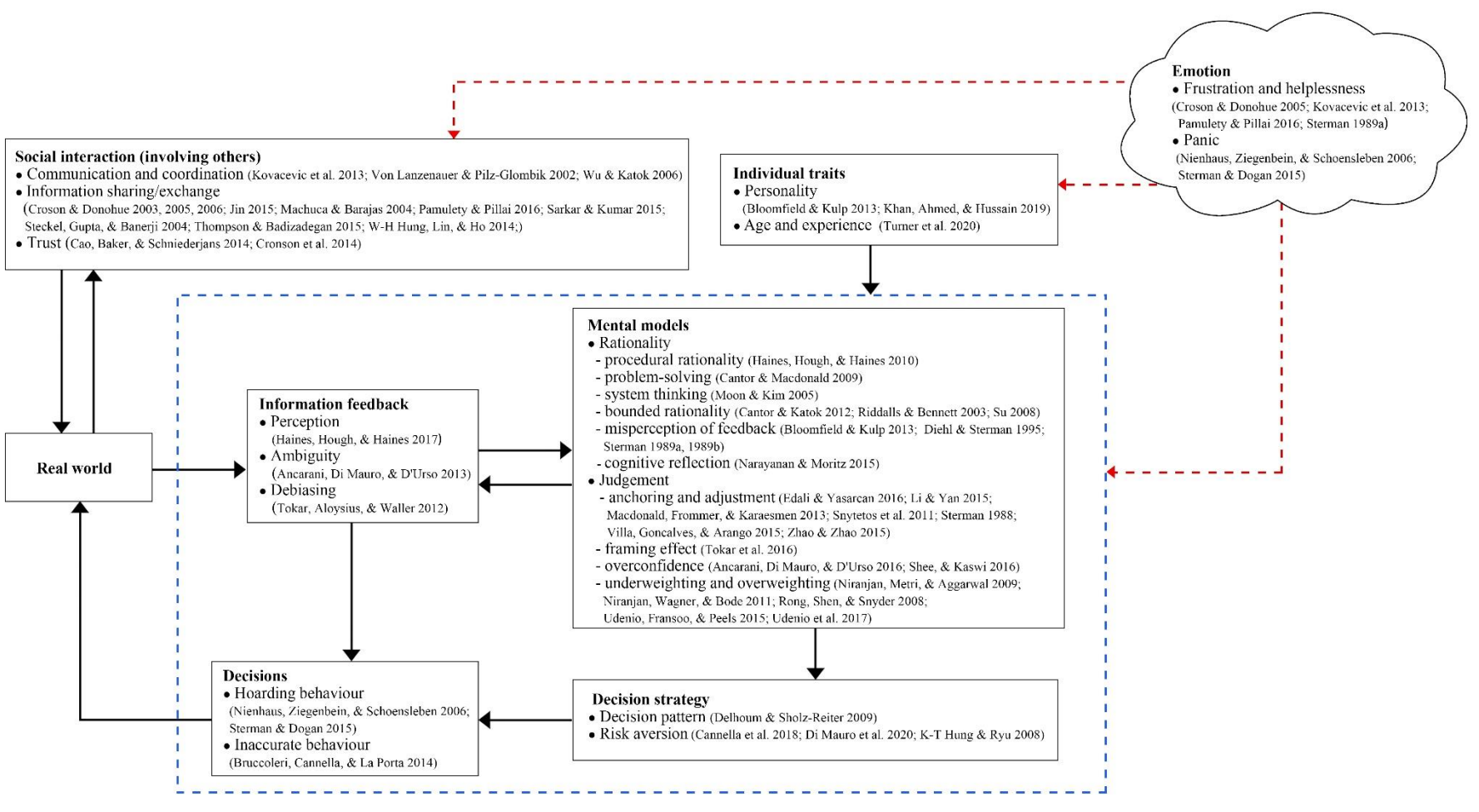


Figure 5: Advanced decision-making model (adapted from Sterman 1994, 2000)

5.1 Social Interaction

5.1.1 Communication and coordination

According to Sterman (1994, 2000), mental models of decision-making can be altered by social interactions with the real world. Communication and coordination are social interactions that can provide additional information feedback about the dynamic system in supply chains to decision-makers. These interactions can solve the bullwhip effect problem caused by irrational decisions made with limited information. Among the selected articles, Von Lanzenauer and Pilz-Glombik (2002), Kovacevic et al. (2013) and Wu and Katok (2006) studied the role of these social interactions in supply chain management. By applying the approach of contrasting model-based and human decision-making, Von Lanzenauer and Pilz-Glombik (2002) demonstrated that centralised decision-making can produce better performance than decentralised decision-making owing to the coordination among supply chain members. Kovacevic et al. (2013) proposed a theoretical approach to identify the patterns of communication through transactional analysis. An appropriate communication pattern can result in efficient coordination, which can help reduce the bullwhip effect in a supply chain. Wu and Katok (2006) found through the beer game experiment that the bullwhip effect still occurs in the absence of communication and coordination even when participants are trained with relevant knowledge; however, decision-making with communication and coordination could improve supply chain performance.

5.1.2 Information sharing and exchange

Another form of social interaction is information sharing and exchange. By controlling all the operational causes proposed by Lee, Padmanabhan and Whang (1997) in the beer game, the results showed that sharing point-of-sale (POS) information could help reduce the bullwhip

effect in a stationary and known demand setting, and downstream inventory information sharing could benefit upstream members and reduce the bullwhip effect, but that sharing upstream information has no significant effect (Croson & Donohue 2003, 2005, 2006). Steckel, Gupta and Banerji (2004) examined the effect of reduced order and delivery cycles and shared POS information on the bullwhip effect. Jin (2015) conducted a controlled experiment with the beer game and noted that information sharing greatly reduced the bullwhip effect. Thompson and Badizadegan (2015) also demonstrated the importance of information sharing in reducing the bullwhip effect through an integrated analytical approach using the beer game. Through a case study, W-H Hung, Lin and Ho (2014) highlighted that information sharing could be affected by the degree of trust between partners; thus, strengthening trust could help increase information sharing and reduce the uncertainties that cause the bullwhip effect. Pamulety and Pillai (2016) studied customer demand information sharing and indicated that such demand sharing outperforms other forms of information sharing for reducing the magnitude of order variance. Sarkar and Kumar (2015) investigated information sharing using the beer game in a controlled experiment and suggested that sharing disruption information is beneficial in improving performance. Irrational decisions are made not only because of limited information but also because of information feedback delay; in this regard, Machuca and Barajas (2004) illustrated how to use an electronic data interchange to reduce information feedback delay to reduce the bullwhip effect and improve supply chain performance. However, even when information is shared with decision-makers, the bullwhip effect still exists.

5.1.3 Trust

By increasing confidence among members in supply chains, trust could lessen uncertainties and increase information sharing (Hung, W-H, Lin, & Ho 2014). Based on the survey method, Cao, Baker and Schniederjans (2014) proposed that *guanxi*—as an important element of social

capital in Chinese culture and society—has a positive influence on the bullwhip effect, and this influence would be weakened in an environment of uncertainty because of the lack of trust. Croson et al. (2014) conducted a study on trust by eliminating all the demand variability and forecasting without time limits in a controlled beer game experiment. Their study differed from the other controlled experimental beer games in that it was one of the three studies involving both participants and computer agents. Unlike the other two studies (Cantor & Macdonald 2009; Haines, Hough, & Haines 2017), they compared the condition in which participants manipulated all positions with that in which participants manipulated only one of the positions and computer agents managed the remaining positions. Each participant was informed about the presence of other participants and the computer agents and was also provided the publicly information about an optimal decision rule. The results indicated that treatment with all humans manipulated all positions performed worse than treatment involving computer agents. They found that the lack of trust and the lack of knowledge about the decision rules of the system were not only the drivers of coordination risk, but also the behavioural causes of the bullwhip effect.

In summary, the controlled experiment is the most frequently used research method, and the common conclusion is that building a good buyer–supplier relationship is central to reducing the bullwhip effect. For example, if participants believe in their partners and their abilities, it improves the supply chain performance (Croson et al. 2014). This finding is consistent with those about numerous real-world supply chain scenarios, such as the classic Barilla SpA (A) example (Hammond 1994). In this case, Barilla experienced the bullwhip effect caused by the lack of coordination, information sharing and trust among suppliers. Customers downstream focused on different objectives, without considering the effect on suppliers upstream. For instance, distributors purchased more dry products during a promotion so they could reduce

purchasing costs; however, they did not consider that this could cause demand fluctuations for their suppliers. Order fluctuations were generated by this hoarding behaviour because of some customers' distrust that their suppliers could not satisfy their demand. Moreover, some of Barilla's customers were unwilling to share POS information, which meant that Barilla could not forecast with accuracy, even though many articles have demonstrated such forecasting to be beneficial for the whole supply chain (e.g. Croson & Donohue 2003). If the supply chain members are willing to cooperate and build a strong relationship based on mutual trust, they can improve their own performance and the performance of the entire supply chain.

5.2 Information Feedback

5.2.1 Perception

Perception is the way that information is organised, selected and interpreted, so that the environment can be represented and understood. Perception can be shaped by other cognitive processes, such as attention (Schacter, Gilbert, & Wegner 2011), and can be guided by mental models. Haines, Hough and Haines (2017) investigated the effect of perception on the decision-making process in supply chains. In a laboratory experiment of supply chain simulation, they suggested that decision-makers in supply chains do not use all the available information in their decision-making with decision rules. However, they will select useful information and incorporate it into decisions based on their perception if they understand the cause-and-effect relationship regarding the information feedback in their mental models.

5.2.2 Ambiguity

Ambiguity occurs owing to a lack of information and understanding about the cause-and-effect relationship regarding perceived information feedback (Sterman 1994, 2000). Ancarani, Di Mauro and D'Urso (2013) introduced the concepts of demand and lead time uncertainty in

the controlled beer game setting and found that participants held fewer inventories when higher uncertainty existed. In addition, order variance tended to be higher under stochastic lead time in the experiment. This result can be explained by our adapted model. As a result of limited information, decision-makers do not understand the cause-and-effect relationship between their decisions and the effects of these decisions on the supply chain. Ambiguity results from limited information; yet decision-makers do not understand the effects of decisions because of the system complexity. Thus, they tend to make decisions based on known information and causality.

5.2.3 Debiasing

Debiasing is an intervention and a method to improve decision-making in supply chains. Based on an experiment in a single-echelon setting, Tokar, Aloysius and Waller (2012) tested the effects of debiasing on the inventory level, the order decision-making and the bullwhip effect and found that training on procedural knowledge can help improve the performance of supply chains. We categorised debiasing under information feedback because the results of applying knowledge gained through such training are perceived as information feedback to decision-makers. With feedback on information obtained through training, decision-makers are able to understand the cause-and-effect relationships and can thus alter their mental models and form new decision strategies.

The information feedback and mental models are highly related in the double-loop learning model. Perceived information feedback could help to change the mental model or to determine whether the feedback is consistent with the expectations in the existing mental model. Moreover, the information feedback is perceived based on the existing mental model about cause-and-effect relationships, and then, appropriate decision rules are adapted to make decisions. This

category includes only three articles, which discussed how perceived information feedback influences the decision-making process. The primary contribution of these articles was that decision-makers could make better decisions on understanding the cause-and-effect relationships among perceived feedback. Training and learning could help them better understand the causality among information feedback. Then, the mental model could be altered and could help decision-makers to seek useful information based on the feedback about causality. The difference between these three studies is that they used different information and supply chain settings. Haines, Hough and Haines (2017) manipulated information on the supply line and consumer demand, whereas Ancarani, Di Mauro and D'Urso (2013) manipulated information on lead time and demand, but not the actual demand or inventory sharing. Last, Tokar, Aloysius and Waller (2012) considered complete information sharing and found that too much information had a negative effect on performance. They tested both single-echelon and four-echelon settings, and the other two studies investigated only four-echelon settings. We suggest that more studies be extended to include other research settings, rather than only four echelons, such as through case studies with a single-echelon setting, for an in-depth study of the whole supply chain network, thus addressing the limitations of the beer game.

5.3 Mental Models

5.3.1 Rationality

Rationality refers to reasoning to achieve goals within mental models. However, cognitive limitations and imperfect mental models cause bounded rationality and affect decision-making (Simon 1947; Sterman 2000). Some selected articles study rationality from different perspectives.

Cantor and Katok (2012), Riddalls and Bennett (2003) and Su (2008) studied bounded rationality. By using a two-echelon supply chain setting, Cantor and Katok (2012) smoothed production when customer demand was seasonal; the smoothing behaviour became more significant when the cost of changing an order was high. Riddalls and Bennett (2003) redefined the beer distribution game as a time delay controlling system and demonstrated that instability can be improved once the bounded rationality level in the system is overcome. To further explore bounded rationality and the bullwhip effect, Su (2008) applied the quantal choice model to simulate bounded rationality and indicated that bounded rationality can explain the bullwhip effect, since humans do not always make optimal decisions. These studies applied modelling and simulation to connect the experiment and theories, to stimulate future behavioural studies regarding the bullwhip effect.

Procedural rationality refers to collecting information to make rational decisions in the process of pursing goals (Dean & Sharfman 1993). Using a controlled experiment, Haines, Hough and Haines (2010) studied procedural rationality and found that decision-makers made their choice depending on the analysis of their perceived information feedback from the experiment. Using different treatments of information availability, they found that performance was most affected by the procedural rationality of decision-makers in the retailer role and that providing limited information can cause the bullwhip effect.

Cantor and Macdonald (2009) studied the problem-solving approach. They investigated the bullwhip effect under different degrees of information availability, using a 2 × 2 experimental design of the beer game framework. They found that under limited information sharing, individuals with concrete (low-level) problem-solving skills perform worse than do those with abstract (high-level) problem-solving skills. In addition, having more system information does not result in better decisions and performance. This result may be attributable to the fact that

people do not have the mental model to perceive and understand the causality between information and decisions; thus, they do not have effective feedback to alter their current mental models and decision rules for decision optimisation.

Moon and Kim (2005) tested how the bullwhip effect changed based on the relationship between consistency and individual systems thinking ability. This ability refers to an individual's ability to solve a problem in a complex environment or system. Based on the survey, test and simulation research methods, the results indicated that individuals with high consistency and high systems thinking ability produce less bullwhip effect. This study demonstrated that a broad, holistic view of the dynamic system will have a positive influence on supply chain management. Moreover, determining how to develop systems thinking abilities should be the rationale underlying studies on human factors in supply chains.

Cognitive reflection is another behavioural factor under the rationality category. Narayanan and Moritz (2015) stated that cognitive reflection is a structured analytical problem-solving process that enables individuals to overturn or approve an immediately available answer. They argued that making decisions about supply line underweighting is related to the level of individual cognitive reflection, and that individuals with higher cognitive reflection have higher performance. The incorporation of perceived information in the decision-making process plays a key role in enabling the understanding of the causality of known information during problem-solving and analysis. Thus, future studies should examine how to improve relevant abilities in problem-solving to enable decision-makers to seek information feedback and alter mental models in a dynamic environment.

Sterman (1994, 2000) revealed that the misperception of feedback influences decision-makers' ability to understand the structure of the dynamic world from information feedback.

Using a simulation experimental method, Sterman (1989a, 1989b) identified misperception of feedback during the decision-making process and considered it as the driver of players' poor dynamic performance. One type of misperceived feedback was misperception of time delay, in which participants tended to ignore the delay between a control action and its full effect and tended to perform correction behaviour in capital stock. The second type was misperception of feedback between the environment and participants' decisions. This indicated that participants misunderstood information about the dynamic system when they placed orders or did not understand the dynamic system at all. As a result of their misperception of feedback from the environment and decisions, decision-makers cannot form accurate mental models and optimal decisions. The misperception of feedback view was strongly supported by Diehl and Sterman (1995) and Bloomfield and Kulp (2013). The former conducted an experiment with stochastic sales and indicated that feedback misperception worsened as the cause and effect increased. The latter found that the durability of inventory and transit delays decreased optimal decisions, even within one single-echelon experimental setting.

5.3.2 Judgement

The anchoring and adjustment heuristic can be considered as judgemental bias, which can affect decision-makers' mental model. Sterman (1988) stated that a simple heuristic method in judgement and behavioural decision theory could explain the behaviour of participants. Using modelling and a simulation experiment, he demonstrated that the heuristic that participants use can produce chaos in decision-making processes. This study created the foundation for studies on human factors of the bullwhip effect. By modelling Sterman's (1989a) experiment, Macdonald, Frommer and Karaesmen (2013) simulated the beer game and proposed that long-term performance cannot be forecast by short-term performance, and strong underweighting will not only cause the bullwhip effect but also affect the period of chaos before the system

reaches final stability. Villa, Gonçalves and Arango (2015) tested anchoring and adjustment, similar to Sterman (1989a), with a linear econometric model, and suggested that participants were unable to process the effects of delay and information feedback. Through systematic dynamic modelling of human judgemental interventions, Syntetos et al. (2011) explained the sources of the bullwhip effect in customer–supplier chains. They stated that human judgemental interventions strongly influence adjustments in forecasting and ordering. Zhao and Zhao (2015) decreased the biases of anchoring and underweighting with linear regression models, with full information shared during the experiment. Li and Yan (2015) found that different behavioural adjustment levels can lead to different performance levels because of individual differences, and that adjustment behaviour has less effect on performance under demand uncertainty than under supply uncertainty. They also suggested that over-adjustment is a behaviour that should be avoided in the decision-making process.

Further, Tokar et al. (2016) studied the framing effect bias through conducting experimental studies. This bias refers to making decisions based on decision-making choices framed as gains or losses (Tokar et al. 2016). In their study, negative frame resulted in greater inventory and orders; understocking occurred when orders and inventory in the positive frame, which can be debiased by framing decisions as losses.

Overconfidence has been defined as a judgemental bias in mental models that affects reasoning in decision-making (Sterman 1994, 2000). In most economic activities, people tend to be overconfident or overly optimistic about their knowledge, their ability level and the accuracy of the information they receive, and hence tend to underestimate uncertainties (Dessí & Zhao 2018). Ancarani, Di Mauro and D'Urso (2016) used the beer game to investigate overconfidence in supply chain ordering decisions and found that overconfidence may lead to the bullwhip effect and that environmental uncertainty is a cause of overconfidence. In contrast

to earlier studies, their participants were familiar with supply chain management. This fact led us to understand that in the experimental environment, even experts can be affected by overconfidence in their decisions. Shee and Kaswi (2016) also found that the managers from a local and multinational supermarket in Indonesia were overconfident about their decisions, which caused increasing variability to create the bullwhip effect. Unlike Ancarani, Di Mauro and D'Urso (2016), they used surveys to investigate a real situation, which helped them realise the true problem. However, the study only tested one country; thus, it was difficult to determine whether there would be different results in other countries.

Supply line underestimation/underweighting has been studied in many articles. Sterman (1989a) modelled decision-makers' behaviour in stock management and found that participants tended to ignore the supply line and underestimate the time delay between an action and its effect. His study influenced later research on behaviour theories for the bullwhip effect. Based on his study, Croson and Donohue (2003, 2006) also demonstrated that supply line underweighting contributed to the bullwhip effect, even though their controlled experiments allowed information sharing. To further test the results from prior studies, Niranjan, Metri and Aggarwal (2009) re-examined the study methods and found that subjects not only ignored or underweighted the supply line but sometimes even distributed a negative weight for the supply line. Moreover, Niranjan, Wagner and Bode (2011) presented a 'correction model' based on a simple recurrent network and stated that over-ordering occurs because of considering the supply line, rather than ignoring the supply line. By developing a system dynamics model, Udenio, Fransoo and Peels (2015) suggested that underweighting the supply line was not only caused by individual decision-making biases but also by the combination of organisations' reaction speed and a decision rule, and this decision rule prevents decision-makers from tracking the supply line by controlling the number of on-hand inventories.

In contrast, few studies have focused on the overestimation/overweighting of the supply line. Using simulation, Rong, Shen and Snyder (2008) focused on uncertainties from both the supply and demand sides and demonstrated that supply line overweighting and overreaction to shocks of capacity were the behavioural reasons for the reverse bullwhip effect in supply chain management. In addition, Udenio et al. (2017) used a control theoretic model to analyse the effects of behavioural biases on the stability and performance of supply chains. They demonstrated that underestimating the supply line can produce the bullwhip effect with demand shocks, which cannot be limited by order smoothing. They found no differences between the performance caused by supply line estimation biases and by unbiased policies when demand was stationary. Under this condition, order smoothing could improve supply chain performance, but only when demand was unpredictable in the worst case of order amplification.

This category covered 26 articles from our literature pool, indicating that most researchers focus on mental model–related causes of the bullwhip effect—the fundamental element of studying system dynamics and building models. The most frequently used research method was a controlled experiment (thirteen articles), followed by modelling (nine articles). By using a controlled experiment in a specific setting, different variables can be manipulated in treatment groups, and then compared with the control group. This enables understanding the cause-and-effect relationship between biases and the bullwhip effect, which can help build models and simulate optimal decisions based on this understanding in more complex scenarios. The information resulting from modelling and simulation could help individuals alter mental models, learn new decision rules and optimise decisions in the real world. Moreover, the studies in this category mainly focused on decision-making biases, such as the misperception of feedback, the anchoring and adjustment heuristic, overconfidence and underweighting/overweighting the supply line. This indicates that with limited information and limited understanding of the

information based on current mental models, human tend to use heuristics to make decisions. These decisions could also be influenced by other biases. However, based on the findings, these decisions could be improved by obtaining more information and more knowledge about this information.

5.4 Decision Strategy

5.4.1 Decision patterns

By implementing the supply net game, a simulation game of production networks, which differs from the beer game, Delhoum and Scholz-Reiter (2009) applied and assessed six different decision patterns of game participants: immoderate intuitive, selective intuitive, moderate intuitive, counterintuitive, collaborative and deceptive routines. Among these patterns, the counterintuitive pattern was the cause of the bullwhip effect since the players in this pattern continued to place orders even when inventories were full. The collaborative decision-making pattern allowed the participants to integrate production plans and design a more balanced production network through collaboration (without demand information).

5.4.2 Risk aversion

We placed risk aversion in this main category because it is a strategy or decision rule that decision-makers apply under risk. K-T Hung and Ryu (2008) found that changing the risk preferences of participants for demand variance was a critical behavioural factor that explained the deviation in ordering decisions in the bullwhip effect. Through controlled experiments and modelling, they found that order quantities were based on participants' expectations, as the degree of risk seeking altered with a change in supplier shortage and demand deviation. When the outcomes matched participants' expectations, they preferred to be risk averse. Contrarily, if the outcomes mismatched their expectations, they preferred to be risk seeking. Cannella et al.

(2019) applied the method of human experiment and multi-agent simulation to study risk aversion in a setting of a multi-echelon supply chain. To reduce the risk of stock out, inventory holding behaviour was observed in risk-averse participants when making order decisions. Di Mauro et al. (2020) studied the effect of risk aversion on replenishment decisions in the context of a multi-echelon supply chain. The results indicated that people with high risk aversion tended to display hoarding behaviour and could be less affected by experiential learning.

Thus, four articles fell into this category. All studies were undertaken with a multi-echelon supply chain. One study used a simulation experiment, rather than the beer game, to study decision patterns. The other three focused on risk aversion, with two of them observing hoarding behaviour when no information sharing and no communication were allowed, and one study proposing that information sharing could change risk aversion to risk seeking.

5.5 Decisions

Decisions can be considered the behavioural implementation after the decision-making process. Several studies have focused on the behaviour caused by decision-making. Through a simulation experiment of the beer game, Nienhaus, Ziegenbein and Schoensleben (2006) studied hoarding behaviour and panic reactions. Using a sample of more than 4,000 participants, they found that these two behaviours caused the underestimation of information, which amplified the bullwhip effect. However, the demand information in their experiment was not fully known to the participants, although this was supplemented in a later study on irrational behaviour. Sterman and Dogan (2015) observed hoarding behaviour in the context of the beer game through modelling and illustrated that hoarding and phantom behaviours were more likely to be triggered by real-world stressors. For instance, poor supplier delivery performance and increasing demand can be the stressors that trigger irrational decisions and behaviours. Real-

world stressors also lead to inaccurate behaviour in inventory recording (Bruccoleri, Cannella, & La Porta 2014). Bruccoleri, Cannella and La Porta (2014) proposed that stress (e.g. workload) can lead workers to make mistakes because of psychological sensitivity. This inaccuracy could also contribute to the bullwhip effect.

In all, three articles examined the actual behaviours of humans. The findings illustrated that environmental stressors and fear of having too much or too little inventory can influence rational decision-making. Few settings and methods have been used to study external factors, such as stressors, that may influence human behaviour when implementing decisions.

5.6 Individual Traits

5.6.1 Personality

Personality is an influential factor in decision-making processes and varies from individual to individual (Byrne, Silasi-Mansat, & Worthy 2015). Khan, Ahmed and Hussain (2019) analysed the bullwhip effect using the personality trait approach through the beer game and a questionnaire and noted a negative relationship between conscientiousness and the bullwhip effect. Bloomfield and Kulp (2013) examined the variables of the need for cognition, impulsiveness and the locus of control related to personality through a questionnaire and found that inventory durability and transit delay may be altered by these personality variables.

5.6.2 Age and experience

Recently, Turner et al. (2020) focused on the influence of age and experience on supply chain performance through the beer game simulation experiment. They compared the results of managers with those of students. The managers were older and had at least 15 years of professional experience in production agriculture, and the students were mostly younger undergraduates without managerial experience. In this case, the age of participants was

proportional to their professional work experience. This study revealed that more experienced managers did not perform better than less experienced students and that students tended to be more heavily anchored to the inventory level resulting in lower cost.

Thus, the studies under this category mainly focused on individual differences in decision-making for inventory management. One mainly focused on personality, and the other discussed findings about personality based on a survey. The results of the last article provide a basis for the fact that managers do not perform much better than students. In addition, we suggest that more research should be undertaken in this category within different supply chain settings, such as different echelons, different levels of information sharing and different disruptions, to find the impact of different individual traits on system dynamics.

5.7 Emotions

Emotion-induced irrational behaviours and decisions are present not only in experimental studies but also in the real world. Two noteworthy points are identified on comparing the emotional influence on participants in a laboratory experiment and in real life. First, participants in both settings could panic and feel frustrated on not getting what they want (Croson & Donohue 2005, Kovacevic et al. 2013; Pamulety & Pillai 2016; Sterman 1989a). This could result in panic buying and hoarding behaviour by participants in experiments and in real life when they are afraid that suppliers cannot satisfy their demand and begin to increase their orders and stock (Nienhaus, Ziegenbein, & Schoensleben 2006; Sterman & Dogan 2015). Participants tend to use this behaviour and strategy to cope with the fear and anxiety caused by the unknown. Second, it is difficult for the laboratory experiment setting to replicate some scenarios, such as the supply chain disruptions caused by natural disasters or human-made disasters in real life. Therefore, the emotions of participants in the laboratory may be less intense than those of real-

life participants who face real supply chain disruptions and unexpected risks. For instance, a toilet paper shortage has emerged in Western countries because of the coronavirus disease pandemic. Nobody anticipated the sudden onset and the severity of this pandemic. People feel anxious and helpless when they see the empty shelves in stores and they do not know what to do. Therefore, under the influence of such emotions, when they next see toilet paper in stock, they will buy more than they actually need and try to stock as much as they can to cope with their anxiety and fear of the future stockout of toilet paper. In turn, this sudden increase in demand and the consequent disruptions in supply will lead suppliers in the supply chain to feel the emotion of panic and to engage in hoarding behaviour.

6. Conclusion and Future Research Directions

In this study, we aimed to demonstrate the importance of human behavioural factors in analysing the bullwhip effect and to identify research gaps by considering possible problems in real business scenarios through a systematic review. We selected and analysed 53 peer-reviewed academic studies, using a systematic literature search procedure. The results indicated that behavioural factors involving social interactions and cognitive processes are important in the decision-making process in a dynamic system. Cognitive limitations and incomplete mental models can result in bounded rationality in decision-making and negatively influence supply chain performance (Sterman 1994, 2000).

We adapted Sterman's (1994, 2000) double-loop learning model to classify the behavioural factors revealed in the collected articles into seven main categories: social interaction, information feedback, mental models, decision strategy, decisions, individual traits and emotion. The results of each main category reflected the social and cognitive factors that have been studied in dynamic decision-making. Among these categories, most articles based their

studies on the beer game experiment (66%), whereas the controlled experiment method was the most used research method (56.6%). The category of social interaction revealed the importance of interaction involving communication, information sharing and trust in supply chain coordination. Further, in cognitive psychology, by applying the research methods of surveys/questionnaires or controlled experiments, the effects of individual traits (including personality) were demonstrated. The information feedback category demonstrated that the perceptions of information, ambiguity and debiasing can influence the information perceived from the real world and result in failure or success in altering mental models in decision-making. In addition, 26 studies focused on the mental model category, and were classified into the two main subcategories of rationality and judgement. The mental model category involved the largest number of studies, which indicated its importance in the behavioural factor research on the bullwhip effect. The next largest category was social interaction, which had 15 articles. The remaining categories had fewer than six articles. Further, the decision strategy and decision categories were shown to influence the bullwhip effect through controlled experiments, simulation experiments and computer simulation. In addition, the emotion category needs more research to determine its relationship with other behavioural factors.

All these main results implied that improvements to individual mental models would help to mitigate the bullwhip effect and to optimise supply chain decision-making. Moreover, the aggregated results indicated that most of the studies concentrated on analysing behavioural factors at the individual level, and few have considered behavioural factors at the social and cultural levels. Based on our research findings, we provide the following suggestions from various aspects regarding potential future research directions:

- *Research-level aspect:* Most of the studies were conducted at the individual level. This finding leads us to call for the study of the behavioural causes of the bullwhip effect at

the group level. Group decisions have been demonstrated to improve the quality of decision-making in the context of inventory management. In the newsvendor problem, group decisions debias the anchoring and adjustment in individual decision-making when receiving various pieces of information (Gavirneni & Xia 2009). Based on our findings, debiasing could help improve supply chain performance and reduce the bullwhip effect at the individual level (Tokar, Aloysius, & Waller 2012). Thus, it is worth determining the effect of group decisions on the bullwhip effect and whether group decisions result in better performance than individual decisions. Moreover, further studies should be conducted at the cultural level. Decision-makers from different cultures may have mental models that capture different information and result in different decisions. The 'pull-to-centre' effect of Chinese decision-makers tends to be more significant in the newsvendor problem than does that of American decision-makers because of 'the Doctrine of the Mean' in the Chinese culture (Feng, Keller, & Zheng 2011). No article has yet examined the bullwhip effect in terms of the effect of group decisions and cultural differences on decision-making. Thus, this is a research direction for future bullwhip effect studies.

- *Social psychology aspect:* Cultural factors (e.g. cultural differences and fairness), which have been found to be important in making decisions, little research considered in the selected articles (Ng, Lee, & Soutar 2007; Podrug 2011; Schramm 2001). In addition, trust in social interactions was studied in a controlled beer game experiment by comparing the condition in which participants manipulated all positions with the condition in which participants completed the inventory task individually and computer agents managed other positions (Croson et al. 2014). However, it could be extended to consider whether trust issues will decrease or increase with an increase in the number

of human participants in the experiment. Further, trust has not been measured at different levels in different scenarios. Moreover, other factors that could influence buyer–supplier relationships, such as commitment and contiguity (e.g. Zhao et al. 2008), have not been studied in terms of the behavioural elements of the bullwhip effect. Thus, further research can be conducted to fill the remaining gaps from the social psychology aspect, including on social norms and culture that can affect the supply chain management of multinational enterprises. In addition, the unexplored behavioural factors in buyer–supplier relationships involving social interactions provide avenues for future research.

- *Cognitive psychology aspect:* In this study, we adopted Sterman's (1994, 2000) double-loop learning model. This model involves the cognitive processes that influence how humans perceive environmental elements and detect useful information to make effective decisions (see the box within blue dashes in Figure 5). Scholars have studied the behavioural causes of the bullwhip effect in each category involving cognitive processes. Most studies investigated mental models, and we categorised only three as considering information feedback; thus, this area requires further study. Further, other factors in information feedback, such as attention (Simon 1957), have not been studied until date. The categories of decision strategy, decisions and individual traits require more attention, given the limited studies focusing on these two categories. The influence of emotions was highlighted as a crucial factor causing the bullwhip effect in selected studies. Helplessness, frustration and blaming have been observed during decision-making (Croson & Donohue 2005; Kovacevic et al. 2013; Pamulety & Pillai 2016; Sterman 1989a), and stressors created by the environment have been found to affect emotional state, resulting in irrational decisions and behaviours (Nienhaus, Ziegenbein,

& Schoensleben 2006; Sterman & Dogan 2015). Irrational behaviour, such as panic buying, can result in supply chain disruptions not only in experiments but also in real life. Thus, future studies should consider the influence of emotions on decision-making and behaviours, and more studies should be undertaken in the category of information feedback, decision strategy, decisions and personality, and their relationships with emotion.

- *Research method aspect:* Overall, most studies adopted the beer game simulation experiment as the research method. However, this approach has a few limitations. Although it is able to represent the dynamic system of supply chains in a laboratory experiment, the setting is not as complex as a real-world business scenario. In addition, this method takes some time to introduce to the participants, and the experimental process is relatively slow if involving human participants. Hence, future studies should consider case studies as the research method to determine the effect of behavioural causes in the real world, because case studies can identify and describe the key variables and could thus represent the supply chain management field (Stuart et al. 2002). Moreover, case studies have the advantage of offering deep insights into human behaviour within a specific context (e.g. the decision-making environment and industrial settings). In addition, the category of social interactions and mental models should be investigated using research methods other than the controlled experiment. Further, more studies should compare the performance of professional and MBA student participants with rich work experience with that of student participants without experience to identify the differences in performance.
- *Research setting aspect:* More studies on the bullwhip effect should be undertaken in more complex research settings that are closer to real-world scenarios, rather than

deterministic settings. Most studies applied deterministic beer game settings, and few applied a stochastic variable setting, such as stochastic lead time and demand, which contribute to worsening supply chain stability in the real world. In addition, studies on the bullwhip effect should extend the laboratory setting from the traditional forward supply chains to closed-loop supply chains based on the beer game. Further, considering that only Sarkar and Kumar (2015) studied supply chain disruption, more supply chain disruption settings could be introduced to the beer game to gain insight into the performance of supply chain systems under sudden change. This could help to better understand the effects of supply chain disruptions and to identify ways to mitigate these effects.

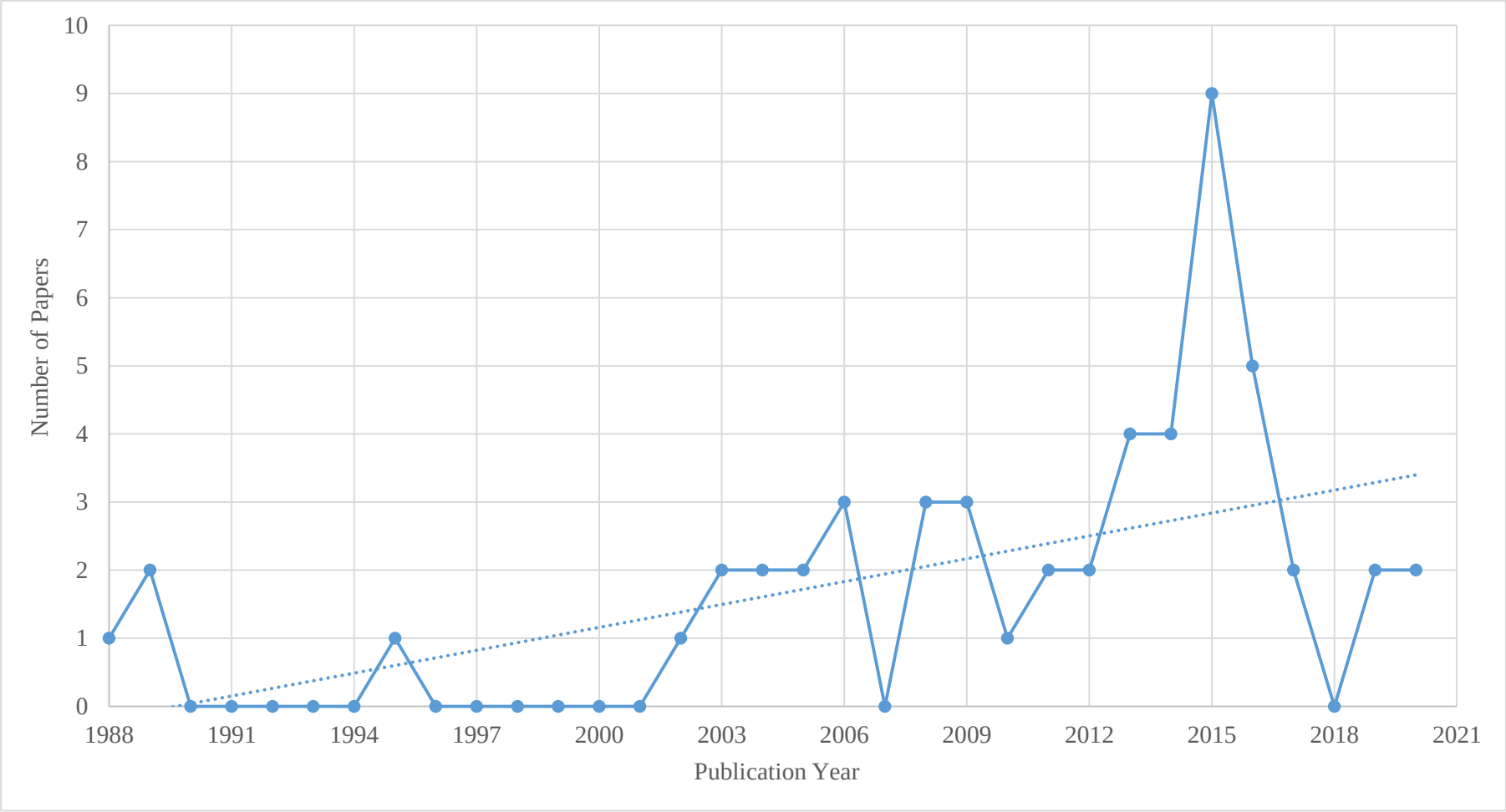
- *Supply chain digitalisation and automation aspect:* Digital technologies, including cloud computing, artificial intelligence, blockchain technology, autonomous robots, cyber-physical systems and additive manufacturing, have been applied to supply chains and may be able to reduce the bullwhip effect (Wiedenmann & Größler 2019). For example, blockchain technology could increase the information transparency and reliability in supply chains and thus reduce the bullwhip effect (Van Engelenburg, Janssen, & Klievink 2018). These technologies provide a way for supply chain networks to integrate and manage information, resources and materials, which could help to optimise the related decision-making and realise the optimal combination of cost, efficiency and experience. Therefore, the impact of human decision-makers on mitigating the bullwhip effect may depend on the degree of digitalisation of supply chains. From such perspective, bullwhip effect can be reduced if decision markers can trust more in artificial intelligence (AI) agent rather than other humans such as other supply chain members (Croson et al. 2014). However, high level of automation may

lead to the negative impact on bullwhip as decision markers tend to over trust AI or put less efforts and thoughts on decision marking, although the influence of human factors on the bullwhip effect has not been explored in the supply chain digitalisation context. Thus, more studies should include supply chain digitalisation in their research setting or should consider the context of Industry 4.0 to investigate the impact of incremental supply chain automation on the behavioural causes of bullwhip in the future.

Thus, we have contributed to this research field by systematically reviewing and analysing the behavioural causes of the bullwhip effect, synthesising existing academic findings and indicating a future research agenda. We have demonstrated that human behaviours are a factor that cannot be ignored in considering the bullwhip effect, since human mental models are significant in dynamic decision-making. By studying, understanding and analysing mental models and the constraints to improving mental models, we can gradually alter mental models based on the enhanced understanding of cause-and-effect relationships of information feedback. Thus, we can make better decisions and optimal decisions eventually. However, this study has some limitations, even though we conducted our search process carefully and strictly. We used the databases of Scopus, Science Direct and Wiley Online Library and performed cross-checking with Google Scholar; however, different search results may be found, given that other literature databases have different search terms. Further, considering that different authors and disciplines use different terminologies, the keywords and terminologies are inconsistent in the literature. Thus, we may have overlooked articles because some studies may have used incorrect terminologies or may not have used the terminologies that we used as keywords during the source identification stage. Last, we may also have overlooked articles related to our research scope because we were unable to exhaust all possible keywords.

7. Appendices

Appendix A: Linear Growth in Research Based on Publication Year



Appendix B: Journal Classification

Research Field	Journal Title	Number of Articles	Reviewed Articles	ABS
Operations and technology management	*Journal of Operations Management*	3	Cantor and Macdonald (2009), Sterman and Dogan (2015), Wu and Katok (2006)	4*
	Production and Operations Management	5	Bloomfield and Kulp (2013), Croson and Donohue (2003), Croson et al. (2014), Narayanan and Moritz (2015), Tokar et al. (2016)	4
	International Journal of Production Economics	6	Ancarani, Di Mauro and D'Urso (2013), Cao, Baker and Schniederjans (2014), Haines, Hough and Haines (2017), Sarkar and Kumar (2015), Udenio, Fransoo and Peels (2015), Zhao and Zhao (2015)	3
	International Journal of Production Research	1	Cannella et al. (2019)	3
	Manufacturing and Service Operations Management	1	Su (2008)	3
	Production Planning and Control	3	Delhoum and Scholz-Reiter (2009), K-T Hung and Ryu (2008), Nienhaus, Ziegenbein and Schoensleben (2006)	3
	Supply Chain Management: An International Journal	1	Moon and Kim (2005)	3
	International Journal of Physical Distribution and Logistics Management	1	Bruccoleri, Cannella and La Porta (2014)	2
	Journal of Business Logistics	1	Haines, Hough and Haines (2010)	2
	Journal of Purchasing and Supply Management	2	Ancarani, Di Mauro and D'Urso (2016), Di Mauro et al. (2020)	2
	Flexible Services and Manufacturing Journal	1	Rong, Shen and Snyder (2008)	1
	International Journal of Logistics Research and Application	1	W-H Hung, Lin and Ho (2014)	1
	International Journal of Services and Operations Management	1	Niranjan, Metri and Aggarwal (2009)	1
	Operations Management Research: Advancing Practice through Theory	1	Macdonald, Frommer and Karaesmen (2013)	1
	Supply Chain Forum: An International Journal	1	Khan, Ahmed, S & Hussain (2019)	1

Operations research and management science	*Management Science*	3	Croson and Donohue (2006), Steckel, Gupta and Banerji (2004), Sterman (1989a)	4*
	Decision Science	2	Niranjan, Wagner and Bode (2011), Tokar, Aloysius and Waller (2012)	3
	IISE Transactions (IIE Transactions)	1	Udenio et al. (2017)	3
	Journal of the Operational Research Society	1	Syntetos et al. (2011)	3
	OR Spectrum	1	Von Lanzenauer and Pilz-Glombik (2002)	3
	System Dynamics Review	3	Croson and Donohue (2005), Sterman (1988), Villa, Gonçalves and Arango (2015)	2
Psychology (organisational)	*Organizational Behavior and Human Decision Processes*	2	Sterman (1989b), Diehl and Sterman (1995)	4
Sector studies	*Transportation Research Part E: Logistics and Transportation Review*	2	Cantor and Katok (2012), Machuca and Barajas (2004)	3
Economics, econometric and finance	*Amfiteatru Economic*	1	Kovacevic et al. (2013)	Non-ABS
Multidisciplinary	*Complexity*	1	Edali and Yasarcan (2016)	Non-ABS
	Systems	1	Turner et al. (2020)	Non-ABS
Mathematics	*Discrete Dynamics in Nature and Society*	1	Li and Yan (2015)	Non-ABS
Computer science; multidisciplinary	*Information (Japan)*	1	Jin (2015)	Non-ABS
Computer science, engineering and mathematics	*International Journal of Systems Science*	1	Riddalls and Bennett (2003)	Non-ABS
Computer science	*IEEE Access*	1	Thompson and Badizadegan (2015)	Non-ABS
Business, management and accounting	*Uncertain Supply Chain Management*	1	Pamulety and Pillai (2016)	Non-ABS
Operations and supply chain management	*Operations and Supply Chain Management: An International Journal (OSCM)*	1	Shee and Kaswi (2016)	Non-ABS

Appendix C: Research Methodology Classification

Reviewed Articles by Year	Research Method						Major Behavioural Category					
	Case Study	**Controlled Experiment**	**Survey/ Questionnaire**	**Modelling**	**Simulation Experiment**	**Computer Simulation**	**Social Interaction**	**Individual Traits**	**Information Feedback**	**Mental Models**	**Decision Strategy**	**Decision**
Sterman (1988)				√	√ (BG)					√		
Sterman (1989a)				√	√ (BG)					√		
Sterman (1989b)					√	√				√		
Diehl and Sterman (1995)		√								√		
Haehling and Pilz-Glombik (2002)				√	√ (BG)		√					
Croson and Donohue (2003)		√ (BG)					√					
Riddalls and Bennett (2003)				√						√		
Machuca and Barajas (2004)		√ (BG)					√					
Steckel, Gupta and Banerji (2004)		√ (BG)					√					
Croson and Donohue (2005)		√ (BG)					√					
Moon and Kim (2005)		√ (BG)	√			√				√		

Croson and Donohue (2006)		√ (BG)					√			
Nienhaus, Ziegenbein and Schoensleben (2006)					√ (BG)					√
Wu and Katok (2006)		√ (BG)	√				√			
Su (2008)				√				√		
Rong, Shen and Snyder (2008)					√ (BG)	√		√		
K-T Hung and Ryu (2008)		√ (BG)		√					√	
Niranjan, Metri and Aggarwal (2009)		√ (BG)						√		
Cantor and Macdonald (2009)		√ (BG)						√		
Delhoum and Scholz-Reiter (2009)		√ (SNG)							√	
Haines, Hough and Haines (2010)		√ (BG)	√					√		
Syntetos et al. (2011)				√				√		
Niranjan, Wagner and Bode (2011)	√	√ (BG)						√		
Cantor and Katok (2012)		√ (BG)						√		

Tokar, Aloysius and Waller (2012)		√ (BG)						√		
Kovacevic et al. (2013)		√ (BG)	√			√				
Ancarani, Di Mauro and D’Urso (2013)		√ (BG)			√ (BG)			√		
Bloomfield and Kulp (2013)		√					√		√	
Macdonald, Frommer and Karaesmen (2013)					√ (BG)				√	
Bruccoleri, Cannella and La Porta (2014)				√	√					√
Cao, Baker and Schniederjans (2014)			√	√		√				
W-H Hung, Lin and Ho (2014)	√					√				
Croson et al. (2014)		√ (BG)				√				
Sarkar and Kumar (2015)		√ (BG)				√				
Narayanan and Moritz (2015)		√ (BG)							√	
Li and Yan (2015)				√	√				√	

Villa, Gonçalves and Arango (2015)	√		√					√		
Zhao and Zhao (2015)	√							√		
Udenio, Fransoo and Peels (2015)			√					√		
Jin (2015)	√ (BG)					√				
Sterman and Dogan (2015)			√							√
Thompson and Badizadegan (2015)				√ (BG)	√ (BG)	√				
Tokar et al. (2016)	√ (BG)							√		
Ancarani, Di Mauro and D’Urso (2016)	√ (BG)							√		
Edali and Yasarcan (2016)					√ (BG)			√		
Pamulety and Pillai (2016)	√ (BG)					√				
Shee and Kaswi (2016)		√						√		
Haines, Hough and Haines (2017)	√ (BG)	√					√			
Udenio et al. (2017)			√					√		
Cannella et al. (2019)	√ (BG)				√				√	

Khan, Ahmed and Hussain (2019)			√			√		√				
Di Mauro et al. (2020)			√		√ (BG)						√	
Turner et al. (2020)					√ (BG)			√				
Total number	2	30 (25 BG)	9	14	9 (8 BG)	11 (4 BG)	15	3	3	26	4	3

Note: BG represents the 'beer game', and SNG represents the 'supply net game'.

8. References

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