Investigating the Firm-Level Outcomes of Virtual Reality-Enabled Business Practices

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By

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Declaration of Authorship

I, Yangchun Xiong, declare that this thesis and the work presented in it are my own. I hereby certify that this thesis has been composed by me and is based on my own work, unless stated otherwise. All references and verbatim extracts have been quoted, and all sources of information have been specifically acknowledged. This work was done wholly while in candidature for a research degree at the University of Liverpool. My contribution and those of the other authors to this work have been explicitly indicated within the authorship declaration forms attached at the end of the thesis.

Signed: Yang Chun. Xiong

Date: 17th March 2023

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Abstract

Despite recent advances in virtual reality (VR) having attracted considerable attention from both researchers and practitioners, deep insights into VR applications in the management research context remain limited. This thesis fills this important research gap by conducting three studies to investigate the firm-level outcomes of VR-enabled business practices and identify what contextual factors make VR adoption more valuable. The first study comprised a systematic literature review of existing studies published between 2010 and 2021 related to VR adoption in business practices. The first study proposed an integrative framework to comprehensively conceptualise VR and highlight its potential value creation in relation to business practices. In addition, this study also developed a theoretical model that systematically summarises the drivers, barriers, and outcomes of VR adoption in a general business and management context.

The second study adopted an event study method to quantify the impacts of VR-enabled marketing practices on firm value. Based on 201 VR-enabled marketing practices announced between 2012 and 2019 in the US market, the event study results show that VR-enabled marketing practices lead to the decline of firm value (i.e., negative abnormal stock returns). This finding suggests that shareholders are more concerned about the uncertainties and risks associated with these practices. Consistent with this view, the second study further found that the negative effects of VR-enabled marketing practices become even more pronounced at high levels of firm uncertainty. However, these negative effects are reduced when firms collaborate to implement VR-enabled marketing practices and when firms are focused on value appropriation strategies. Additionally, the post-hoc tests show that firms applying VR in the post-purchase stage (i.e., creating consumption experiences) will not experience a loss of firm value compared with those applying VR in the pre-purchase stage (i.e., communications and advertising) and the intra-purchase stage (i.e., retailing and selling).

The third study adopted a difference-in-differences model to examine whether VR-enabled manufacturing practices can help firms improve production efficiency. This study's sample consists of 87 US treatment firms that have adopted VR-enabled manufacturing practices and 87 matched control firms without such adoption over the period 2010 to 2020. The results suggest that the treatment firms gain production efficiency improvements relative to the matched control firms. The third study also finds that improvements in production efficiency are more pronounced for firms with high levels of labour volatility and market dynamism. The post-hoc tests further show that only the application of VR in pre-manufacturing training activities and intra-manufacturing activities can significantly improve production efficiency. In contrast, applying VR to pre-planning and scheduling activities and post-manufacturing activities does not significantly improve production efficiency. The results of post-hoc tests also indicate that firms in the non-service industries tend to reap more benefits from VR-enabled manufacturing practices than those in the service industries.

Overall, this thesis not only provides important research directions and implications for future studies but also documents important empirical evidence regarding the application of VR in a range of business practices.

Keywords: VR, marketing practices, manufacturing practices, event study, firm value, difference-in-difference model, production efficiency

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Glossary of Abbreviation

AR	Augmented Reality
ARs	Abnormal Returns
AARs	Average Abnormal Returns
CAVEs	Cave Automatic Environments
CAR	Cumulative Abnormal Return
CARs	Cumulative Abnormal Returns
CAARs	Cumulative Average Abnormal Returns
DID	Difference-In-Differences
HMDs	Head-Mounted Displays
PBV	Practice-Based View
PSM	Propensity Score Matching
RBV	Resource-Based View
ROA	Return on Assets
SMEs	Small and Medium Enterprises
S-O-R	Stimulus–Organism–Response
SLR	Systematic Literature Review
TAM	Technology Acceptance Model
TR	Technology Readiness
UTAUT	United Theory of Acceptance and Use of Technology
TPB	Theory of Planned Behaviour
TRA	Theory of Reasoned Action
U&G	Use and Gratification
VIF	Variance Inflation Factor
VR	Virtual Reality

Chapter 1. Introduction

1.1 Research Background and Motivation

Virtual reality (VR) refers to computer-generated virtual environments with high interactivity and vividness that offer users multi-sensorial experiences and allow them to manipulate and interact with their environments (Boyd and Koles, 2019; Kim et al., 2023). Despite its widespread recent usage, VR is not a recent term: the origin of VR technologies can be traced back to the work of Sutherland in the 1960s (Schroeder, 1993). Major studies of VR applications began to explosively increase in the early 1990s (Biocca, 1992; Latta and Oberg 1994; Machover, 1994), which discussed both the advances in VR technology development and its application limitations at the time. In 1994, Nintendo, a leading Japanese video gaming company, introduced Virtual Boy, the first VR game console, to consumers, raising the curtain on the commercial development of VR in the global market (Betters, 2013). Despite being launched at the forefront of a VR console, Virtual Boy vanished amid unrealistic expectations (Betters, 2013). The commercial failure of Virtual Boy led to a long period of reduced interest in VR until the development of the Oculus Rift.

In 2013, the ground-breaking VR headset console developed by Oculus VR, the Oculus Rift, launched a new wave of interest in VR (Stein, 2019). Leveraging sophisticated head-mounted displays (HMDs) technology, Oculus VR has offered users an unprecedented immersive experience by integrating advanced motion tracking, motion sensors, and haptic feedback (Monica and Aleotti, 2022; Segura et al., 2020). Following the steps of Oculus Rift, global leading companies including Apple, SONY, Google, HTC, and Samsung announced their own commercial VR console development plans between 2014 and 2018. The involvement of these leading technology companies has advanced the development of VR technology massively in recent years. Nowadays, VR is not confined only to entertainment tool for consumers but is also widely recognised as a disruptive force that can revolutionise industries and business practices (Farah et al., 2019). Given these advances in VR technology, managerial practitioners are widely investing in VR applications to support their business practices. For instance, Macy's launched a VR furniture program that allows customers to virtually design and experience the interior of a room (Bloomberg, 2018). The New York Times partnered with Google on a VR app to allow its customers to experience a new form of storytelling (Somaiya, 2015).

However, despite the growing industry interest in VR, deep insights into VR applications in a management research context are currently lacking (Boyd and Koles, 2019; Hollebeek et al., 2020; Manis and Choi, 2019; Miandar et al., 2020). Academic research has only recently started to conceptualise VR-enabled business practices (Chandra Sekaran et al., 2021; Guo et al., 2020), examine the determinants of behavioural intentions for VR adoption (Manis and Choi, 2019; Huang et al., 2023), and investigate how VR might influence consumers' psychological perceptions, judgements, and behavioural intentions (Flavián et al., 2021; Kim et al., 2023). For instance, both Cowan and Ketron (2019) and Rauschnabel et al. (2022) proposed conceptual frameworks for defining VR and discussing its potential applications in marketing practices. Kim et al. (2023) empirically examined how VR-based shopping experiences enhance consumer creativity. Similarly, Flavián et al. (2021) investigated the impacts of VR on customer experiences.

While these research themes have provided valuable insights from the perspectives of consumer outcomes and technology typology conceptualisation, the effects of VR adoption on firm-level outcomes remain unclear. In addition, there are contradictory findings among the studies that investigated the impacts of VR on customers (Deng et al., 2019; Li and Chen, 2019; Van Kerrebroeck et al., 2017). Among the majority of VR-related consumer-focus studies, there is a consensus that VR benefits firms by shaping customers' perceptions and affecting their behaviours (Van Kerrebroeck et al., 2017; Tussyadiah et al., 2018). However, several studies have shown that VR could reduce customers' purchasing intentions under certain circumstances (Deng et al., 2019; Li and Chen, 2019). These mixed results hinder the ability of managers to assess the net returns of VR adoption. In addition, a recent study indicated that disruptive technology adoption (e.g., artificial intelligence) would significantly reduce firm value (Lui et al., 2022). Accordingly, there is a crucial need for a systematic examination of whether VR adoption in business practices will generate positive firm-level outcomes and what contextual factors make VR adoption more valuable. Building upon prior VR-related studies, this thesis conducted three studies to identify the current research status of VR in a business context, investigate its firm-level outcomes in marketing and manufacturing practices, and document the underlying moderating factors.

1.2 Research Aim and Questions

This thesis aims to examine the firm-level outcomes of VR-enabled business practices. To achieve this research aim, this thesis developed three overarching research questions and conducted three studies to address these proposed questions. First, existing business and management literature fails to clearly conceptualize VR technology and offer a full picture of its applications in business practices. The current fragmented state of VR adoption-related business research serves to hinder the ability of researchers to disseminate meaningful theoretical knowledge and managerial implications of VR adoption. Accordingly, the first research question was developed as follows, and a study based on the systematic literature review method was conducted to answer this research question.

Research Question 1: 'How do we understand VR technology and its application in business practices from a holistic perspective?'

After developing a holistic understanding of VR-enabled business practices, the second research question asks whether these VR-enabled business practices benefit firm's performance. This is because the empirical research into the firm-level outcomes associated with VR-enabled business practices remains nascent. Additionally, there are ongoing controversies that the effect of VR-enabled business practices on firms may not always be as positive as the firms expect (Deng et al., 2019; Kim et al., 2018). In this regard, two empirical studies were conducted to address the second research question. Specifically, the two empirical studies included in this thesis investigate the effects of VR applications in marketing practices on firm value and the effects of VR applications in manufacturing practices on production efficiency, respectively. The research context for two empirical studies is based on US-listed firms. According to the report of Statista (2023a), the US market is experiencing a significant surge in demand for VR technology, with companies intensifying their investment in VR-related R&D activities to craft immersive consumer experiences. Consequently, the US is generating the highest revenue in the VR sector, with a projected market volume of US$8.6 billion in 2023 (Statista, 2023a). Despite the substantial investments and advancements in VR technology in the US, there is a notable lack of empirical studies investigating the impact of VR-enabled business practices on firm value. This gap underscores the potential of the US market as an optimal setting for conducting these two empirical studies.

Research Question 2: 'What are the impacts of VR adoption on firms when VR is applied to different business practices?'

Finally, the last research question aims to explore the boundary conditions of firm-level outcomes arising from VR-enabled business practices. This is because it is unlikely that all firms will gain the same firm-level outcomes from their VR-enabled business practices. This thesis thus will further examine how the VR-enabled manufacturing practices-induced production efficiency improvement might vary across firms depending on their firm-level characteristics and operating environments. The third research question was addressed by investigating the moderating roles of firm-level characteristics (tested in the second study), and internal and external environmental conditions (tested in the third study) on the effects of VR-enabled business practices on firm-level outcomes.

Research Question 3: 'In which situations will the impacts of VR adoption on firms be more pronounced or less pronounced?'

1.3 Summary of the Three Studies

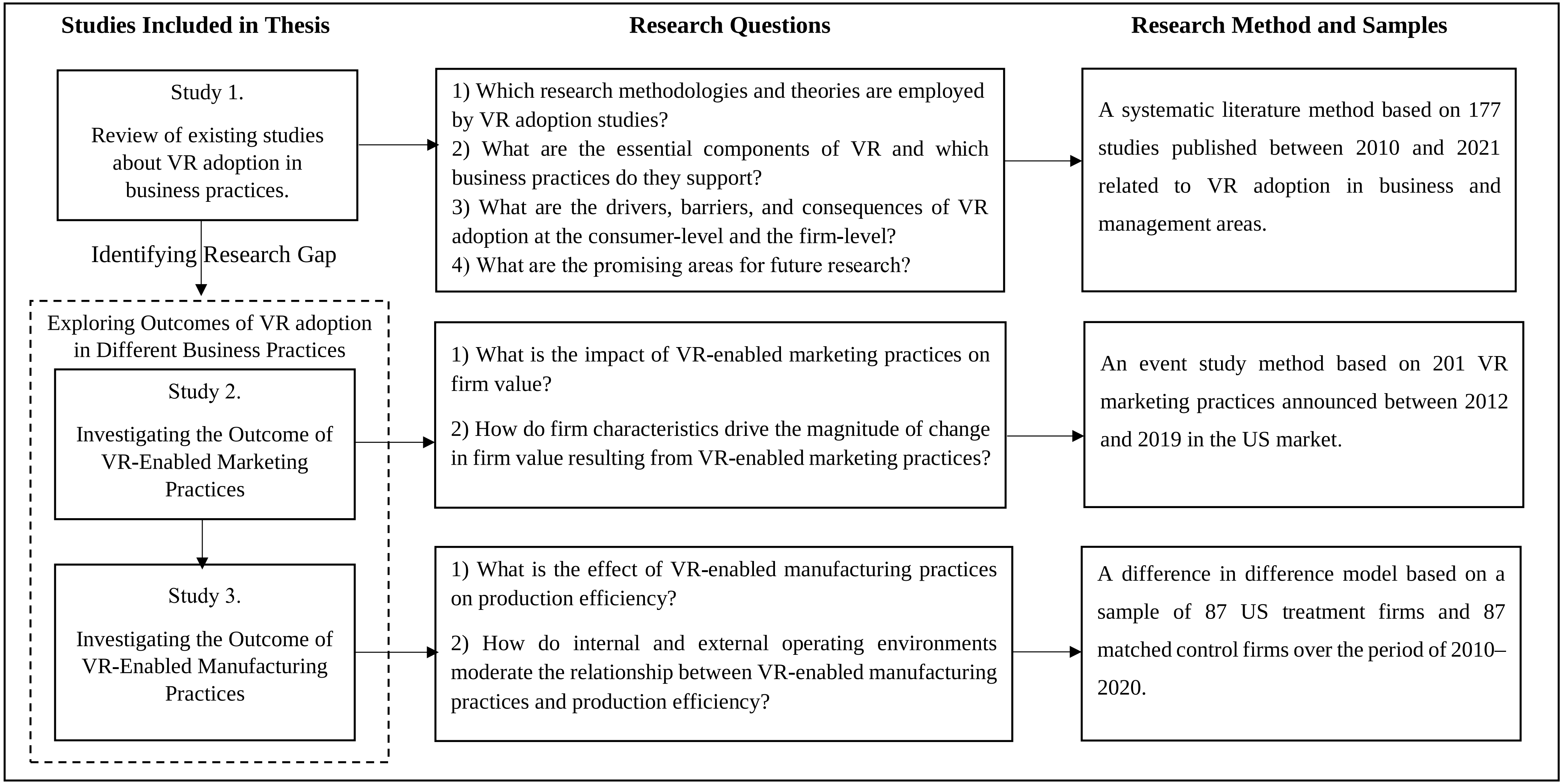
This PhD thesis includes three independent but interconnected studies that jointly address the three research questions described above. Figure 1.1 shows the internal connections between these three studies.

The first study employed a systematic literature review method to synthesise existing literature concerning VR adoption in business practices, based on 177 studies published between 2010 and 2021. The findings of this study offer an integrated conceptualisation of VR systems, summarise the major business practices supported by VR, and identify the potential drivers, barriers, and outcomes of VR adoption in the business context. Moreover, the first study identifies current research gaps and opportunities for future studies, thus establishing a solid research rationale for the subsequent second and third studies.

The second study adopted the event study method to investigate the effects of VR-enabled marketing practices on firm value (measured as abnormal stock returns). Based on 201 VR-enabled marketing practices announced between 2012 and 2019 in the US market, the event study results show that VR-enabled marketing practices led to negative abnormal stock returns. This unexpected finding is likely due to shareholder concerns about the uncertainties and risks associated with these marketing practices. Consistent with this view, the second study further reveals that these negative effects become more pronounced at high levels of firm uncertainty but are less pronounced for firms with a greater focus on marketing alliance and value appropriation strategies. Additionally, the post-hoc tests show that applying VR in the pre-purchase stage (i.e., communications and advertising) and the intra-purchase stage (i.e., retailing and selling) can cause a significant loss of firm value. However, applying VR in the post-purchase stage (i.e., creating consumption experiences) causes a negative but insignificant change in firm value. Moreover, firms that applied VR in the post-purchase stage suffered fewer firm value losses than those that applied VR in the pre-purchase stage.

The third study employed a combination of propensity score matching and difference-in-differences approaches to examine the impacts of VR-enabled manufacturing practices on production efficiency. Unlike the second study, the third study did not adopt the event study methodology. Specifically, VR-enabled marketing practices can be directly related to how consumers and investors perceive the value proposition offered by the firm and, therefore, can have immediate effects on firm value, which is well-captured by the event study methodology. In contrast, VR manufacturing announcements are likely associated with long-term strategic investments and internal operational changes that do not result in immediate market reactions, making the event study approach less suitable. This study collected a sample of 87 US treatment firms that adopted VR-enabled manufacturing practices and 87 matched control firms without such adoption during the period 2010–2020. The results provide support for the positive impact of VR-enabled manufacturing practices on production efficiency. This positive impact is stronger for firms operating with high levels of labour volatility and market dynamism. Furthermore, the post-hoc tests show that only the application of VR in pre-manufacturing training activities and intra-manufacturing activities can significantly improve production efficiency. In contrast, applying VR to pre-planning and scheduling activities and post-manufacturing activities does not significantly improve production efficiency. The results of post-hoc tests also indicate that firms in the non-service industries tend to reap more benefits from VR-enabled manufacturing practices than those in the service industries.

Figure 1.1 Overview of Three Studies included in the Thesis



1.4 Research Contribution and Implications

1.4.1 Contribution to Theory and Literature

By conducting three studies of VR adoption in business practices, this PhD thesis contributes to the theory and literature in the following three ways. First, the first study proposed two conceptual frameworks that offer important insights into the components of VR and its applications in different business practices, in addition to the potential outcomes of such technology adoption. These important findings serve as a foundation and guide future empirical studies examining the firm-level outcomes of VR adoption. In addition, the research gaps and opportunities identified in the first study delineate a range of future research avenues that merit investigation.

Second, this thesis contributes to the literature on the intersection of disruptive technology adoption, marketing, and operations management by empirically examining the outcomes of VR adoption in different business practices. In doing so, this PhD thesis also responds to the recent calls from marketing and operations scholars that increased attention should be paid to the firm-level outcomes of disruptive technology adoption (Edeling et al., 2021). In addition, existing studies have failed to distinguish the value creation of VR when it is leveraged in different business practices (Kim et al., 2020a; Lin, 2017; Wang and Chen, 2019). This thesis also addresses this important research gap by revealing the divergent firm-level outcomes from VR adoption in marketing and manufacturing practices. The results of the second and third studies show that although VR improves production efficiency when applied to manufacturing practices, it significantly reduces firm value (i.e., negative abnormal stock returns) when it is used in marketing practices. These divergent firm-level outcomes in terms of VR adoption can also motivate future studies to further examine the risks and uncertainties associated with disruptive technology adoption.

Third, this PhD thesis extends the extant literature on the interplay between disruptive technology adoption and contingency effects by investigating the moderating effects of firm-level characteristics and operating environments on VR adoption. Understanding how firm-level characteristics and environmental dynamism affect the benefits gained from VR adoption is essential given that disruptive technology adoption is currently unavoidably embedded in dynamic internal and external environments. Future studies can build on this work to investigate how the firm-level outcomes of VR adoption are contingent on other internal and external contextual factors, such as innovation capability and market competition.

1.4.2 Contribution to Managerial Practices

The findings of this PhD thesis have important managerial implications for VR adopters and practitioners. Firstly, this thesis provides marketing and operation managers with fundamental guidance in the implementation of VR-enabled business practices by (i) conceptualising VR, (ii) describing its applications in business practices, and (iii) identifying potential drivers and outcomes of VR adoption. The important findings presented in this work can provide practical advice for practitioners to develop a strategic understanding of VR technology and the potential opportunities afforded by VR-enabled business practices.

Second, from an adoption purpose perspective, the results from the second study and third study indicate that both managers and practitioners must be aware that the value creation of VR adoption may vary across different business practices. In particular, adopting VR in manufacturing practices can allow firms to improve their production efficiency; however, adopting VR in marketing practices may lead to a loss of firm value, as highlighted by these two studies. As such, this PhD thesis also offers practitioners valuable insights into the potential outcomes of applying VR to different business practices. Moreover, this result serves to alert managers to the risks of assuming a ‘one-size-fits-all’ strategy, particularly when adopting other disruptive technologies.

Third, the two studies also pinpoint the situations in which VR adopters can reap additional benefits (or suffer fewer losses) by testing the moderating effects of firm-level characteristics and operations environments. Specifically, for adopting VR in marketing practices, the adoption outcomes (i.e., abnormal stock returns) can vary depending on whether firms have a marketing alliance, the firms' level of internal uncertainty and their strategic focus types. In terms of VR adoption in manufacturing practices, the main positive adoption outcome (i.e., enhanced production efficiency) is contingent on an individual firm's level of employee fluctuation and level of market dynamism. Overall, managers are advised to carefully assess their firms' internal resources and environmental factors before adopting VR-enabled business practices.

Lastly, these two studies' post-hoc analysis provides detailed guidance for firms considering VR adoption. For marketing practices, managers should prioritise considering the applications of VR in developing new products since such an application would not cause firm value decreases. Regarding VR enabled-manufacturing practices, the enhanced production efficiency is primarily driven by pre-manufacturing training and intra-manufacturing activities. Moreover, firms in the non-service industries tend to reap more benefits from VR enabled-manufacturing practices than those in the service industries.

1.5 Overview of Thesis

This thesis consists of five chapters, as shown in Figure 1.2. Chapter 1 introduces the study's research background, identifies current research gaps, describes the work's research aims and objectives, and summarises the overall contributions of the thesis to literature and managerial practices. Chapters 2, 3, and 4 present the three studies that address the proposed research questions in this thesis. Chapter 5 summarises the overall contribution and implications by synthesising the findings from the three studies and discusses the research limitations and potential future research avenues.

Figure 1.2 Structure of Thesis

Chapter 1. Introduction

- Research Background and Rationale
- Research Aim and Questions
- Summary of Three Studies
- Research Contribution and Implications
- Overview of Thesis

Three Studies included in Thesis

Chapter 2. First Study- Understanding Virtual Reality Adoption in Business Practices: A Systematic Review and Future Research Agenda

- Introduction
- Theoretical Background
- Methodology
- Findings
- Future Research Agenda for VR Adoption in Business Practices
- Conclusion and Limitations

Chapter 3. Second Study-Gaining Virtual or Real Value? Exploring the Impact of Virtual Reality-Enabled Marketing Practices on Firm Value

- Introduction
- Literature and Hypothesis Development
- Methodology
- Results
- Discussion and Implications
- Conclusion and Limitations

Chapter 4. Third Study -The Effect of Virtual Reality-Enabled Manufacturing Practices on Production Efficiency

- Introduction
- Literature and Hypothesis Development
- Methodology
- Results
- Discussion and Implications
- Conclusion and Limitations

Chapter 5. Conclusion

- Summary of the Thesis
- Contribution and Implications
- Limitations and Recommendations for Future Work

Chapter 2.

Understanding Virtual Reality Adoption in Business Practices: A Systematic Review and Future Research Agenda

Abstract: The popularity of virtual reality (VR) adoption in business practices has created a new research avenue for the management area. Yet, the existing research about VR adoption in business practices has produced fragmentation and theoretical confusion. There is a lack of holistic understanding regarding what a VR system entails, what drivers and barriers of VR adoption are, and how VR improves performances at both consumer and firm levels. To address this knowledge gap and identify future research opportunities for VR adoption business research, we conducted a systematic literature review (SLR) of existing studies published between 2010 and 2021 related to VR adoption in business practices. Our study has proposed an integrative framework that offers a comprehensive conceptualisation of VR and highlights its potential value creation in relation to business practices. We also developed a theoretical model that systematically summarises the drivers, barriers, and outcomes of VR adoption in a general business and management context. Above all, our study contributes to business research on VR adoption by identifying new research opportunities.

Keywords: VR adoption, business practices, systematic literature review

2.1 Introduction

Virtual reality (VR) refers to a three-dimensional computer technology which creates a virtual environment that users can navigate (Jin et al., 2021; Kim et al., 2021). One distinctive feature of VR is its ability to provide users with the feeling of being present in another world through the incorporation of enhanced sensory elements to elicit telepresence in high-involvement situations (Cowan and Ketron, 2019). According to Fortune (2022), the VR market growth rate was 50% for 2020-2021. Moreover, it is expected to reach 84.09 billion USD by 2028. The basis for this stupendous growth is the fact that VR has attracted the attention of growing numbers of firms seeking to embed VR within their business practices (Pantano and Servidio, 2012; Xi and Hamari, 2021). For example, Ford created VR production lines to install vehicle parts (Ford, 2019). Zillow employed VR to enable its customers to benefit from a 360-degree view of its houses (Zillow 2021).

In a similar vein, academic research into VR adoption has also increased, not least in the fields of management studies (Boyd and Koles, 2019, Xi and Hamari, 2021). Recent business management studies have begun to elaborate on the value creation of VR adoption in multifaceted business practices, including retailing (Xi and Hamari, 2021), manufacturing (Berg and Vance, 2017), tourism (Skard et al, 2021), and employee training (Lau et al., 2015). For instance, Andrushchenko et al. (2019) provided a conceptual discussion of how VR improves enterprise competitiveness. Hudson et al. (2019) investigated the impact of VR supported product placement practices on consumer behavioural intentions. Pizzi et al. (2020) examined how VR marketing positively improved consumer experiences.

However, recent research into VR adoption has produced fragmentation and theoretical confusion. There is a lack of holistic understanding regarding what a VR system entails, what drivers and barriers of VR adoption are, and how VR improves performances at both firm- and consumer-levels. Some studies delimit the typology of VR system to its output devices, such as head-mounted devices (Xi and Hamari, 2021), whilst others view it more broadly as the involvement level of VR, including simulations, and automated virtual environment and virtual worlds (Cowan and Ketron, 2019). This diverse conceptualization of VR creates significant confusion and impedes further theory development and empirical studies in the field of VR adoption. Similarly, some studies focus on the outcomes of VR adoption in marketing practices (Kang et al., 2020; Ghorbanzadeh et al. 2021), whereas others concentrate on its potential value creation in operations and manufacturing practices (Bu et al., 2021). Hence, confusion and fragmentation also prevail in terms of the drivers, barriers, and outcomes of VR adoption. Overall, the current fragmented state of VR adoption related business research serves to hinder the ability of researchers to disseminate meaningful theoretical knowledge and managerial implications of VR adoption.

Although recent business studies have paid some attention to this issue and conducted VR adoption-related systematic reviews (Hollebeek et al., 2020; Xi and Hamari, 2021), there are some important limitations in these review papers. First, both Hollebeek et al. (2020), and Xi and Hamari (2021) primarily discussed the impact of VR on individual-level outcomes (e.g., customer engagement and brand relationships). The holistic impact of VR adoption on firm-level outcomes is not taken into consideration. Second, their studies only focused on VR adoption in marketing practices and overlooked VR adoption in other business practices (e.g., product design and employee training). Third, there is lack of detailed and systematic discussion of the conceptualisation of VR system and its application in business practices. To offer a holistic view of VR adoption in business practices and outline future research opportunities to help scholars generate more meaningful implications about VR adoption in business practices, our research aims to conduct a systematic literature review (SLR). The review will address the following important research questions:

1. Which research methodologies and theories have been employed by VR adoption studies?
2. What are the essential components of VR, and which business practices do they support?
3. What are the drivers, barriers, and consequences of VR adoption at the consumer- and firm-levels?
4. What are the promising areas for future research?

Our research contributes to the management literature in several ways, the first of which is that our study has synthesised the industry context and country context, methodologies, and theories in VR adoption research. This critical synthesis allows researchers to avoid overlaps and generates new insights for future management research into VR adoption. Second, our study has proposed a theoretical framework which shows an integrative conceptualisation of VR and highlights its potential value creation in relation to business practices. Our findings inspire future researchers to explore the outcomes of VR adoption in different business practices. Third, our study developed a theoretical model that systematically summarises the drivers, barriers, and outcomes of VR adoption in a more general business context based on existing literature. In accordance with our theoretical model, we further explain how management researchers can enrich their investigations into VR adoption by identifying new research opportunities from previously overlooked studies.

The remainder of this chapter is divided into several sections. Section 2.2 provides a brief theoretical introduction to VR. Section 2.3 describes the systematic literature review process used to identify the articles. Section 2.4 discusses the results obtained from the synthesis of previous studies. Section 2.5 presents a research agenda for future research into VR adoption in business practices. Section 2.6 concludes this paper and outlines limitations.

2.2 Theoretical Background

Before proceeding with the synthesis of existing literature, we offer a brief discussion of the concept of VR and its adoption in business practices. VR refers to a three-dimensional technology that generates virtual spaces that users can visit and interact with by donning sophisticated computer equipment (Lanier, 1992). Nowadays, the concept of VR has been extended to computer-generated virtual environments that offer highly vivid, interactive, and immersive experiences for users (Berg and Vance, 2017; Cowan and Ketron, 2018). In other words, advances in VR technology not only allow it to generate 3D virtual environments for users, but also permit individuals to experience more sensory stimuli (i.e., haptics, sights, smells, views, and hearing), and freely navigate within the environment (Hollebeek et al., 2020). A recent study conducted by Wang et al. (2021) further identified immersion and interaction as the major characteristics of VR. VR users experience the sensation of immersion in the simulated world by receiving high levels of stimuli and interactions from the virtual environment (Wang et al., 2021). These two characteristics of VR indicate its vast potential as a business application, thus prompting managers to regard it as an essential tool for promoting business practices (Dobrowolski et al., 2014). Although recent studies have examined how VR-enabled business practices benefit firms (Boyd and Koles, 2019, Xi and Hamari, 2021), most of them are fragmented and fail to present a complete view regarding the concept of VR, as well as the drivers, barriers, and outcomes of VR-enabled business practices (Bu et al., 2021; Luna-Nevarez and McGovern, 2021; Rekapalli and Martinez, 2011). Our study aims to adopt the SLR method to address these important research gaps.

2.3 Methodology

Our study employed the SLR approach to synthesise the literature on VR adoption through the structured evaluation of relevant academic articles (Mikalef et al., 2018). The SLR approach helps summarise the current state of knowledge and present future research opportunities in a specific field of interest (Tranfield et al., 2003; Xiao and Watson, 2019). In this way, the SLR presented in our study helps business researchers and managers to gain a more complete view of VR adoption in business practices and understand its future meaningful theoretical and managerial implications.

The process of SLR is summarised in Figure 2.1. Phase 1 of Figure 2.1 shows the search method used in this SLR study. In accordance with previous review studies, we identified three primary databases, namely: Scopus, Springer, and Wiley (e.g., Hollebeek et al., 2020; Van Klompenburg et al., 2020). To identify relevant studies about VR adoption in business and management practices, we followed the search strategy of prior VR-related SLR studies (i.e., Hollebeek et al., 2020; Xi and Hamari, 2021). In particular, we used a combination of search terms: ["virtual reality"] AND ["adoption" OR "marketing" OR "operations" OR "management" OR "manufacturing" OR "production" OR "design" OR "training" OR "customer" OR "consumer" OR "employee" OR "company" OR "firm"]. We then applied several inclusion criteria including, English language, peer-reviewed journals, academic articles, and publication years between 2010 and 2021. This basic search resulted in 612 articles. We then carefully read the full texts of these articles, and further excluded those with non-business and management research scopes (e.g., medicine and VR-related technology equipment production). This exclusion process removed 435 articles and yielded a final sample of 177 articles that were used for our systematic review and analysis.

Phase 2 of Figure 2.1 summarises the analysis process used in this SLR paper. Based on the 177 identified articles, we followed the study of Chaudhary et al. (2021) and first performed a two-step thematic analysis with open coding, followed by axial coding to uncover common core themes and findings in the literature. Specifically, we re-read the 177 identified articles and used the open-coding method to code their research aims, contexts, publication years, employed methodologies and theories, and research variables. Subsequently, we used the axial coding method to identify sub-themes, and further linked different sub-themes together to develop some common major themes.

After identifying the major theories and methodologies employed by prior VR adoption research, we proposed two integrative conceptual models to offer a comprehensive view of the application of VR in business practices, as well as the drivers, barriers, and outcomes of VR adoption. Finally, we proposed an agenda for future business research on VR adoption, including theoretical focuses, methodological focuses, driver, and barrier focuses, moderating factor focuses, and outcome focuses. The following section presents our findings.

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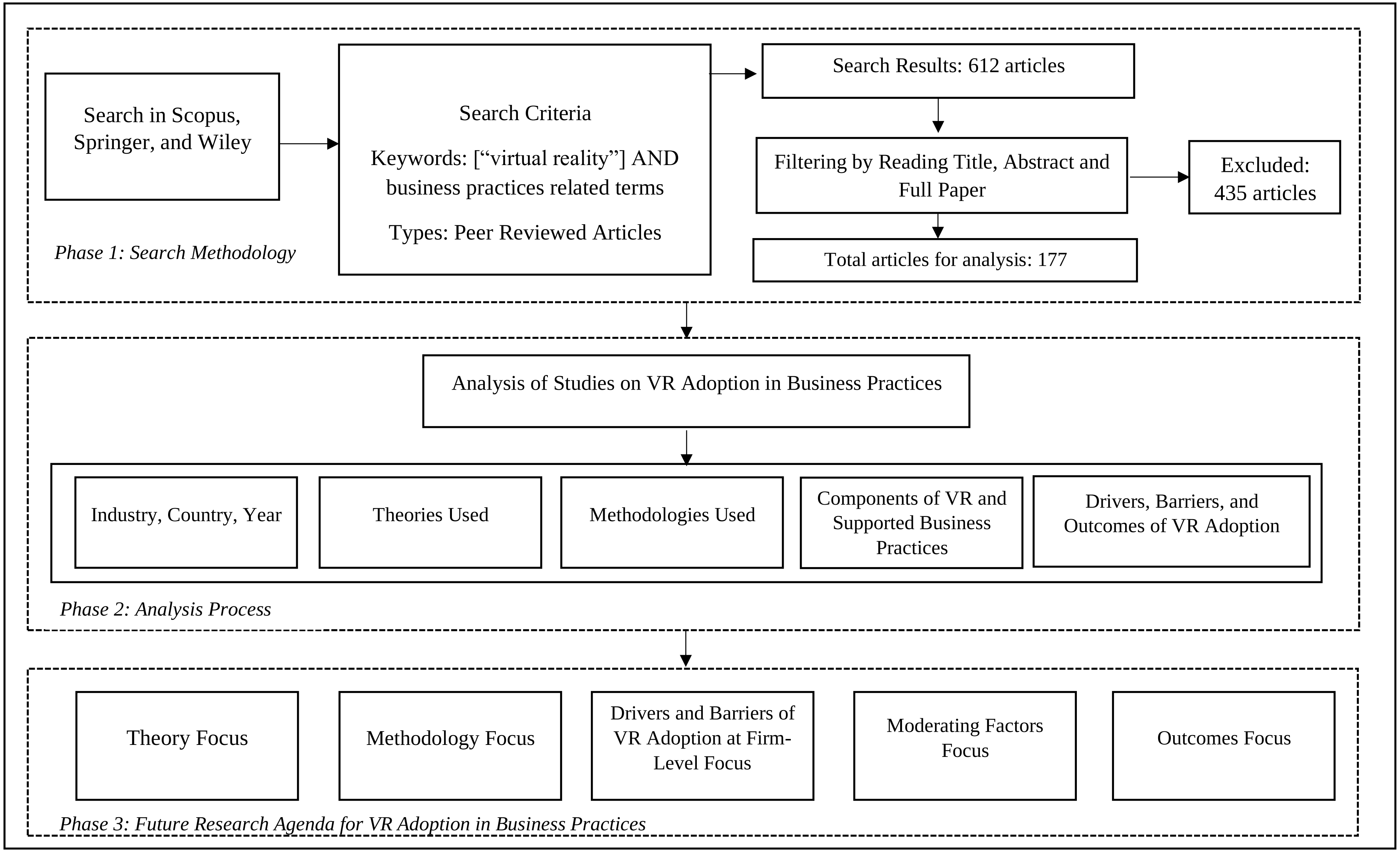
Figure 2.1 SLR Process



2.4 Findings

2.4.1 Overview of Identified Articles

Table 2.1 shows the 177 identified articles in accordance with the distribution of industry context, the country context, and the publication year. It should be noted that Table 2.1 only counts the identified articles with clear industry and country contexts. The identified articles without a specific industry or country context (e.g., reviewed studies and conceptual discussion) were included in *others* option in Table 2.1.

Panel A of Table 2.1 provides an overview of the industry distribution across the 177 reviewed articles. Existing business research on VR adoption mainly focuses on hospitality, retailing, manufacturing, education, healthcare, and real estate industry contexts. Of these industry contexts, about one-third of the research articles focuses on hospitality (29.94%), followed by the retail sector (12.43%). It is the experiential power of VR that allows hospitality and retailing companies to better improve customer experiences, and stimulate their purchasing decisions (Kim and Hall, 2019).

Panel B of Table 2.1 presents the country distribution of the review articles, including China, the US, the UK, Canada, Italy, Australia, Germany, and India. China (7.91%), the US (7.34%), and the UK (4.52%) account for the greatest number of studies. Panel C of Table 1 summarises the publication year distribution for the 177 identified articles. Over 85% of the identified articles were published between 2018 and 2021. Moreover, there were 60 identified articles published in 2021, accounting for 33.90% of the total identified articles over this eleven-year period. The apparent upward trend in the number of published articles indicates that the business and management research on VR adoption is becoming an emerging research stream, highlighting the importance of synthesising the current research and identifying new opportunities for future studies.

Table 2.1 Distributions of Industry, Country, and Publication Year of the Reviewed Articles

Panel A. Industry Distribution			
Industry Context	Number of Articles	Percentage	Exemplary Study
Hospitality	53	29.94%	Kim and Hall (2019)
Retailing	22	12.43%	Alzayat and Lee (2021)
Manufacturing	20	11.30%	Lawson et al. (2016)
Education	11	6.21%	Akdere et al. (2021)
Healthcare	8	4.52%	Plotzky et al. (2021)
Real Estate	4	2.26%	Pleyers and Poncin (2020)
Others	59	33.33%	Pizzi et al. (2020)
Panel B. Country Distribution			
Country Context	Number of Articles	Percentage	Exemplary Study
China	14	7.91%	Huang et al. (2021)
US	13	7.34%	Lee et al. (2020)
UK	8	4.52%	De Regt et al. (2021)
Canada	5	2.82%	Alzayat and Lee (2021)
Italy	2	1.13%	Pizzi et al. (2020)
Australia	4	2.26%	Yung et al. (2021a)
Germany	4	2.26%	Peukert et al. (2019)
India	4	2.26%	Vishwakarma et al. (2020)
Others	123	69.49%	Bu et al. (2021)
Panel C. Publication Year Distribution			
Year	Number of Articles	Percentage	Exemplary Study
2010	2	1.13%	Guttentag (2010)
2011	2	1.13%	Drake-Bridges et al. (2011)
2012	1	0.56%	Menck et al. (2012)
2013	3	1.69%	Tomas (2013)
2014	3	1.69%	Ausburn and Ausburn (2014)
2015	5	2.82%	Lee et al. (2015)
2016	2	1.13%	O'Brolcháin et al. (2016)
2017	1	0.56%	Jung and tom Dieck (2017)
2018	18	10.17%	Tham et al. (2018)
2019	37	20.90%	Peukert et al. (2019)
2020	43	24.29%	Pizzi et al. (2020)
2021	60	33.90%	Van Berlo et al. (2021)

2.4.2 Relevant Theories and Methodologies

2.4.2.1 Theories Used in the Reviewed Articles

The underlying theories in the reviewed papers can be classified into three streams, referring to technology adoption theory (e.g., technology acceptance model and unified theory of acceptance, and the use of technology), consumer psychological cognition and behaviour intention theory (e.g., stimulus-organism-response theory, theory of planned behaviour, and theory of reasoned action), and media and communication theory (e.g., media richness theory and social presence theory). Table 2.2 offers a detailed explanation of these theories.

First, the technology adoption theoretical stream, including models such as the technology acceptance model (TAM) and the unified theory of acceptance and use of technology (UTAUT), have been previously used to explain why consumers intend to use VR or how they perceive the values brought by VR adoption (e.g., Luna-Nevarez and McGovern, 2021; Kunz and Santomier, 2019). Second, consumer psychological cognition and behaviour intention theory (e.g., stimulus–organism–response theory, theory of planned behaviour and theory of reasoned action) is used to understand how VR shapes individuals' perceptions and further lead to their behavioural intentions. For example, Kim et al. (2020a) proposed a theoretical framework based on stimulus–organism–response theory to explain the influence of VR on customers' intentions to visit a destination. Third, the media and communication theory, including media richness and social presence theories, is used in the reviewed papers to explain the mechanisms of VR in detail and explore which VR-related mechanisms influence individuals' perceptions and behavioural intentions. For example, based on a social presence theory, Kandaurova and Lee (2019) identified that the immersion and presence brought by VR can affect individuals' attitudes and intentions. Table 2.3 presents some exemplary studies of VR adoption research based on the above three theoretical streams.

Table 2.2 Relevant Major Theories Used in The Reviewed Articles

Technology Adoption Theory		
Relevant Major Theories	Description	Exemplary Study
Technology Acceptance Model (TAM)	TAM is a basic information system management theory that explains why people choose and accept a certain technology. TAM argues that individuals' perceived ease of use (i.e., the degree to which individuals perceive how much effort will be required to learn to use the technology) and perceived usefulness (i.e., the extent to which individuals perceive that the technology will improve their performance) will shape their attitudes towards a particular technology. Accordingly, this attitude will further affect their behavioural intentions and finally determine their actual technology use.	Luna-Nevarez and McGovern (2021)
Unified Theory of Acceptance and Use of Technology (UTAUT) Model	UTAUT can be considered as an advanced TAM. UTAUT explains that users' performance expectancy, effort expectancy, and social influence determine their intentions of using a certain technology. Facilitating conditions can directly influence individuals' actual technology usage behaviour. Users' demographic characteristics (i.e., gender, age, experience, voluntariness of use) moderate the relationships between these four factors and behavioural usage intentions.	Kunz and Santomier (2019)
Consumer Psychological Cognition and Behaviour Intention Theory		
Relevant Major Theories	Description	Exemplary Study
Stimulus–Organism–Response (S-O-R) Model	The S-O-R model is a psychology-based model that has been broadly used to investigate the relationships between inputs (stimulus), processes (organism), and outputs (response). Specifically, the S-O-R model explains that stimuli (e.g., external environment factors) will affect individuals' organisms (e.g., their internal cognitions and emotions) and subsequently influence their behavioural responses.	Kim et al. (2020a)
Theory of Reasoned Action (TRA)	TRA is a psychological theory that explores the relationships between individuals' actions and their attitudes and beliefs. TRA suggests that an individual's behaviours are determined by their behavioural intention to perform an act. This behavioural intention is the result of an individual's subjective norms and their attitudes toward the behaviour.	Alyahya and McLean (2021)

Table 2.2 (Continued)

Consumer Psychological Cognition and Behaviour Intention Theory		
Relevant Major Theories	Description	Exemplary Study
Theory of Planned Behaviour (TPB)	As an extension of TRA, TPB identifies three components: attitude, subjective norms, and perceived behaviour control. Individuals' attitudes, subjective norms, and perceived behaviour controls drive their behavioural intentions, which ultimately lead to their actual behaviour.	Alyahya and McLean (2021)
Media and Communication Theory		
Relevant Major Theories	Description	Exemplary Study
Uses and Gratification (U&G) Theory	The U&G theory focuses on the interactions between individuals and media, stating that the use of media is due to its ability to satisfy individuals' specific demands. The basic antecedents of U&G, including entertainment, informativeness and irritation, can shape individuals' attitudes towards different media (e.g., email, web, and social media). Their attitudes towards different media further motivate them to select media to gratify their specific needs.	Hsu et al. (2020)
Media Richness Theory	Media richness theory, originating from communication media theory, posits that different media types have different capabilities for transmitting information and messages. A richer media type can allow individuals to communicate more quickly and better comprehend information and would thus have a better performance in equivocal tasks.	Lee et al. (2021)
Social Presence Theory	Social presence theory argues that media can make users experience a feeling of social presence (i.e., individuals perceive that they are real and present in an environment). The degree of social presence is based on the richness level of the information conveyed by the medium. The typical types of social presence include immersion and telepresence, leading to behavioural intention for media and technology usage.	Kandaurova and Lee (2019)

Table 2.3 Exemplary Studies Based on Different Theories

Author	Theory	Research Aim	Key Findings
Luna-Nevarez and McGovern (2021)	TAM	To explore the antecedents and consequences of consumer attitudes towards VR-supported commerce.	Immersion, enjoyment, trust and VR self-efficacy are potential antecedents of consumer attitudes toward VR-supported commerce. The consumers' attitudes towards VR-supported commerce can further increase their purchase intentions, visit intentions, and word-of-mouth.
Kunz and Santomier (2019)	UTAUT	To examine consumers' acceptance of VR technology.	Three influencing factors, namely, hedonistic motivation, social influence and performance expectancy, all showed significant effects on VR acceptance. In addition, flow and content quality have direct positive impacts.
Kim et al. (2020a)	S-O-R Model	To analyse how VR influences customers' intentions of visiting a destination.	VR improves customers' cognitive and emotional values and promotes their future willingness to visit a destination.
Kilic et al. (2021)	TPB	To explore the impact of VR-supported promotional activities on purchasing intention.	VR can positively affect customers' perceived service quality and product attitude. These perceived service quality and product attitude further lead to their purchasing intention.
Alyahya and McLean (2021)	TRA	To examine the role of VR in influencing travel customers' attitudes towards tourist destinations.	VR can exert a more positive influence on consumer attitudes towards a destination relative to less immersive technologies such as websites.
Hsu et al. (2020)	U&G Theory	To investigate how individuals' perceptions towards VR shopping website affect their behavioural intentions.	The perceived informativeness, perceived entertainment value, perceived usefulness and perceived ease of use towards VR shopping website significantly and positively individuals' online shopping intentions.
Lee et al. (2021)	Media Richness Theory	To explore the impact of VR's vividness and interactivity on consumer perceptions, information sharing and seeking behaviour.	VR's vividness and interactivity affect consumer perceptions and have further positive impacts on customers' information sharing and seeking behaviours.
Kandaurova and Lee (2019)	Social Presence Theory	To test the impact of VR on charitable giving in the context of social marketing.	VR increases the degree of both social responsibility and guilt, ultimately leading to a higher willingness to give to charity.

2.4.2.2 Methodologies Used in the Reviewed Articles

The methodologies used by the 177 reviewed articles can be divided into six groups, namely: survey, experimental design, conceptual discussion, case studies, interviews, and mixed method. Table 2.4 presents examples of studies that used these six methodologies.

Most reviewed articles (30.51%) are based on conceptual discussions. These studies typically focus on elaborating on the business potential of VR, and proposing conceptual models intended to explain how the internal mechanisms of VR can impact individuals or firm (Andrushchenko et al., 2019; Xi and Hamari, 2021). Survey methodology (25.99%) is the second most common approach in the reviewed articles. Most survey-based reviewed studies focus on using questionnaires to collect data and explore the relationships between VR adoption and its outcomes at the consumer level (Wu et al., 2020; Ghorbanzadeh, 2021).

Experimental research (23.73%) is the third most common type of research method. This approach is widely used in the field of business research, with the aim of estimating the effect of VR adoption on firms and individuals. For example, Pizzi et al. (2020) used the experimental design method to examine whether consumers display similar brand perceptions in both physical and virtual store environments. Several VR adoption business studies have also used case studies (7.34%), interviews (6.78%), and mixed methods (5.56%).

Table 2.4 Exemplary Studies Based on Methodology Classifications

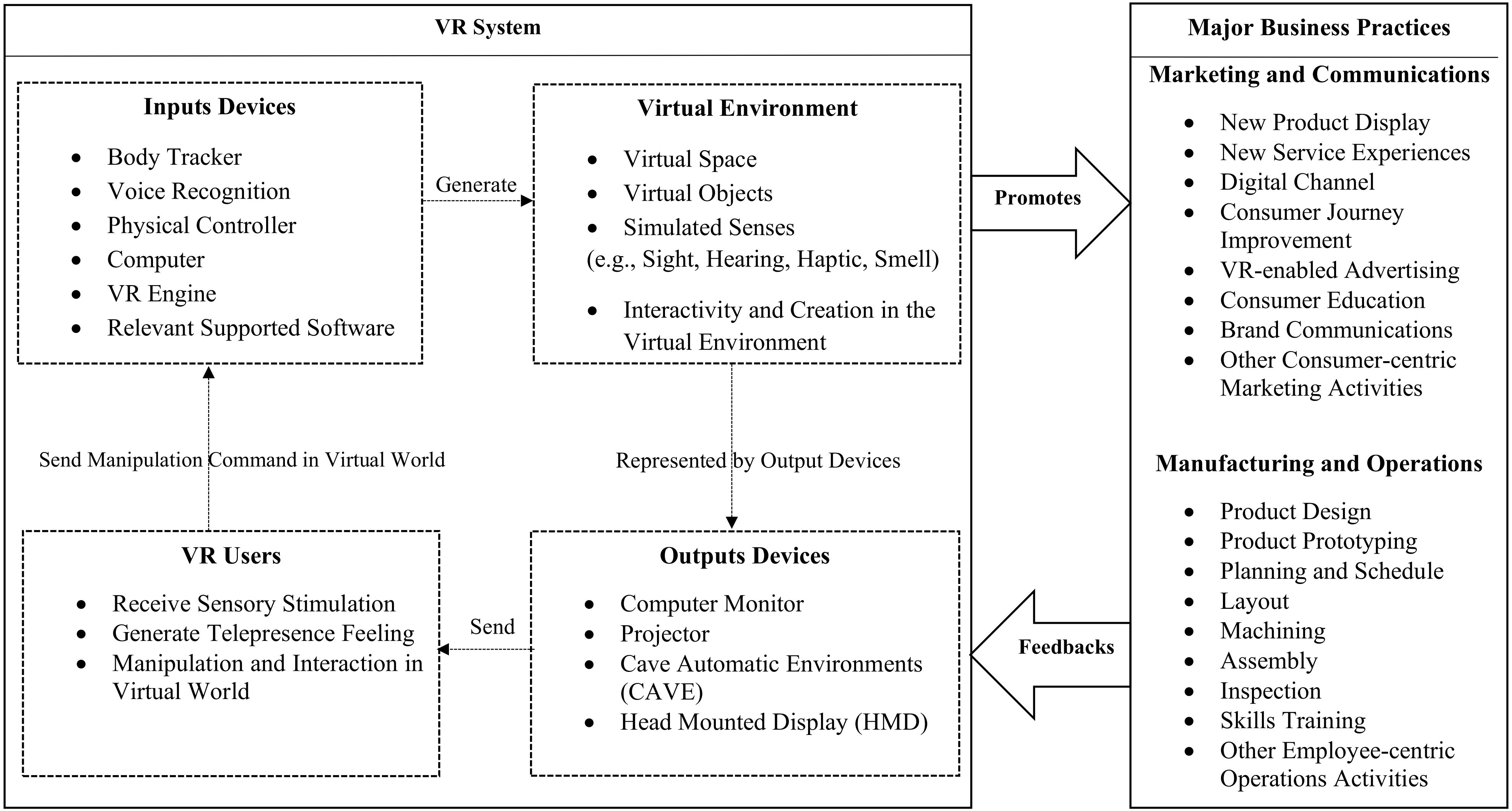
Author	Methodology	Research Aims	Key Findings
Andrushchenko et al. (2019)	Conceptual Discussion	To discuss how VR improves enterprise competitiveness.	They identified the main characteristics of VR and the significant advantages of VR in enterprises.
Xi and Hamari (2021)	Conceptual Discussion	To conduct a literature review and create a future agenda for VR shopping.	This study proposed future research avenues pertaining to concepts, themes, methodologies, and technologies related to VR research.
Wu et al. (2020)	Survey	To investigate the impacts of VR experiences on VR experiential outcomes	The VR experiences (i.e., immersion, interaction, illusion), VR identity, and VR familiarity can affect VR experiential satisfaction.
Ghorbanzadeh (2021)	Survey	To examine the relationships between the VR experiences, the experiential quality, and advocacy.	VR experiences of immersion, interaction and illusion have positive impacts on individual's experiential satisfaction.
Pizzi et al. (2020)	Experimental Study	To investigate whether consumers display similar brand perceptions between physical and virtual store environments.	VR environments lead to higher levels of presence than physical store environments.
Meißner et al. (2020)	Experimental Study	To investigate how VR shapes consumer choices.	Consumers in high-immersive VR choose a larger variety of products and are less price-sensitive. Choice satisfaction, however, did not increase in highly immersive VR.
Bu et al. (2021)	Case Study	To verify the feasibility and effectiveness of VR rowing machines.	The developed smart VR rowing machine can significantly enhance user experience. Moreover, user-generated and system-generated data can further support the solution design.
Jung et al. (2021)	Interviews	To theorize and investigate how consumers derive meanings from VR experiences of luxury brand fashion shows.	Developing a framework into the discussion of how VR technology is likely to shape marketing communications and consumer behaviour.
Davila Delgado et al. (2021)	Mixed Method	To investigate drivers and limitations for VR adoption in industry application.	This research concludes that performance-orientation (e.g., brand image, R&D), technological limitations, and dynamics affect VR adoption intention in industry context.

2.4.3 Essential Components of VR and VR-Enabled Business Practices

Based on a synthesis of the reviewed papers, we propose the following framework to explain the essential components of VR and VR-enabled business practices. As shown in Figure 2.2, a VR system is made up of four main components – input devices, virtual environment, output devices and VR users (Kim et al., 2020b; Xi and Hamari, 2021). These four components interact to form a circular chain that constitutes a complete VR system.

VR input devices refer to sensation-capture equipment (i.e., body trackers, voice recognition, physical controllers), computer hardware, and software (i.e., VR Engine and relevant supported software); in general, input devices aim to collect users' sensory information and use it to generate a virtual environment. Second, the virtual environment itself, generated based on the VR input devices, offers an interactive virtual space and objects that can be created or manipulated by users with simulated sensory stimuli (e.g., sight, hearing, haptic feedback and smell). Third, the virtual environment is then represented by several output devices, with typical output devices including computer monitors, projectors, Cave Automatic Environments (CAVEs) and HMDs (Gandhi and Patel, 2018). The fourth and final component, VR users, represents a key element of VR systems. By equipping them with output devices, VR users can receive sensory stimuli that are created based on the virtual environment. Simultaneously, VR users can use input devices to send manipulation commands in the virtual world and, ultimately, interact with the virtual environment. Managers extensively apply VR to support their marketing and communications practices (e.g., product displays, service experiences and digital channels) and manufacturing and operations practices (e.g., product design, prototyping, planning and employee training). Through these applications, VR-enabled business practices will provide feedback for VR systems, thereby contributing to future advances in this technology. We will further elaborate above concepts in the following sections.

Figure 2.2 A Framework for the Components of VR and VR-Enabled Business Practices



2.4.3.1 Components of VR

Input Devices and Virtual Environment

As shown in Figure 2.2, input devices and virtual environments are two components of the VR system. The VR input devices are used to generate the virtual environment, input actions sent by system users and allow users to interact with the virtual environment (Kim et al., 2020b; Xi and Hamari, 2021). Major VR system input devices include body trackers, voice recognition systems, physical controllers, computers, VR engines and any relevant supported software. Body trackers represent some of the most important VR system input devices (Peukert et al., 2019) and operate by monitoring the position of a user's body and its movements. Similarly, physical controllers and voice recognition systems allow users to send their manipulation and integration commands to virtual environments. Computers, VR engines and relevant supported software are then used to create the basic simulated virtual spaces and objects (Vishwakarma et al., 2020). Overall, these input devices can generate a virtual environment, consisting of interactive virtual space and virtual objects, with simulated human senses (e.g., sight, hearing, haptic, and smell). Users can change and manipulate the virtual environment using input devices and will receive immediate feedback for their actions (Cowan and Ketron, 2019; Lee et al., 2021).

Outputs Devices and VR Users

While the VR system's input devices generate the virtual environment itself, the major function of VR output devices is to represent virtual environments for users. The principal VR output devices are computer monitors, projectors, CAVEs and HMDs. First, as the most cost-effective output devices, computer monitors have limited capability to deliver the information and stimuli emerging from virtual environments (Peukert et al., 2019). Thus, projectors have been applied in VR systems as improved output devices in comparison to computer monitors. However, both computer monitors and projectors have clear drawbacks, such as, a lack of sense of immersion for users. Accordingly, more advanced technologies that offer a greater sense of immersion have been developed.

CAVEs (i.e., cubes with display screens surrounding the viewer) can create a powerful and comprehensive view of virtual environments from a user perspective (Xi and Hamari, 2021; Cowan and Ketron, 2019). The CAVE provides not only stereoscopic displays and computer graphics but also motion-tracking technology and the potential to replicate virtual environments on a large scale. This approach requires several projection walls and stereoscopic sound, as well as 3D glasses. Using this technology, users can partake in more vivid VR experiences. Lastly, HMDs are more advanced VR output devices (Xi and Hamari, 2021; Cowan and Ketron, 2019). By using headset equipment to isolate users from the real physical world, HMDs allow users to interact with the virtual environment via a 360° view. Among the four output device types, HMDs provide the best quality and sense of immersion (Kim et al., 2021).

Lastly, our study also considers VR users as a key component of the whole VR system. VR users can both receive sensory information from outputs and send manipulation commands in the virtual world to achieve a sensation of telepresence (Kim et al., 2021). In other words, VR users are considered receivers and senders of information and stimuli created in virtual environments. VR users serve as a key node that connects input devices, interactive and immersive virtual environments and output devices to form a complete VR system.

2.4.3.2 VR-Enabled Business Practices

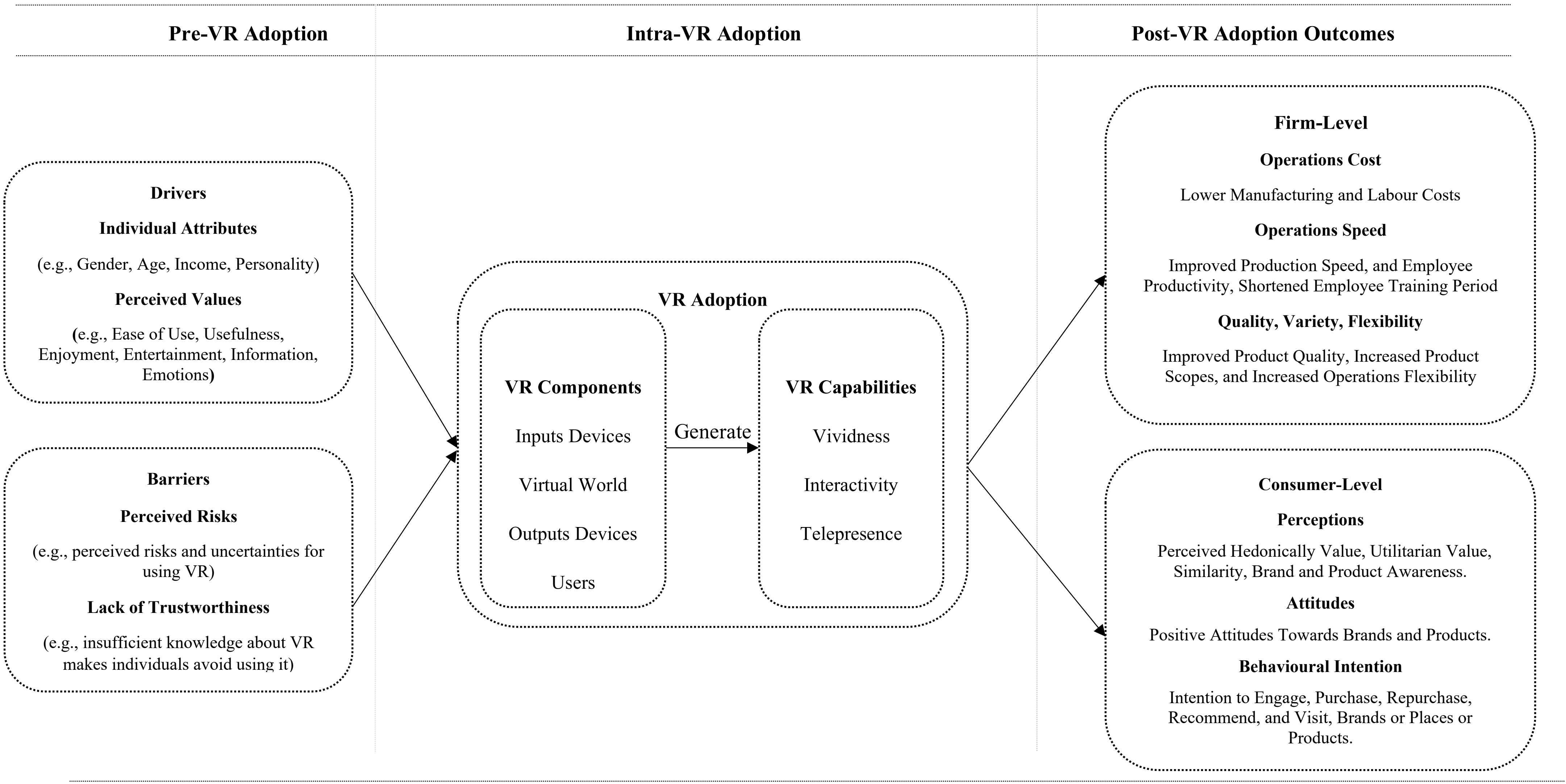
Based on a synthesis of previous studies (e.g., De Regt et al., 2021; Loureiro et al., 2019; Proffitt et al., 2019), we divided VR-enabled business practices into two types, namely, marketing communications practices (e.g., product displays, service experiences, and digital channels), and manufacturing and operations practices (e.g., product design, prototyping, planning and employee training). A key difference between these two business practice types is that the former focuses on consumer-centric activities while the latter is concerned with employee-centric activities. Another core difference is that VR-supported marketing communications practices are focused on generating short-term and more intangible values (e.g., brand perceptions, attitudes, engagement and behavioural intentions), whereas the primary focus of VR-supported manufacturing and operations practices is to produce more long-term and tangible returns (e.g., costs, profits and efficiency).

Although the reviewed studies have empirically investigated the positive impacts of VR-supported marketing communications practices on consumers, a remaining issue is about the behavioural intention gap – strong behavioural intentions may not ultimately lead to actual purchase behaviours. It is challenging to observe consumers' actual purchase behaviours as a result of VR-supported marketing communications practices. This gap raises a natural question, how do we measure the financial returns from VR-supported marketing communications practices? In addition, we also find that there is a lack of empirical studies to quantify the value creation of VR-supported manufacturing and operations practices.

2.4.4 A Theoretical Model for the Drivers, Barriers and Outcomes of VR Adoption

Figure 2.3 shows a theoretical model summarising the drivers, barriers and outcomes of VR adoption. Unlike previous review studies of VR adoption (Manis and Choi, 2019; Vishwakarma et al., 2020; Luna-Nevarez and McGovern, 2021), our model offers a more systematic and complete view by integrating both drivers and barriers, VR capabilities and both firm-level and consumer-level outcomes.

Figure 2.3 A Theoretical Mode for the Drivers, Barriers and Outcomes of VR Adoption



2.4.4.1 Drivers and Barriers

Figure 2.3 summarises that individual attributes (e.g., gender, age, income and personality) and perceived values (e.g., ease of use, usefulness, enjoyment, entertainment, information, emotions) are important drivers of VR adoption. Individual attributes reflect the unique characteristics of individuals that affect their intentions to use VR (Manis and Choi, 2019; Kunz and Santomier, 2019). Perceived values focus more on consumers' pre-existing evaluations of VR usage in terms of the extent to which VR will bring value or benefit to themselves. For example, perceived ease of use refers to the degree to which users believe that using VR will be free of effort (Jorgensen and Sorensen, 2021; Luna-Nevarez and McGovern, 2021; Vishwakarma et al., 2020). Similarly, perceived enjoyment relates to the degree to which users perceive VR usage as being fun (Ben-Ur, 2015). Regarding the firm-level perspective, these perceived values are more about managers' positive perceptions towards VR adoption that VR adoption can improve operational performances or brand image (Davila Delgado et al., 2021).

Compared with drivers of VR adoption, there is considerably less discussion of barriers in the reviewed studies. We identify that perceived risks, and lack of trustworthiness and expertise represent the two major barriers to VR adoption (Adegoke, 2021; Vishwakarma et al., 2020; Spiegel, 2018). For instance, perceived physical risk relates to users' fears of the harms that VR could cause, including depersonalisation and derealisation disorder (Spiegel et al., 2018). The lack of trustworthiness relates to users' greater concerns and lower confidence about the performance of VR (Spiegel et al., 2018). This perceived lack of trustworthiness of VR motivates individuals to avoid using VR. From a firm-level perspective, the perceived risks and lack of trustworthiness refer to managers' or decision-makers' concerns about the burdens of VR adoption (e.g., massive resources commitment) and related technological limitations (Davila Delgado et al., 2021).

It should also be noted that most of the reviewed articles concerning the determinants of VR adoption in this research focus only on consumer-level aspects, which hinders us from generating more insightful findings regarding the determinants of VR adoption at the firm-level aspects. In particular, the significant differences between consumers and managers in terms of the drivers of technology adoption make it difficult to generalise VR driving factors from the individual level to the firm level. We thus acknowledge that this model stage cannot fully explain managers' intentions to adopt VR and urge future empirical studies to investigate the firm-level drivers of VR adoption.

2.4.4.2 VR Capabilities

VR capabilities emerge and are received by users when they are using VR. We conclude that VR has three principal characteristics: vividness, interactivity and telepresence. These three VR capabilities are able to evoke users' arousal, affect their emotions, shape their perceptions and attitudes, increase their involvement, and finally affect their behavioural intentions. First, vividness refers to the richness of sensory information presented by a virtual environment (Loureiro et al., 2021; Kim et al., 2021; Lee et al., 2020). This richness comprises two dimensions: depth (i.e., the quality of sensory information perceived by users) and breadth (i.e., the number of sensory dimensions provided to users) (Kim et al., 2021; Lee et al., 2020; Lee et al., 2021). Hence, when devices deliver higher-quality image information and contain multiple sensory receptors, their perceived vividness is expected to be high (Lee et al., 2021; Peukert et al., 2019).

Second, interactivity represents the ability of users to easily interact and be involved in an immersive environment (Lee et al., 2021). The degree of interactivity is determined by three components: (1) the speed of manipulating the content of the immersive environment, (2) the similarity between the controls used in the immersive environment and real-world controls and (3) the range of content within the immersive environment that can be manipulated (Kim et al., 2021). VR devices can provide high levels of experience interactivity for their users. For instance, HMDs or CAVEs can imitate the size and appearance of objects, making them appear similar to reality (Peukert et al., 2019). In addition, users can use VR controllers to manipulate these virtual objects and receive immediate feedback regarding their manipulation.

Third, telepresence represents users' feeling that they perceive a highly immersive environment as an actual, realistic place and forget the outside physical world (Kim et al., 2021; Shen et al., 2020; Yung et al., 2021b). Unlike presence which generally emphasises a feeling of presenting in the environment, telepresence is more about a sense of being transported into a virtual world created by technology. In short, the sensation of telepresence is more related to the result of individuals' experiences with technology. Thus, we consider the term telepresence is more appropriate than presence for describing the unique capability of VR. To achieve a full telepresence status, two preconditions must both be satisfied: the feeling of being present in the immersive environment and the feeling of not being present in a physical environment (Kim et al., 2021). Although traditional media such as novels, pictures, two-dimensional videos and online games can generate immersive environments, they are unable to block out the distracting elements of the physical world (Hudson et al., 2019; Kim et al., 2021). With recent advances in VR technology, output devices such as HMDs or CAVE can completely encompass users' five sensory channels, and provide a 3D and 360° computer-generated virtual environment (Lee et al., 2021; Peukert et al., 2019; Wei et al., 2019; Yung et al., 2021b). As VR output devices allow users to isolate themselves from the real world and sustain immersion within the virtual world, these users thus likely experience a strong telepresence sense.

2.4.4.3 Outcomes at Firm-Level and Consumer-Level

As shown in Figure 2.3, we divided the outcomes of VR adoption into firm-level and consumer-level consequences. The VR adoption at firm-level refers to internal employees being the VR adopters. These internal VR adopters acquired improvements in professional skills, efficiency, and working performance, which further led to an overall improvement on organisational performance. We classified the firm-level outcomes of VR adoption into five categories, referring to operations cost, operations speed, quality, variety, and flexibility (Corallo et al., 2020; Kim et al., 2020b; Pooladvand et al., 2021). Operations cost is the essential resource commitment (i.e., manufacturing and labour resources) for maintaining the organisation's operations. The VR-supported manufacturing practices including virtual planning and virtual prototype allows companies to decrease manufacturing and labour costs. Operations speed refers to the time required by companies to transform inputs (e.g., raw materials) into outputs (e.g., finished goods). VR can facilitate effective production workflows, as highly interactive immersive virtual environments ensure design feasibility, while VR-synchronised networks guarantee communication efficiency and design decision-making speed (Juan et al., 2019; Prabhakaran et al., 2021). VR training may also enhance employee productivity in a real workplace setting (Chang, 2021). The quality and variety refer to the quality and scopes of outputs. That is, VR-supported business practices enable organisations to virtually identify the flaws of products, and develop more customised new products, which enhances the organization's product quality and variety. Lastly, flexibility refers to the organisation's capability to adapt its business practices to the change of environments. For example, VR has been used to simulate new working environments, helping employees to learn new operating practices and enhancing their production capabilities in turn (Pooladvand et al., 2021; Corallo et al., 2020).

Compared with VR adoption at firm-level, VR adoption at a consumer-level indicates consumers are the VR adopters. By synthesising the reviewed papers, we classified consumer-level outcomes into three categories: perceptions, attitudes, and behavioural intention. The three categories comprise a whole consumers' decision-making processes starting from perceptions to behavioural intention in VR adoption. Firstly, VR shapes consumer's multifaceted perceptions, such as hedonic value (Alzayat et al., 2021), positive emotions (Yung et al., 2021b; Flavián et al., 2021; Martínez-Navarro et al., 2019), enjoyment (Jorgensen and Sorensen, 2021; Luna-Nevarez and McGovern, 2021), hedonic feeling (Xue et al., 2020; Kunz and Santomier, 2019) and utilitarian value (Alzayat et al., 2021; Beh et al., 2021), brand and product awareness (Bogicevic et al., 2021). Notably, Deng et al. (2019) highlight that high consumer-perceived similarity between the virtual and real world will tend to reduce their intention to visit the actual destination or use the actual product in the future.

The perceptions shaped by VR can further affect consumers' attitudes towards brands and their behavioural intentions (Xi and Hamari 2021; Kim et al., 2021; Lyu et al., 2021; Lee et al., 2020; Tussyadiah et al., 2018). Attitude is based on customers' subjective evaluations of the overall VR experience and is an important driver of certain customers' behavioural intentions (Lee et al., 2020; Tussyadiah et al., 2018). Finally, VR can stimulate customers' intentions to engage (De Regt et al., 2021), purchase (Skard et al., 2021; Luna-Nevarez and McGovern, 2021; Van Berlo et al., 2021; Martínez-Navarro et al., 2019), recommend (Luna-Nevarez and McGovern, 2021; Wei et al., 2019) or visit (Luna-Nevarez and McGovern, 2021; Kim et al., 2020a). Notably, the impact of VR on consumers' decision-making processes does not follow a strictly sequential process in which VR first affects perceptions, then attitudes and finally leads to behavioural intentions. For instance, individuals' perceptions towards VR can also directly shape their behavioural intentions without the mediating role of attitudes (Zeng et al., 2020).

2.5 Future Research Agenda for VR Adoption in Business Practices

2.5.1 Theory Focus

We urge future research to develop VR-specific theories to explain the phenomena relevant to VR adoption in business practices. Current empirical studies still use traditional technology adoption theories (e.g., TAM, UTAUT) or consumer psychological cognition and behaviour intention theories (e.g., S-O-R, TPB) to explore the drivers and outcomes of VR adoption in business practices. While these theories offer a general theoretical explanation, it is still questionable to what extent these traditional theories can fully explain the mechanisms underlying the drivers and consequences of VR adoption. For instance, most previous studies have adopted the TAM to explain the drivers of VR adoption at the consumer-level, however, this model only emphasises driving factors such as perceived ease of use while ignoring barriers associated with VR adoption (Manis and Choi, 2019; Adegoke et al., 2021).

Overlooking the theory construction in terms of potential barriers to VR adoption impedes the development of empirical studies focusing on both firm-level and consumer-level VR adoption. Hence, future studies should address this important theoretical gap by proposing new theories to identify the barriers to VR adoption. Moreover, these traditional technology acceptance models fail to fully determine the underlying theoretical mechanisms specifically related to VR that explain how and which VR capabilities shape consumer-level outcomes. Although a few recent studies have started to use media communication theories (e.g., social presence theory) to decompose the capabilities of VR into different dimensions (e.g., immersion, interaction, vividness), these studies only provide minimal insights into the theoretical constructs of VR technology. Given this, a promising area for future theoretical development direction is to develop new indicators and constructs that are specifically linked to VR. This new research stream will contribute to future survey-based empirical studies by elucidating the theoretical mechanisms explaining the impacts of VR adoption on individuals and organisations.

2.5.2 Methodology Focus

Conceptual discussion, questionnaire-based surveys, experimental studies, interviews, case studies and mixed methods are the prevalent methodologies used in the reviewed papers reviewed. We propose the following suggestions to help future studies to develop more diversified research methodologies for business research on VR adoption.

First, most of the existing studies concerning the outcomes of firm-level VR adoption are based on conceptual discussion. It thus remains unclear whether VR adoption can generate tangible financial returns for firms. For future studies focused on the outcomes of VR adoption at the firm-level, we suggest an exploration of empirical methods to quantify the financial returns from VR adoption. Second, the outcomes of VR adoption at a consumer-level are controversial; while some studies show that VR can yield positive effects on consumer behavioural intentions (Lee et al, 2020; Tussyadiah et al, 2018), other recent studies have found that VR prevents behavioural intentions (Deng et al., 2019; Li and Chen, 2019). Accordingly, future research could adopt a meta-analysis approach to show the overall outcomes of VR adoption by combining these empirical studies.

In addition, all the reviewed empirical studies are cross-sectional studies, highlighting the need for longitudinal surveys. The longitudinal survey research method involves repeated observations of the same participants for an extended period (Rindfleisch et al., 2008). This approach can provide greater insights into the causal relationship between VR adoption and firm-level or consumer-level outcomes, as well as determine whether these relationships endure over time (Wamba et al., 2015).

2.5.3 Drivers and Barriers of VR Adoption at Firm-Level Focus

As VR becomes increasingly important in firms' business practices, it is crucial to comprehensively understand the drivers and barriers of VR adoption. We thus encourage future studies to focus on the following drivers and barriers that have been overlooked in previous studies.

First, future research should focus more on the drivers and barriers of VR adoption at the firm-level as previous empirical studies have largely focused on individuals' acceptance of VR usage rather than firms' adoption perspectives. In particular, the drivers and barriers to technology adoption at firm and individual levels are distinctly different (Proffitt et al., 2019). Li and Chen (2019) also suggest that it is essential to focus on the drivers and barriers of VR adoption at a firm-level. An improved understanding of these aspects in VR adoption would allow increased application of VR in business practices. For instance, by understanding the potential barriers to VR adoption (e.g., lack of R&D resources, technical skills and financial resources), researchers can examine how to overcome these barriers and thus contribute to VR adoption in business practices.

Second, we suggest that future researchers should explore the following potential drivers and barriers to VR adoption at the firm-level. Potential drivers at firm-level include competitive pressures (e.g., number of competitors and market structure), firm resources (e.g., firm size, financial resources, and R&D investment) and firms' strategic emphasis (e.g., exploitation, exploration, cost-leadership and differentiation). Competitive pressures represent one of the foremost drivers focus for technology adoption (Abdallah et al., 2014); a high level of competitive pressure may force organisations to adopt VR. Firm resources as a potential driver type relate to whether firms have the basic support for adopting new technologies (Oliveira and Martins, 2011). Future research should place greater emphasis on technology-related resources such as R&D investment. In addition, another area of particular interest is examining whether firms' strategic emphasis will direct their intentions for VR adoption in business practices.

We also recommend that future research should consider resource constraints (e.g., high cost of capital, lack of R&D infrastructure and lack of talent) as important barriers to VR adoption in business practices. Investigating these specific barriers to VR adoption is particularly worthy of research attention, as some small and medium enterprises often experience difficulties arising from limited available resources. In particular, VR adoption requires high levels of R&D infrastructure that determine the ability to implement this technology, while professional talents are required to conduct training using VR. Apart from internal resource constraints, external industry environment factors (e.g., government policy uncertainty and industry uncertainty) may also hinder organisations' technology adoption (Chae et al., 2018). Overall, future research into this theme could generate new theoretical and managerial implications for a complete comprehension of determinants of VR adoption at the firm-level.

2.5.4 Moderating Factors Focus

In addition to identifying the main determinants of VR adoption and its outcomes, we also suggest that future research should consider the factors that moderate these relationships. The VR studies reviewed in our research did not fully investigate moderating factors, except for a few studies that examined the moderating effects of VR on consumers' perceptions and intentions (e.g., Hudson et al., 2019; Kandaurova and Lee et al., 2019; Ying et al., 2021). The factors moderating the impact of VR adoption on firm-level outcomes are also overlooked by existing studies; accordingly, future research should emphasise the investigation of additional moderating factors at both the consumer and firm levels.

Factors Moderating the Impact of VR Adoption on Consumer-Level Outcomes

In terms of the impact of VR adoption on consumer-level (or individual-level) outcomes, future research should focus on the moderating effects of VR device type and product suitability. The type of VR devices adopted by firms can also lead to a moderating effect on adoption outcomes at an individual level. As VR involves different input and output devices, the use of different devices can yield varying levels of immersion experience (Cowan and Ketron, 2019).

Consumers' attitudes and perceptions may also be strengthened or weakened in VR adoption through the use of different VR devices. Accordingly, further research is required to examine whether different VR devices can moderate the impacts on these outcomes. Additionally, not all products or services are suitable for promotion by VR; thus, the degree of fit between VR and products may also moderate the impact of VR on consumers' perceptions.

Factors Moderating the Impact of VR Adoption on Firm-Level Outcomes

In terms of the impact of VR adoption on firm-level outcomes, future research should focus on the moderating effects of technology capability (i.e., the level of knowledge relevant to the usage of new forms of technology) and organisational culture (i.e., the congruence between a firm's culture and its employee capabilities, work values, and interests) (Liu et al., 2008; Wang et al., 2012). For a complex emerging technology like VR, if a firm's internal capability and culture cannot support the firm or its employees to fully leverage the VR technology, its impacts on business activities will not achieve their maximum potential (Liu et al., 2008; Wang et al., 2012).

Future research could also consider industry-level moderators. For example, the level of competitive intensity (i.e., the extent of competition within an industry) may moderate the impact of VR adoption. When competitive intensity is low, companies can perform well without the need for investing in additional disruptive supported business practices such as VR to attract consumers (Abdallah et al., 2014). In contrast, in a highly competitive market, differentiation and creative advertising are vital (Abdallah et al., 2014). Environmental dynamism (i.e., the extent of unpredictable change in an organisation's environment) should also be considered (Goll and Rasheed, 2004). In a highly dynamic market environment, investing in VR may enable firms to capture new market opportunities and reap extra benefits.

2.5.5 Outcomes Focus

We suggest future research should conduct more empirical studies to investigate the outcomes of VR adoption at both consumer and firm levels.

Consumer-Level Outcomes Focus

Most current research focuses on the positive outcomes of VR adoption on consumers. For instance, the use of VR undeniably provides enhanced opportunities for marketers to communicate with consumers (Farah, 2019). Furthermore, VR technologies can help brands show their products more clearly and vividly, as well as being more convenient for providing quotations (Kim et al, 2021b). While VR has numerous advantages, a recent study conducted by Li and Chen (2019) showed that VR adoption may lead to negative consumer responses. They found that VR inhibits tourists' travel intentions under certain conditions; when the expected enjoyment of the destination is low, the perceived enjoyment of VR is higher. Similarly, as identified by Deng et al. (2019), VR may inhibit consumers' behavioural intentions under certain conditions; when VR yields high perceived similarity between a virtual environment and the real world, consumers feel no need to consume the product in reality, having already experienced it in the virtual world. Hence, further research should be conducted to develop a theoretical framework that can explain both aspects of VR adoption outcomes; in doing so, firm managers and researchers would be able to mitigate the undesirable outcomes of VR adoption. Such a new research stream would help both managers and researchers to better understand the limitations of such technology and allow appropriate approaches to be implemented to maximise its positive effects.

Firm-Level Outcomes Focus

Most existing research has verified the positive outcomes of VR at the consumer level (e.g., improved brand attitudes and purchase intentions). The empirical evidence at the consumer level has motivated several studies to conceptually discuss how VR can also generate firm-level outcomes (e.g., sales, financial returns, operational efficiency, and reduced service costs), but without empirically quantifying its tangible returns for firms. At present, there are some limitations regarding consumer-level outcomes; for example, an attitude–behaviour gap exists during the process of purchasing products. While many consumers may have a positive attitude towards a product or service, they may nonetheless ultimately not purchase it. The behaviour gap theory implies that attitudes towards products develop through feelings and cognition about products and that these attitudes can translate into realistic behaviours; however, this relationship only occurs under certain conditions (Hassan, 2016). Moreover, Hauser et al. (2013) indicate that purchasing behaviours are not wholly governed by cognition. Thus, the investigation of consumer-level outcomes may not fully uncover the net returns of VR adoption in business practices.

We further suggest that future research should focus on firm-level outcomes of VR adoption by empirically investigating whether the use of VR in business practices tends to improve an organisation's financial performance. In summary, researchers should conduct more empirical investigations into the performance impacts of VR from a firm-level perspective. This new research avenue can provide an important benchmark for justifying VR adoption investment.

2.6 Conclusion and Limitation

Overall, our research used a systematic literature review to analyse 177 articles concerning VR adoption in business practices. Our paper then proposed several research directions for future studies. First, future research should develop VR-specific theories to better explain the phenomena relevant to VR adoption in business practices. Especially, future theoretical and conceptual studies need to develop new indicators and constructs that are particularly linked to VR. Second, future research direction should consider using diversified methodologies to increase the understanding of drivers and outcomes of VR adoption. Third, future studies should focus more on the drivers and barriers of VR adoption at the firm-level as previous empirical studies have largely focused on individuals' acceptance of VR technology usage rather than firms' adoption perspectives. Fourth, future studies need to further investigate moderating factors for VR adoption at both the firm and consumer levels. Fifth, we suggest future research focuses on firm-level outcomes of VR adoption by investigating whether the use of VR adoption in business practices tends to bring tangible returns for organisations. Meanwhile, further research should underline both positive and negative aspects of VR adoption outcomes at a consumer level. Overall, these new research opportunities and directions identified in our review contribute to future business research on VR adoption.

However, our study also has certain limitations. As we used only Scopus, Wiley and Springer databases to search for peer-reviewed articles, some grey literature or industry reports were thus not included. Accordingly, future research could incorporate studies from more diverse sources. Furthermore, the reviewed period in our research is from 2010 to 2021. The distribution of the publication years of our reviewed papers indicates that more than 33.90% of the identified articles were published in 2021. We thus suggest that future studies should conduct updated SLR research or adopt a meta-analysis approach to investigate the drivers, barriers and consequences of VR at both consumer and firm levels.

Chapter 3.

Gaining Virtual or Real Value? Exploring the Impact of Virtual Reality-Enabled Marketing Practices on Firm Value

Abstract: Firms have been increasingly adopting virtual reality (VR) technologies in their marketing activities, but it is still unclear whether firms can gain real value from these VR-enabled marketing practices. Although these practices are expected to improve the experience and satisfaction of customers who are immersed in a VR-enabled environment, the uncertainties and risks arising from emerging VR technologies should not be underestimated. We quantify the impact of VR-enabled marketing practices on firm value in terms of abnormal stock returns. Based on 201 VR-enabled marketing practices announced between 2012 and 2019 in the US market, our event study results show that VR-enabled marketing practices lead to negative abnormal stock returns. This suggests that shareholders are more concerned about the uncertainties and risks associated with these practices. Consistent with this view, we further find that the negative effects become even more pronounced at a high level of firm uncertainty. Nevertheless, the negative effects are reduced when firms collaborate with each other to implement VR-enabled marketing practices, when firms are focused on value appropriation strategies, and when firms apply VR in the post-purchase stage (i.e., creating consumption experiences). Overall, our research demonstrates the negative impact of VR-enabled marketing practices on firm value but also reveals how the negative impact can be mitigated through marketing alliance, strategic focus, and application area.

Keywords: VR-enabled marketing practices, marketing-finance interface, event study, abnormal stock returns

3.1 Introduction

As an ever-increasing range of disruptive technologies significantly impacts the market, marketers are seeking these technologies to support their marketing activities and improve firm performance (Hua et al., 2015; McAfee, 2002). Nowadays, the potential value of virtual reality (VR), one of the most promising disruptive technologies, is rapidly attracting marketing practitioners' attention (Grewal et al., 2017; Wedel et al., 2020). Unlike traditional digital marketing tools (e.g., websites, digital advertising and social media), VR allows for higher user control and involvement than 2D environments. It creates an immersive virtual 3D environment within which users navigate and interact, experiencing a feeling of being present in another world (Cowan and Ketron, 2019). The business potential of VR has driven brands to incorporate it into their marketing practices as an alternative way to reach and communicate with consumers. For instance, Macy's launched a VR furniture program that allows customers to virtually design and experience the interior of a room for which they are purchasing furnishings (Bloomberg, 2018), and Marriott used VR to create the Marriott Hotel 4-D sensory and immersive virtual travel experience for its customers (PR Newswire, 2014).

While the emerging VR-enabled marketing practices have attracted much attention, the extant research has mainly focused on their effects on customers' mindset metrics (e.g., awareness, perception, attitude and behavioural intention). For example, prior studies have suggested that VR-enabled marketing activities can improve consumers' intentions to visit a destination (Huang et al., 2016), attitudes toward tourism destinations (Tussyadiah et al., 2018), purchase intentions and brand attitudes (Van Kerrebroeck et al., 2017). However, a few recent studies also contend that VR-enabled marketing practices yield negative consequences such as decreasing customers' behavioural intention in some situations (Deng et al., 2019; Li and Chen, 2019). Given the scarcity of research on VR marketing–financial performance relationship and the debate over VR marketing, it thus remains unclear whether these consumer-level outcomes from VR-enabled marketing practices can ultimately be converted into financial returns (i.e., firm value) for companies.

Our research responds to the call by Edeling et al. (2021) for further investigation into the impacts of digital marketing practices on firm value. The firm value is manifested by previous marketing–finance studies based on the event study method as abnormal stock returns (Borah et al., 2022; Eshghi, 2022; Sadovnikova and Pujari, 2017; Srinivasan and Hanssens, 2009). Compared with the consumer mindset metrics, using firm value as a performance indicator of marketing investments enables researchers and managers to capture the precise financial implications of marketing practices (Edeling and Fischer, 2016; Lee and Kim, 2010).

Recent empirical studies have demonstrated that marketing practices (e.g., customer engagement initiatives, unprofitable customer management strategies, cause-related marketing strategies) do not always benefit firms, and sometimes even lead to a significant loss of firm value (Beckers et al., 2018; Feng et al., 2020; Woodroof et al., 2019). Moreover, shareholders hold a more negative evaluation about the adoption of disruptive technologies (e.g., artificial intelligence) in a firm's business practices due to the risks and uncertainties associated with such investments (Lui et al., 2022). These continuing controversies also indicate that the impact of VR-enabled marketing practices on firms may not always be positive as the firms expect, and thus there is an urgent need to empirically investigate whether and when VR-enabled marketing practices create value for firms. As a result, our study intends to shed new light on the firm value implications of VR-enabled marketing practices and answer the following two questions:

1. What is the impact of VR-enabled marketing practices on firm value?
2. How do firm characteristics drive the magnitude of change in firm value resulting from VR-enabled marketing practices?

Our research contributes to the literature and managerial practices in several ways. First, we contribute to the emerging research stream on leveraging VR in marketing practices to create value. While extant studies regarding the consequences of VR-enabled marketing practices focus on consumer-level outcomes, we show their impact on firm value by using an event study approach that measures firms' abnormal stock returns associated with VR-enabled marketing practices. Our findings offer a timely empirical evidence of the value creation of VR-enabled marketing practices from a firm-level perspective, which complements the research stream on marketing-finance interface (Edeling et al., 2021; Healey and Mintz, 2021; Lamey et al., 2021).

Moreover, our study contributes to the literature on the adoption of disruptive technology in marketing practices. Our findings provide empirical evidence that VR-enabled marketing practices exert a negative impact on firm value. In accordance with the logic of technology readiness (TR), we argue that investors are more concerned about the uncertainties arising from (rather than the innovation embedded in) VR-enabled marketing practices. This result supports the argument of prior studies that VR marketing is a double-edged sword for firms (Deng et al., 2019; Li and Chen, 2019). We urge managers to be cautious in implementing VR-enabled marketing practices and to consider the potential negative impacts of adopting disruptive technologies in marketing practices.

Finally, our results reveal that the negative impact of VR-enabled marketing practices on firm value is contingent on firm characteristics (i.e., marketing alliance, firm uncertainty, and strategic emphasis) and the application area in the customer journey stages (i.e., the pre-purchase, purchase, and post-purchase stages). This finding outlines the pathways managers can use to offset the negative impacts and increase the value creation associated with VR-enabled marketing practices.

3.2 Conceptual Background and Hypothesis Development

3.2.1 Conceptualizing VR-Enabled Marketing Practices

Sherman and Craig (2018, p. 16) provide a comprehensive definition of VR, which is "a medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation." By simulating a virtual world with a high level of interactivity and vividness, VR enables users to experience a sense of telepresence (Boyd and Koles, 2019; Coyle and Thorson, 2001; Sherman and Craig, 2018). The multisensory inputs generated by VR allow users to interact with virtual objects in an immediate manner and view the results of their interaction in real-time, as well as being both physically and mentally immersed in the virtual environment (Cowan and Ketron, 2019; Kang et al., 2020; Deng et al., 2019). As a result, VR gives brands the ability to communicate with customers more easily and innovatively. An impressive example is the partnership between Humana and the National Park Service in the United States, which launched a 360-degree virtual park experience wherein users simply put on VR headsets to experience virtual interactions with the natural environment without the need to be physically present.

In this research, we investigate the application of VR in consumer-focused marketing activities wherein organisations use VR to deliver marketing offerings to customers. The study of Wedel et al. (2020) provides a comprehensive summary of VR applications in marketing practice from a customer journey perspective (See Table 3.1). In particular, VR-enabled marketing practices can be divided into three application areas: 1) communications and advertising, 2) retailing and selling, and 3) creating or enhancing the consumption experience. These three VR application classes roughly correspond to the pre-purchase, purchase, and post-purchase stages in the customer journey (Wedel et al., 2020).

Table 3.1 VR Applications in Marketing Practices

Customer Journey	VR Application Area	Application Examples
The Pre-Purchase Stage	Communications and Advertising	• Introducing digital VR advertising • VR-supported brand and product showcase
The Intra-Purchase Stage	Retailing and Selling	• Virtual store and retail space for buying products • VR-enabled product and service trials
The Post-Purchase Stage	Creating or Enhancing Consumption Experience	• VR-supported new products and services

Source: Wedel et al. (2020)

The pre-purchase stage involves a process in which consumers search for products and service information and evaluate alternatives (Ozer and Gultekin, 2015). During this stage, VR is applied for marketing communication and advertising activities, i.e., firms use VR as a medium to deliver marketing messages to customers, increase customer engagement and brand awareness, and shape customers' perceptions (Song et al., 2021). For example, General Electric collaborated with The New York Times to launch VR advertising (Castillo, 2015).

Second, the intra-purchase stage refers to the stage in which customers make their buying decisions but do not consume the purchased products or services (Karimi et al., 2015). In this stage, VR is applied to retailing and selling practices to facilitate customers' planned purchases (Wedel et al., 2020). An example of this stage is Alibaba's introduction of VR shopping to help customers better view and compare products (Business Wire, 2016a).

Third, the post-purchase stage refers to customers' final consumption activities and self-evaluation regarding their consumption experience (Karimi et al., 2015). For this final stage of the customer journey, VR is applied by firms to offer customers new products and experiences or enhance their existing products and experiences (Talwar et al., 2022). For example, the IMAX corporation and New York Times introduced VR cinema and VR-supported news broadcasting as new service offerings (Rahman, 2016; Business Wire, 2016b). Notably, the core difference between VR applications in the intra-purchase and post-purchase stages is that the former only involves purchasing, whereas the latter relates to actual consumption behaviours and post-consumption behaviours.

Previous studies have explored how VR can be applied as a marketing tool to benefit companies, such as enrichment of the customer's experience (Lin, 2017); improvement of consumers' brand perception and recall (Wang and Chen, 2019); stimulating consumer behavioural intention and purchase decisions (Kim et al., 2020a). Meanwhile, several recent studies argue that VR-enabled marketing practices result in a negative impact on consumers in certain situations (Deng et al., 2019; Kim et al., 2018; Li and Chen, 2019). For instance, Deng et al. (2019) conclude that VR marketing dampens consumers' interest in pursuing the real experience. Yet, the prevailing studies largely employed consumer surveys and experiment designs to investigate the outcomes of VR-enabled marketing practices. These studies have been confined to the mindset metrics (e.g., cognition, attitude and behavioural intentions) and are consumer-focused, with scant empirical research being conducted into how VR-enabled marketing practices affect the firm value. Our research seeks to investigate the implications of VR-enabled marketing practices in relation to firm value from the shareholder standpoint, which clearly differs from existing empirical studies and broadens the extant knowledge of VR marketing impacts (See Table 3.2).

Table 3.2 Summary of Representative Empirical Research Related to VR Marketing

Study	Research Focus	Perspective	Key findings
Huang et al. (2016)	The impact of VR on consumers' visiting intentions in tourism industry	Consumer	VR increases consumers' intentions to visit a destination.
Van Kerrebroeck et al. (2017)	The impact of VR on consumers' purchase intentions and attitudes in retailing industry	Consumer	Organisations can use VR to improve consumers' purchase intentions, and brand attitudes.
Tussyadiah et al. (2018)	The impact of VR and consumers' attitudes toward tourism destinations	Consumer	VR positively shapes consumers' attitudes toward tourism destinations
Domina et al. (2018)	Investigating the determinants of VR behavior usage intention	Consumer	Developing a framework to explain consumers' intention to use VR.
Li and Chen (2019)	Exploring negative impacts of VR on consumers	Consumer	VR will inhibit tourists' travel intention under certain condition.
Deng et al. (2019)	Exploring the mediating effect of perceived similarity between VR and consumer's intention	Consumer	Perceived similarity negatively mediates VR and behavioural intention.
Lo and Cheng (2020)	To explore theoretical mechanisms leading to consumer responses to VR advertising	Consumer	The presence mediates the relationship between the use of VR in tourism advertising and consumer response.
This study	VR-enabled marketing practices and firm value	Shareholder	VR-enabled marketing practices significantly affect firm value.

3.2.2 The Impact of VR-Enabled Marketing Practices on Firm Value

Previous studies have discussed how the use of VR in marketing activities benefits companies by uncovering its positive impacts on consumers (Huang et al., 2016; Van Kerrebroeck et al., 2017). Recent studies highlight that the adoption of VR in marketing activities not only presents opportunities but also results in uncertainties for firms (Deng et al., 2019; Laurell et al., 2019; Li and Chen, 2019; Lui et al., 2016). For instance, consumers may have a poor user experience with VR-enabled marketing practices and fail to perceive their benefits due to unfamiliarity with the technology, sickness during VR usage, visual presentation imperfections and privacy concerns (Wedel et al., 2020). These challenges associated with VR-enabled marketing practices may lead to possible marketing failures and brand damage, resulting in uncertainty for both consumers and firms. The uncertainty arising from VR-enabled marketing practices tends to make customers sceptical of a brand's overall quality and potentially reluctant to engage in subsequent purchase activities (Forsythe and Shi, 2003; Van Ewijk et al., 2022). This may make it challenging for firms to predict marketing outcomes and accordingly make associated decision adjustments (Beckman et al., 2004; Martin et al., 2015).

The above debate about this emerging technology inspired our study to adopt a technology readiness (TR) lens to elaborate on the impact of VR-enabled marketing practices on firm value. TR theory argues that emerging technology adoption can simultaneously trigger people's positive and negative views towards technology (Mick and Fournier, 1998; Walczuch et al., 2007). This is due to the motivators and inhibitors embedded in cutting-edge technology concurrently influencing the propensity of individuals to accept them (Blut and Wang, 2020; Parasuraman, 2000). The motivators foster people's predisposition to embrace new technologies while inhibitors hinder their acceptance intention (Liljander et al., 2006). Based on the TR logic, the motivators and inhibitors associated with VR-enabled marketing practices exert both positive and negative impacts on consumers. Shareholders evaluate these potential consumer impacts to judge the value of the marketing practices (Colicev et al., 2018; Lane and Jacobson, 1995).

First, the increased marketing innovation is the motivator that contributes to consumers' acceptance of VR-enabled marketing practices, bringing positive consumer impacts and resulting in shareholders' positive evaluations regarding these marketing investments (Sorescu and Spanjol, 2008; Tang et al., 2021). Marketing innovation refers to the application of a new marketing method for selling products or services involving significant changes in any of the following aspects: product packaging, design, placement, promotion or pricing (Gupta et al., 2016; OECD, 2005). Marketing innovation allows companies to better satisfy customer demands, penetrate new markets and position products and brands, with the ultimate aim of increasing sales (OECD, 2005). Companies may seek to achieve marketing innovation by applying disruptive technology to obtain a sustainable competitive advantage and differentiate their brands from competitors (Quaye and Mensah, 2019). Unlike other digital marketing practices (e.g., social media marketing and email marketing), VR-enabled marketing practices generate an immersive and virtual environment through advanced visualisation capabilities, which allow consumers to have a more realistic and tangible encounter with products and services, thereby generating optimal customer experiences and facilitating a comprehensive pre-purchase evaluation (Jung et al., 2021; Tussyadiah et al., 2018; Violante et al., 2019). One example is that of online ticket vendor StubHub, which employs VR technology to provide its consumers with virtual views of their seats prior to purchase (Cowan and Ketron, 2019). Another example is the virtual property viewing activities launched by estate agent Foxtons, which uses VR technology to present prospective customers with a fully furnished space, despite the space being empty in reality (Foxtons, 2016). Such innovative marketing practices also improve a firm's marketing efficiency by effectively shaping consumer perceptions and behavioural intentions (Pizzi et al., 2020; Tussyadiah et al., 2018; Wang and Chen, 2019). In this way, increased marketing innovation as the result of VR-enabled marketing practices enables companies to develop unique and inimitable marketing activities, as well as improve their market competitiveness (Gupta et al., 2016).

While it is expected that VR-enabled marketing practices will contribute to marketing innovation and further lead to a positive impact on firm value; the increased uncertainty from VR-enabled marketing practices as an inhibitor may decrease consumers' propensity to accept the use of this cutting-edge technology for marketing purposes, leading to marketing failures and resulting in extra costs for firms. In other words, although VR-enabled marketing practices may improve firms' marketing innovation, they can also generate uncertainty. The uncertainty stems from incomplete knowledge, which makes it difficult to predict future outcomes and performance (Beckman et al., 2004; Gulen and Ion, 2016; Milliken, 1987). According to KPMG (2016), as a nascent disruptive technology, there is high uncertainty regarding the potential outcomes of VR. This is exemplified by Deng et al. (2019), who suggest that VR may also dissuade consumers' interest in future consumption due to a strong perceived similarity between virtual and real experiences.

Moreover, the hardware and software limitations of technology further enlarge this kind of uncertainty for a firm's VR-enabled marketing practices (Lawrie, 2020; Reuters Institute, 2018). Using social media analytics and machine learning method, Laurell et al. (2019) concludes that adopting VR for marketing purposes at the present time faces the risk of not meeting consumers' expectations and revealing a gap between the perceived total value of this technology and the market price. This is because VR offers too little stand-alone value and has not reached operational maturity that there is a lack of sufficient technological performance and applications to support firms' marketing activities (Deloitte, 2020; Laurell et al., 2019). Meanwhile, Kim et al. (2018) highlight a major concern about VR is the health risks associated with this technology, with other scholars indicating that VR may lead to simulator sickness, including dizziness and visual disturbances (Lim et al., 2020; Somrak et al., 2019; Tyrrell et al., 2018). For example, the leading VR headset maker Oculus recently issued an emergent product recall due to potential health risks (BBC News, 2021). These health hazards pose substantial risks to susceptible users and may have potentially devastating consequences for firms that use this technology for marketing purposes. Shareholders may thus hold reasonable concerns over the potentially uncertain consequences of VR-enabled marketing practices. As noted by Blut and Wang (2020), if individuals are distrustful of and sceptical about technology, they not only tend to expect risks rather than benefits in any technology but also avoid it as a consequence. Therefore, it is possible that VR-enabled marketing practices may be seen by shareholders as a risky undertaking due to its high uncertainty.

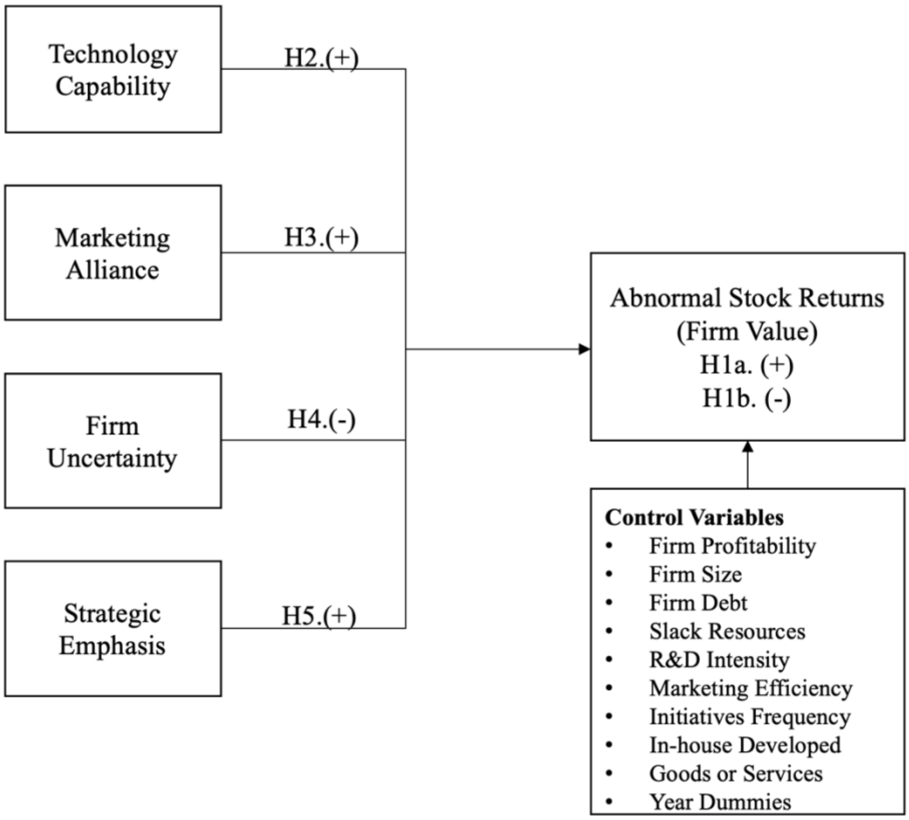
Our above discussion suggests that enhanced marketing innovation as a motivator may generate a positive consumer impact which allows shareholders to positively evaluate VR-enabled marketing practices. Conversely, increased uncertainty is an inhibitor that may lead to a negative consumer impact, resulting in shareholders' negative evaluations of VR-enabled marketing practices. Therefore, we posit the following competing hypotheses.

Hypothesis 1a. VR-enabled marketing practices positively affect firm value.

Hypothesis 1b. VR-enabled marketing practices negatively affect firm value.

Based on a contingency perspective, we argue that the magnitude of such effects may vary across a firm's characteristics including its technology capability, marketing alliance, firm uncertainty and strategic emphasis. These characteristics are related to the previous two theoretical explanations (i.e., increased marketing innovation and uncertainty) through which VR-enabled marketing practices may create or destroy value. In particular, as we have argued that VR-enabled marketing practices increase both marketing innovation and uncertainty, a firm that has a high level of technology capability and seeks a marketing alliance may have more chances to effectively exploit this technology and reduce related uncertainty, thus reaping more firm value in VR-enabled marketing practices. Yet, a firm with a high level of internal firm uncertainty weakens its forecasting and planning activities, thus further increasing the uncertainty of VR-enabled marketing practices. Finally, those firms who focus on value appropriation have more marketing resources and experiences to contribute to their VR-enabled marketing practices and thus may be more capable of reducing uncertainty. The role of these firm characteristics will be further discussed in the following sections and shown in Figure 3.1.

Figure 3.1 Conceptual Framework of Second Study



3.2.3 The Effect of Technology Capability on Firm Value

Technology capability manifests an organisation's ability to absorb, deploy, leverage and integrate information technology into its operational processes to accomplish the organisation's objectives (Bharadwaj et al., 2000; Ravichandran et al., 2005). Technology capability enables companies to improve their performance and reduce uncertainty when adopting new technology (El Sawy and Pavlou, 2008; Mao et al., 2015). This is because companies with a high level of technology capability benefit from strong IT expertise, better IT infrastructure and enhanced information flow, which increase the chance of a successful implementation of emerging technology (Chen et al., 2014). In fact, the failures of launching new technologies are rooted in the lack of essential resources such as experience and expertise in the relevant technologies. Technology capability thus plays a critical role in the case of VR-enabled marketing practices and can determine its success.

VR-enabled marketing practices as a marketing innovation activity require firms to invest in essential technological resources to support these activities. The resources and expertise associated with technology capability contribute to the launch of VR marketing activities and provide companies with the opportunity to effectively exploit the potential value of VR in their marketing activities. A strong technology capability also reduces the uncertainties associated with VR-enabled marketing practices by decreasing the chance of implementation failure and providing the required infrastructure. Therefore, technology capability strengthens the positive impact and weakens the negative impact of VR-enabled marketing practices. Accordingly, we posit the following hypothesis:

Hypothesis 2. The firm value arising from VR-enabled marketing practices will be more positive (or less negative) for firms with high levels of technology capability.

3.2.4 The Effect of Marketing Alliance on Firm Value

Inter-firm partnerships are an important vehicle for firms reducing uncertainty and fostering performance in cutting-edge technology supported marketing practices (Soh and Roberts, 2005). Marketing alliance refers to a partnership between two or more firms in downstream value chain activities (Swaminathan and Moorman, 2009). Marketing alliance enables firms to benefit from the complementarity of resources and competencies contributed by their respective partners within the collaboration (Lavie, 2007; Yeniyurt et al., 2009). These combined resources and knowledge arising from marketing alliances contribute to innovation, and reduce the inefficiencies and uncertainties associated with emerging technology-supported marketing activities (Gnyawali and Park, 2009; Hora and Dutta, 2013). In this way, firms with marketing alliances have better chances in effectively employing VR-enabled marketing practices and reducing the uncertainties associated with VR-enabled marketing practices. We thus posit the following:

Hypothesis 3. The firm value arising from VR-enabled marketing practices will be more positive (or less negative) for firms implementing these practices through marketing alliances rather than by individual firms.

3.2.5 The Effect of Firm Uncertainty on Firm Value

Firm uncertainty refers to internal financial performance instability and variability (Martin et al., 2015; Lee et al., 2011). The frequent fluctuation of internal financial performance impairs firms' forecasting and planning activities, and negatively affects firm performance (Roy and Cohen, 2015; Parnell et al., 2000). A high firm uncertainty leads to unpredictable internal resources status and thus reduces managers' ability to effectively implement projects with high level of uncertainty, estimate future outcomes, and push forward further strategy (Bstieler, 2005; Martin et al., 2015). Conversely, a low firm uncertainty indicates that a company has a stable and robust internal resource status, which is beneficial for investment in high-uncertainty projects (Beckman et al., 2004; Orlitzky and Benjamin, 2001). Since VR-enabled marketing practices may increase uncertainty; implementing VR-enabled marketing practices under the high uncertainty situation will further amplify shareholders' concerns about whether the firm will have sufficient resources to support the practices. Thus, shareholders may not appreciate and thus negatively respond to the implementation of VR-enabled marketing practices in firms with high internal uncertainty. We thus developed the following hypothesis:

Hypothesis 4. The firm value arising from VR-enabled marketing practices will be more negative (or less positive) for firms with high levels of uncertainty.

3.2.6 The Effect of Strategic Emphasis on Firm Value

A firm's strategic emphasis refers to its degree of resource allocation to R&D and marketing activities (Healey and Mintz, 2021; Jia, 2020; Mizik and Jacobson, 2003). According to Mizik and Jacobson (2003), firms allocate their limited resources between two fundamental processes: (1) value creation, which involves innovating new products and creating superior knowledge via R&D activities; (2) value appropriation, which extracts profits via marketing activities. The core difference between these two strategic emphases is that value creation is an innovation process in which firms transform R&D investments into innovation outputs, while value appropriation is the process whereby firms use marketing activities to transform these innovation outputs into financial returns (Mizik and Jacobson, 2003; Morgan et al., 2018). Although both value creation and value appropriation contribute to firms' sustainable competitive advantages (Huang et al., 2015; Tower et al., 2021), it is important for companies to attempt to align their new strategic practices with general strategic orientation. This is because strategic incompatibilities require new resource redeployments and coordination, leading to extra costs and uncertainties (Swaminathan et al., 2008). Conversely, aligning a firm's new strategic practices with overall strategic emphasis reduces uncertainty, increases the likelihood of successful practices, and finally has more chances in reaping profits (Avison, 2004). More importantly, a firm's strategic emphasis on value appropriation tends to experience fewer uncertainties than a value creation emphasis (Healey and Mintz, 2021). In our study, VR-enabled marketing practices are a type of firm value appropriation activities. When firms with a value appropriation emphasis implement VR-enabled marketing practices, strategic emphasis alignment can be better achieved. This strategic emphasis alignment indicates that firms have more marketing resources and experiences to contribute to their VR-enabled marketing practices. Finally, this strategic emphasis alignment reduces the uncertainty related to VR-enabled marketing practices. Therefore, we developed the following hypothesis:

Hypothesis 5. The firm value arising from VR-enabled marketing practices will be more positive (or less negative) for firms with a value appropriation emphasis.

3.3 Methodology

3.3.1 Sample

We tested our hypotheses using a sample of VR-enabled marketing practices announced by publicly traded US companies. Following previous event study research, we used Factiva to identify the announcements of VR-enabled marketing practices (Sadovnikova and Pujari, 2017; Sorescu et al., 2017). Factiva is a database that includes full-text information from news, official announcements, media and magazines across 200 countries (Modi et al., 2015). As VR-enabled marketing practices are still an emerging phenomenon, the search was limited to an eight-year period from 2012 to 2019. Additionally, this study did not include announcements from the years 2020 and 2022 to avoid potential confounding effects due to the COVID-19 pandemic. We also searched Factiva to identify firms' VR-enabled marketing practices prior to 2012 and did not find any VR marketing-related announcements discoloured by US-listed firms, supporting the decision to focus on this period.

We employed several combinations of keywords to search for announcements about VR-enabled marketing practices, including VR-related keywords (immersive technology *or* virtual reality *or* VR) and stock market-related keywords (NASDAQ *or* NYSE). There were two reasons behind the selection of combinations of keywords; first, using the sole VR-related keywords allowed us to cover all VR-related announcements and avoid the omission of samples as far as possible; second, the stock market-related keywords enabled us to identify the US listed firms because we need to use their available stock data to calculate the abnormal stock returns associated with VR-enabled marketing practices as discussed in section 3.2.

We carefully read all searched VR-related announcements and performed a content analysis to ensure that VR was adopted by firms only for marketing rather than for other purposes (e.g., employee learning and training, manufacturing activities, and product design).

In particular, we applied a set of marketing-specific keywords (e.g., marketing, consumers, customer, retailing, selling, communication, advertising, and consumption) to identify relevant VR marketing-related announcements. The announcements identified for inclusion in the study were required to meet the following three criteria: (1) the announcement should be related to applying VR to consumer-centred marketing activities, such as product display, product and service promotions, brand communications and consumption experiences activities; (2) when firms announced the same type of VR-enabled marketing practices more than once, only the earliest announcement was retained; (3) VR-enabled marketing practices must be announced by US-listed firms. We gathered a total of 240 announcements concerning VR-enabled marketing practices, some examples of which are presented below.

- Ford Motor announced that it would use VR to display its new vehicles.
- Dolby Laboratories combined VR in their showcase festival.
- Alibaba employed VR to enable visitors to get a taste of virtual shopping.
- IMAX Corporation introduced VR cinema as new service offerings.
- The New York Times introduced VR-supported news broadcasting.

Based on the initial sample of 240 announcements identified, we further checked for confounding events (e.g., acquisitions, mergers, dividends, lawsuits) in the three days on either side of the VR-enabled marketing practices announcement day via *Factiva*. In cases where such confounding events occurred during in these seven days, the relevant announcements were eliminated from the sample. This strategy is commonly applied in event study research to segregate the influence of different confounding events (Sadovnikova and Pujari, 2017). A total of 19 announcements were eliminated on the grounds of co-founding events. We also excluded 20 announcements as the stock price data of corresponding firms were unavailable. Our final sample thus comprised 201 VR-enabled marketing practices announced by publicly traded US companies from 2012 to 2019. Figure 3.2 shows the overview of sample firms identification strategy in this study. Table 3.3 presents the descriptive statistics of the final sample.

Figure 3.2 Overview of Sample Firms Identification Strategy

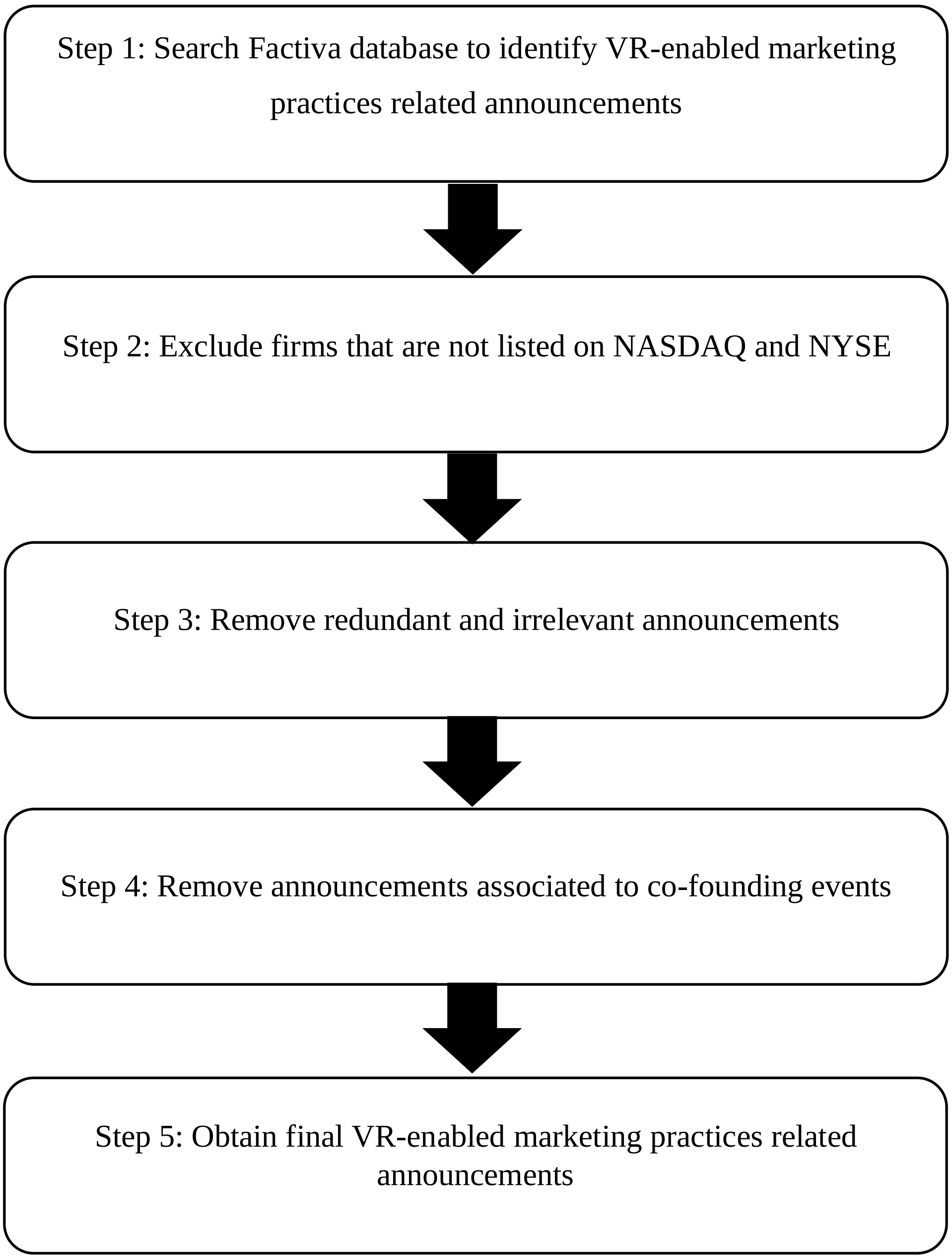


Table 3.3 Characteristics and Distribution of Samples

Panel A: Descriptive Statistics of Samples					
Variable	Unit	Mean	Std. Deviation	Min	Max
Net Income	Million US$	3186.33	4719.44	-3864.00	21878.00
Current Assets	Million US$	16166.45	25333.11	5.53	161978.00
Liabilities	Million US$	58475.56	165433.78	5.50	1508118.00
Inventories	Million US$	4311.10	15547.38	0.00	193772.00
Market Value	Million US$	56648.96	74872.08	24.90	399535.36

Panel B: Industry Distribution of Samples			
Industry	2-Digit SIC Code	Frequency	Percentage
Manufacturing	20-39	81	40.30%
Services	60-89	65	32.34%
Transportation and Public Utilities	40-49	27	13.43%
Wholesale and Retail Trade	52-49	22	8.46%
Public Administration	91-99	4	1.99%
Mining and Construction	10-17	2	1.00%
Total		201	100.00%

Panel C: Year Distribution of Samples		
Year	Frequency	Percentage
2012	2	1.00%
2013	4	1.99%
2014	7	3.48%
2015	25	12.44%
2016	64	31.84%
2017	48	23.88%
2018	36	17.91%
2019	15	7.46%
Total	201	100.00%

3.3.2 Event Study Design

We employ the event study methodology to investigate the impact of VR-enabled marketing practices on firm value. Event study methodology originates from the semi-strong efficient market hypothesis, which asserts that stock prices reflect public information and instantly change upon the emergence of new information (Fama, 1970). This methodology has been used in marketing research to assess the impact of marketing practices on firm value, such as customer engagement practices (Beckers et al., 2018) and retail service innovation practices (Lamey et al., 2021).

Event study methodology measures the magnitude of impact arising from an unanticipated event on firm value by estimating the abnormal stock returns (ARs) associated with the event after controlling for market-wide factors that might influence stock prices (Agrawal and Kamakura, 1995; Beckers et al., 2018; Sadovnikova and Pujari, 2017). The event study approach allows us to capture the influence of VR-enabled marketing practices on firm value by measuring ARs resulting from VR-enabled marketing practices. ARs are calculated as the difference between the real stock return of firm *i* on event day *t* and its expected stock return on event day *t* as shown in the following equation.

$$AR_{it} = R_{it} - E(R_{it}), \quad (1)$$

where R_{it} is the daily stock return of firm *i* on day *t*, $E(R_{it})$ signifies the expected stock return of firm *i* on day *t*, and AR_{it} represents the abnormal stock return of firm *i* on day *t*.

$E(R_{it})$ is calculated by employing the Fama-French three-factor model over a period of 210 days, ending on the 11 days prior to the event date (Blau et al., 2019; Fuller et al., 2019). The event date was identified based on the publication date shown in the VR-related announcements. The Fama-French three-factor model has more explanatory power for estimating expected stock return than the one-factor or market models (Madden et al., 2006).

$$E(R_{it}) = R_{ft} + \beta_1(R_{mt} - R_{ft}) + \beta_2 SMB_t + \beta_3 HML_t, \quad (2)$$

where R_{ft} is the risk-free rate of return on day *t*, and R_{mt} denotes the average rate of return of all stocks trading in the stock market on day *t*. SMB_t equates to the size risk that accounts for the return of publicly-traded companies on the small-minus-big portfolio. HML_t as the value factor accounts for the return of publicly-traded companies on the high-minus-low portfolio.

Following previous event study research (e.g., Borah and Tellis, 2014; Swaminathan et al., 2008), we use a three-day event window ranging from one day before the VR-enabled marketing practices announcement ($t = -1$) to one day after the VR-enabled marketing practices announcement (t = +1) to address potential information leakage and market response delay. Consequently, cumulative abnormal returns (CARs) of firms were obtained as the sum of daily ARs over the event window. To test H1, the Patell z-test and the standardised cross-sectional t-test were used to verify whether the CARs arising from announcements of VR-enabled marketing practices were significantly different from zero.

3.3.3 Cross-Sectional Regression

Consistent with prior event studies (e.g., Beckers et al., 2018; Sadovnikova and Pujari, 2017), we construct a cross-sectional regression model to further test H2 to H5. Specifically, we regress the CARs obtained from the event study on the explanatory and control variables introduced below and shown in equation 3. One-tailed significance tests were chosen to examine the hypothesised variables due to a clear expectation of the direction of their effects. Conversely, two-tailed tests were applied to control variables, where such directional hypotheses were not established. Table 3.4 summarises the measurement of all variables, while Table 3.5 presents an overview of the descriptive statistics and correlations between variables.

$$CAR_i = \beta_0 + \beta_1 Technology\ Capaiblity_i + \beta_2 Marketing\ Alliance_i + \\ \beta_3 Firm\ Uncertainty_i + \beta_4 Strategic\ Emphasis_i + \beta_5 Firm\ Profitability_i + \\ \beta_6 Firm\ Size_i + \beta_7 Firm\ Debt_i + \beta_8 Slack\ Resources_i + \beta_9 R\&D\ Intensity_i + \\ \beta_{10} Initiatives\ Frequency_i + \beta_{11} In-house\ Developed_i + \beta_{12} Goods\ or\ Services_i + \\ \beta_{13} Year\ Dummies + \varepsilon_i \qquad (3)$$

CARs. The dependent variable is the CARs of firms arising from the announcements of VR-enabled marketing practices. In line with previous event studies (Lam et al., 2016; Lam et al., 2019), the most significant CARs across all event windows will be chosen as the dependent variable in the regression model. This selection criterion is based on the premise that the most significant CARs are indicative of the immediate impact of VR-enabled marketing practices on firm value, thereby representing the most pronounced outcomes.

Technology Capability. Following prior marketing research (Kashmiri et al., 2017), we measure technology capability in accordance with whether a company has appeared on the InformationWeek 500 list before their VR initiative announcements. This public database annually identifies and honours the most innovative adopters of information technology by evaluating their IT budgets, size of IT staff and percentages of IT budget devoted to various technologies (Bharadwaj, 2000). A company's appearance on the InformationWeek 500 list indicates that it has strong and sufficient IT infrastructure and resources and represents a high level of technology capability.

Marketing Alliance. As shareholders rely on public information to evaluate the value of VR-enabled marketing practices, we perform a content analysis of companies' VR-enabled marketing practices announcements to identify whether the company forms a partnership with other companies to deliver its marketing offerings. We measure marketing alliance through a dummy variable, wherein it is coded as 1 if a company is involved in a collaboration on VR-enabled marketing practices, and 0 otherwise (Lam et al., 2019; Swaminathan and Moorman, 2009).

Firm Uncertainty. Firm uncertainty indicates the fluctuations of financial performance over time (Henkel, 2009; Orlitzky and Benjamin, 2001). Following the study of Henkel (2009), we measure firm uncertainty as the standard deviation of a firm's return on assets (ROA) during the five-year period before the announcement of its VR-enabled marketing practices. A high standard deviation of ROA indicates a high volatility, instability or fluctuation in a firm's financial performance. Hence, this measurement is in line with the notion of firm uncertainty and provides an adequate measure.

Strategic Emphasis. We operationalise strategic emphasis by calculating the difference between advertising expenditures and R&D expenditures, and dividing this by a firm's total assets (Mizik and Jacobson, 2003; Swaminathan et al., 2008). Firms with a heavy advertising investment tend to have a greater association with value appropriation emphasis, while firms with heavy R&D investment are more inclined towards value creation emphasis (Mizik and Jacobson, 2003). A more positive score suggests that a firm has a stronger commitment to value appropriation-based marketing strategies; a less positive score or more negative score suggests that a firm has a stronger commitment to value creation-based strategies.

Control Variables. We control for several firm-level variables, including firm profitability, firm size, firm debt, slack resources, R&D intensity, marketing efficiency, initiatives frequency and VR-enabled marketing practices via in-house development or outsourcing as these variables might be related to a firm's stock returns (Ding et al., 2018; Lam et al., 2019). Specifically, we measure firm profitability as net income divided by total assets (Sorescu et al., 2017), firm size as the log transformation of total assets (Beckers et al., 2018), firm debt as total liabilities divided by total assets (Delen et al., 2013), slack resources as current assets divided by total assets (Lui et al., 2016), R&D intensity as R&D expense divided by total assets (Sorescu et al., 2017), marketing efficiency as the total sales divided by advertising expenditures (Manikas and Pankaj, 2016), initiatives frequency as the frequency that companies implement VR-enabled marketing practices from 2012 to 2019 (Beckers et al., 2018), and in-house developed as a dummy variable and coded as 1 if companies implement VR-enabled marketing practices via own in-house development (Han and Mithas, 2013). Finally, we include industry dummy (i.e., primarily operating in a goods or services setting) and year dummies in our regression model to control the industry- and time-specific effects (Sadovnikova and Pujari, 2017).

Table 3.4 Variable Measurements

Variable	Measurement	Reference	Data Source
Dependent Variable			
CAR	The sum of abnormal stock returns (ARs) over the event window based on Fama-french three-factor model.	Sadovnikova and Pujari (2017)	CRSP
Independent Variables			
Technology Capability	Dummy variable: High level of IT capability was coded as 1 if the firm was part of the InformationWeek 500 (IW 500) list of leaders within one year before the announcement of VR-enabled marketing practices.	Kashmiri et al. (2017)	IW 500
Marketing Alliance	Dummy variable: Coded as 1 if companies collaborate on VR-enabled marketing practices.	Swaminathan and Moorman (2009)	Factiva
Strategic Emphasis	Strategic emphasis is calculated as "(advertising expenditures - R&D expenditures)/ total assets".	Healey and Mintz (2021)	Compustat
Firm Uncertainty	The standard deviation of return on asset (ROA) during the five-year period before the announcement of VR-enabled marketing practices.	Henkel (2009)	Compustat
Control Variables			
Firm Profitability	A company's return on asset (ROA) ratio, calculated as "net income divided by total assets".	Sorescu et al. (2017)	Compustat
Firm Size	A company's total assets (log-transformed).	Beckers et al. (2018)	Compustat
Firm Debt	A company's total liabilities divided by total assets.	Delen et al. (2013)	Compustat
Slack Resources	A company's current assets divided by total assets.	Lui et al. (2016)	Compustat
R&D Intensity	A company's R&D expense divided by total assets.	Sorescu et al. (2017)	Compustat
Marketing Efficiency	A company's total sales divided by advertising expenditures.	Manikas and Pankaj (2016)	Compustat
Initiatives Frequency	The frequency that companies implement VR-enabled marketing practices from 2012 to 2019.	Beckers et al. (2018)	Factiva
In-house Developed	Dummy variable: Coded as 1 if companies implement VR-enabled marketing practices via own in-house development VR consoles and 0 if the companies outsource the VR consoles from external vendors.	Han and Mithas (2013)	Factiva
Goods or Services	Dummy variable based on companies' two-digit SIC code distinguishing companies primarily operating in goods or services setting (SIC 70-89).	Beckers et al. (2018)	Compustat
Year Dummies	Dummy variables; Coded as 1 for each announcement year.	Sadovnikova and Pujari (2017)	Factiva

Table 3.5 Correlation Matrix and Descriptive Statistics

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. CAR (-1, 0)	1.00													
2. Technology Capability	0.01	1.00												
3. Marketing alliance	0.17**	0.00	1.00											
4. Firm Uncertainty	-0.25***	-0.05	0.05	1.00										
5. Strategic Emphasis	0.15**	0.02	-0.11	0.08	1.00									
6. Firm Profitability	0.17**	0.06	-0.02	-0.22***	0.00	1.00								
7. Firm Size	0.03	0.26***	-0.11	-0.38***	-0.09	0.15**	1.00							
8. Firm Debt	0.07	0.09	-0.12*	0.03	0.03	-0.05	0.11	1.00						
9. Slack Resources	-0.23***	-0.19***	0.08	0.30***	-0.08	-0.03	-0.29***	-0.41***	1.00					
10. R&D Intensity	-0.20***	-0.11	0.18**	0.39***	-0.46***	-0.27***	-0.25***	-0.02	0.42***	1.00				
11. Marketing Efficiency	0.00	-0.07	-0.02	-0.06	0.00	0.01	-0.08	0.03	-0.13*	-0.06	1.00			
12. Initiative Frequency	0.08	0.05	0.09	-0.09	-0.04	-0.04	-0.02	-0.07	-0.11	-0.03	-0.07	1.00		
13. In-house Developed	0.07	0.00	-0.03	-0.18**	-0.04	0.03	0.04	0.03	-0.07	-0.04	0.05	0.00	1.00	
14. Goods or Services	0.04	-0.08	-0.09	-0.19***	0.06	0.01	0.29***	-0.09	-0.02	-0.01	-0.17**	0.13*	0.08	1.00
Mean	-0.005	0.194	0.358	0.040	0.001	0.053	9.536	0.238	0.381	0.042	7.580	1.850	0.766	0.761
Standard Deviation	0.018	0.396	0.481	0.049	0.068	0.109	2.112	0.179	0.203	0.056	15.959	1.499	0.424	0.427

Notes: *p< 0.1, **p< 0.05, ***p< 0.01 (two-tailed tests).

3.4. Results

3.4.1 The Abnormal Returns of VR-Enabled Marketing Practices

To test H1, we estimated the abnormal stock returns (ARs) of a firm when implementing VR-enabled marketing practices. Table 6 illustrates the results of average abnormal returns (AARs) and cumulative average abnormal returns (CAARs) across the 201 samples.

Panel A of Table 3.6 shows the AARs for VR-enabled marketing practices on the three days ranging from one day before the event day (−1) to one day after the event (+1). AARs on day -1 are negatively significant (-0.29%, $p<0.01$), which is consistent with the premise that relevant information about VR-enabled marketing practices may be leaked before the formal announcement. AARs on day 0 are also negatively significant (-0.18%, $p<0.01$), but are not statistically significant (-0.06%, $p> 0.1$) on day +1. These results indicate that there are significant negative stock market reactions to VR-enabled marketing practices on one day before the event and on the event day.

Panel B of Table 3.6 further presents the CAARs for VR-enabled marketing practices on three event windows. The CAARs over both the two-day (i.e., days -1 to 0 and days 0 to +1) and three-day (i.e., days -1 to +1) event windows are negative and significant ($p<0.1$). Overall, these negative and significant CAARs results support H1b and indicate that VR-enabled marketing practices on average significantly decrease firm value and shareholders negatively evaluate the value of firms' VR-enabled marketing practices.

Table 3.6 Results of ARs and CARs based on Fama-French Three-Factor Model

Panel A: Abnormal Stock Returns (ARs)				
Day	N	Average ARs (AARs)	*z*-statistics	*t*-statistics
-1	201	-0.29%	-3.00***	-3.20***
0	201	-0.18%	-1.99**	-1.90**
+1	201	-0.06%	-0.22	-0.21
Panel B: Cumulative Abnormal Stock Returns (CARs)				
Event Window	N	Average CARs (CAARs)	*z*-statistics	*t*-statistics
(-1, 0)	201	-0.47%	-3.53***	-3.86***
(0, +1)	201	-0.24%	-1.57*	-1.43*
(-1, +1)	201	-0.53%	-3.00***	-2.97***

Notes: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$ (one-tailed tests).

3.4.2 Cross-Sectional Regression Results

Following prior event study research that recommends the use of the most statistically significant CARs in cross-sectional regression analysis (Boyd et al., 2019), we use the CARs from the event window (-1, 0) as the dependent variable to test our remaining H2 to H5. The cross-sectional regression results are reported in Table 3.7. As the basic model, Model 1 includes all control variables. Models 2 to 4 sequentially add the four hypothesised variables: technology capability, marketing alliance, firm uncertainty and strategic emphasis. All five models are significant ($F \geq 1.68$, $p<0.05$) with adjusted R-squares ranging from 0.06 to 0.13. The variance inflation factor (VIF) values for all variables included in the regression analysis were calculated and ranged from 1.32 to 2.05. Since all the VIF values are well below the maximum acceptable threshold of 10 (Rajesh and Rajendran, 2020), multi-collinearity is not a serious concern in this research.

The coefficient of technology capability is positive across all models but not significant ($p>0.1$). H2 is thus rejected. Marketing alliance is positive and significant ($p<0.01$) in all models, indicating that firms reap more benefits from their VR-enabled marketing practices if they collaborate with other firms to implement these practices. In other words, since this research has identified an overall negative impact of VR-enabled marketing practices; the impact of VR-enabled marketing practices is less negative when companies collaborate with other firms. Therefore, H3 is supported. Moreover, firm uncertainty is negative and significant (p<0.01) in Models 4 and 5, confirming H4 and suggesting that when companies with a high level of firm uncertainty implement VR-enabled marketing practices, they will experience more loss of firm value compared to those with a low level of firm uncertainty. Finally, strategic emphasis exerts a positive and significant (p<0.05) impact on CARs, as shown in Model 5; this suggests that firms with a relatively stronger commitment to value appropriation emphasis will gain more benefits (or suffer less negative impact) from implementing VR-enabled marketing practices. We thus also found support for H5.

Table 3.7 Cross-Sectional Regression Results

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Technology Capability		0.06(0.74)	0.05(0.74)	0.07(0.97)	0.06(0.86)
Marketing Alliance			0.20***(2.80)	0.20***(2.78)	0.20***(2.83)
Firm Uncertainty				-0.22***(-2.78)	-0.24***(-3.02)
Strategic Emphasis					0.16**(1.92)
Firm Profitability	0.17**(2.29)	0.17**(2.28)	0.16**(2.28)	0.14**(2.00)	0.16**(2.21)
Firm Size	-0.13*(-1.67)	-0.15*(-1.80)	-0.14*(-1.75)	-0.21**(-2.52)	-0.17**(-2.09)
Firm Debt	0.04(0.51)	0.04(0.50)	0.06(0.80)	0.09(1.15)	0.07(0.95)
Slack Resources	-0.20**(-2.26)	-0.20**(-2.20)	-0.19***(-2.15)	-0.16*(-1.80)	-0.18**(-2.00)
R&D Intensity	-0.11(-1.38)	-0.11(-1.34)	-0.14*(-1.75)	-0.09(-1.12)	-0.01(-0.06)
Marketing Efficiency	-0.03(-0.37)	-0.02(-0.31)	-0.02(-0.25)	-0.03(-0.41)	-0.03(-0.39)
Initiative Frequency	0.08(1.03)	0.07(1.00)	0.06(0.82)	0.05(0.73)	0.06(0.83)
In-house Developed	0.01(0.09)	0.01(0.09)	0.03(0.34)	0.00 (0.04)	0.01(0.15)
Goods or Services	0.05(0.70)	0.06(0.82)	0.08(1.03)	0.07 (0.89)	0.05(0.66)
Year Dummies	Included	Included	Included	Included	Included
Number of Observations	201	201	201	201	201
R-square	0.13	0.14	0.17	0.20	0.22
Adjusted R-square	0.06	0.06	0.09	0.12	0.13
F-Value	1.76**	1.68**	2.09***	2.46***	2.55***

Notes: *p< 0.1, **p< 0.05, ***p< 0.01 (two-tailed tests for control variables, one-tailed tests for hypothesized variables). Standardised coefficients are reported. t-statistics are in parentheses.

3.4.3 Robustness Analysis

In this section, we performed several additional tests to check the robustness of our findings. The main potential issue in our research is selection bias. In particular, self-selection bias arises when companies' managers self-select their decisions in reporting VR-enabled marketing practices announcements, resulting in a biased sample with nonprobability sampling (Ding et al., 2018; Sorescu et al., 2017). We thus followed previous studies (e.g., Ding et al., 2018) and used propensity score matching (PSM) to construct a matched control group of firms that have the same propensity to implement VR-enabled marketing practices as our sample firms but have not yet done so. These matched control firms serve as the counterfactual group to our sample firms (i.e., treatment firms). Below, we compare the outcomes of VR adoption between the treatment firms and matched control firms.

We first constructed a control group comprising 2,000 US-listed companies that did not undertake VR-enabled marketing practices between 2012 and 2019. We then created a new dummy variable as the dependent variable to indicate whether these companies had undertaken VR-enabled marketing practices in the Probit model. Firm profitability, firm size, firm debt, slack resources, and R&D intensity were included as independent variables in the Probit model. These firm-level characteristics were selected because they affect firms' motivation to implement VR-enabled marketing practices (Matzler et al., 2015; Fotheringham and Wiles, 2022). After implementing the Probit model, we obtained propensity scores (i.e., the probability of implementing VR-enabled marketing practices) for the 2,000 control firms and 201 treatment firms. Subsequently, we employed a one-to-one nearest-neighbour matching approach to match each treatment firm with a control firm using a 0.1 calliper, which required the absolute distance between the propensity scores of a treatment firm and its matched control firm to be less than 0.1. Using this criterion, 178 of the 201 treatment firms were successfully matched.

We then compared the CARs between treatment firms (*n*=178) and matched control firms (*n*=178) on the two-day (days -1 to 0) and three-day (days -1 to 1) event windows. As shown in Panel A of Table 3.8, compared to control firms without VR-enabled marketing practices, the treatment firms with VR-enabled marketing practices experience average CAR losses of 0.62% and 0.53%, respectively, over the three-day (-1, 1) and two-day (-1, 0) event windows. This result is consistent with our previous findings.

Furthermore, we also performed additional tests for our cross-sectional regression model. As shown in Model 1 of Panel A in Table 3.8, we used the CAR over the (-1, 1) event window as the dependent variable to re-run our regression model. The results for our hypothesised variables remain consistent. In addition, we followed the previous event study approach of Fotheringham and Wiles (2022) by adopting the Heckman two-step regression model to control for the impacts of selection bias on our cross-sectional regression model. Similar to the PSM process, we re-ran the Probit model for the 2,000 control firms and 201 treatment firms and obtained the inverse Mills lambda ratio for all treatment firms.

Finally, we included the Mills lambda ratio as an additional explanatory variable in our cross-sectional regression model to control for possible selection bias. Based on this analysis, we obtained consistent results for all hypothesised variables. It should be noted that the inverse Mills lambda ratio (*p*=0.13) is not significant in Model 2 of Panel B.

Table 3.8 Robustness Analysis

Panel A: Average CAR					
Model	Event Window	*N*	Average CAR	*t*-Statistic	*z*-Statistic
1. Propensity Score Matching	(-1, 0)	356	-0.53%	-1.90**	-2.16**
2. Propensity Score Matching	(-1, 1)	356	-0.62%	-2.27**	-2.27**

Panel B: Cross-sectional Regression					
Model	*N*	Technology Capability	Marketing Alliance	Firm Uncertainty	Strategic Emphasis
1. CAR (-1, 1) as Dependent Variable	201	0.07(1.01)	0.20***(2.82)	-0.19**(-2.31)	0.19**(2.29)
2. Heckman Two-Step Selection Model	201	0.07(0.95)	0.18***(2.58)	-0.24***(-2.94)	0.14**(1.68)

Notes: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$ (one-tailed tests). Standardised coefficients are reported. t-statistics are in parentheses.

3.4.4 Post-Hoc Analysis

In this section, we performed post-hoc tests to examine stock market reactions to different types of VR-enabled marketing practices. Based on the study of Wedel et al. (2020), we performed a content analysis for the 201 samples and classified them into three VR-enabled marketing practice types: 1) pre-purchase stage (i.e., communications and advertising), 2) intra-purchase stage (i.e., retailing and selling), and 3) post-purchase stage (i.e., creating consumption experience). In particular, we utilised keywords associated with different types of VR-enabled marketing practices (e.g., communications, advertising, and retailing) to categorise the full sample set into three distinct VR-enabled marketing practices. We then calculated the CARs for these different VR-enabled marketing practice types and compared their impacts. As shown in Panel A of Table 3.9, the average CARs over the event windows (-1,0) and (-1,1) for firms applying VR in the pre-purchase stage were -1.43% and -1.71%, respectively, which are both significant (p<0.01). In comparison to pre-purchase stage adoption, firms applying VR in the intra-purchase experienced only a marginally significant decrease in CARs (p<0.1) in the event window (-1,1). In contrast, firms that applied VR in the post-purchase stage did not experience a significant decline in CARs (p>0.1) in these two event windows.

We further compared the average CAR differences between these types of VR-enabled marketing practices. As shown in Panel B of Table 3.9, significant CAR differences are documented between the pre-purchase and post-purchase stages over the two event windows. In particular, the CAR differences between the pre-purchase and post-purchase stages are -1.32% and -1.63% for the event windows (-1,0) and (-1,1), respectively. In addition, there are also marginally significant CAR differences between the pre-purchase and intra-purchase stages in the two event windows. However, we did not identify any significant CAR differences between the intra-purchase and post-purchase stages.

Overall, these post-hoc tests indicate that applying VR in the pre-purchase stage (i.e., communications and advertising) and the intra-purchase stage (i.e., retailing and selling) can cause a significant loss of firm value. However, applying VR in the post-purchase stage (i.e., creating consumption experiences) causes a negative but insignificant change in firm value. Moreover, firms that applied VR in the post-purchase stage suffered less significant firm value losses than those that applied VR in the pre-purchase stage.

Table 3.9 Results of CARs based on Types of VR-enabled Marketing Practices

Panel A: Abnormal Returns (ARs) and Cumulative Abnormal Returns (CARs)												
		The Pre-Purchase Stage (Communications and Advertising)				The Intra-Purchase Stage (Retailing and Selling)				The Post-Purchase Stage (Creating Consumption Experience)		
Event Window	*N*	Average CAR	*t*-Statistic	*z*-Statistic	*N*	Average CAR	*t*-Statistic	*z*-Statistic	*N*	Average CAR	*t*-Statistic	*z*-Statistic
(-1,0)	41	-1.43%	-3.81***	-3.38***	52	-0.45%	-1.97*	-2.10**	108	-0.11%	-0.76	-1.01
(-1,1)	41	-1.71%	-3.06***	-2.87***	52	-0.51%	-1.40	-1.76*	108	-0.08%	-0.38	-0.43

Panel B: Average CAR Difference Between Types of VR-enabled Marketing Practices

Event Window	VR-enabled Marketing Practices Comparison	Average CAR Difference	*t*-Statistic	*z*-Statistic
(-1,0)	Pre-Purchase Stage and Intra-Purchase Stage Comparison	-0.97%	-2.30**	-1.39
(-1,0)	Pre-Purchase Stage and Post-Purchase Stage Comparison	-1.32%	-3.97***	-2.69***
(-1,0)	Intra-Purchase Stage and Post-Purchase Stage Comparison	-0.34%	-1.29	-1.41
(-1,1)	Pre-Purchase Stage and Intra-Purchase Stage Comparison	-1.20%	-1.88*	-0.70
(-1,1)	Pre-Purchase Stage and Post-Purchase Stage Comparison	-1.63%	-3.27***	-2.27**
(-1,1)	Intra-Purchase Stage and Post-Purchase Stage Comparison	-0.43%	-1.06	-1.47

Notes: *$p< 0.1$, **$p< 0.05$, ***$p< 0.01$ (two-tailed tests).

3.5 Discussion and Implications

The market size of digital marketing in the US was estimated at US $155.3 billion in 2021, with substantial growth driven by emerging technology adoptions such as VR (Global Newswire, 2021). Despite the dominant role of digital marketing practices (e.g., using VR) in both marketing practices and research, few studies have empirically examined the relationship between these practices and firm value (Edeling et al., 2021). Using the event study method for a sample of 201 VR-enabled marketing practices announced between 2012 and 2019 in the US market, we empirically tested the impact of these practices on firm value, measured as abnormal stock returns.

Recently, an alternative view of the consequences of VR-enabled marketing practices suggests that they may exert potential negative impacts on firm performance (Deng et al., 2019; Laurell et al., 2019; Li and Chen, 2019; Lui et al., 2022). Although it may sound counter-intuitive that VR-enabled marketing practices could negatively affect firm value, our results appear to support this contention proposed by previous studies. This unexpected finding is likely due to our study examining the financial value of VR-enabled marketing practices at the firm level, whereas previous studies have focused on the impact of VR on consumer-level outcomes (Huang et al., 2016; Van Kerrebroeck et al., 2017). Unlike consumers, shareholders tend to evaluate firms' marketing investments in terms of expected cash flow and risks (Sorescu et al., 2017). In particular, shareholders are more sensitive to uncertainty and risky investments that put the firm's expected future cash flow at risk (Hsu and Lawrence, 2016). Our results indicate that VR-enabled marketing practices associated with high levels of uncertainty tend to be viewed by investors as more risky marketing investments, diminishing these practices' value.

The subsequent cross-sectional regression results reveal that marketing alliance, firm uncertainty, and emphasis on value appropriation are crucial factors that drive the magnitude of change in firm value resulting from VR-enabled marketing practices. Specifically, while the

VR-enabled marketing practices negatively affect abnormal stock returns, firms with a marketing alliance will suffer less loss. This finding supports those documented in previous studies that emphasised the mitigating impacts of marketing alliances in the implementation of risky strategic practices (Gnyawali and Park, 2009; Hora and Dutta, 2013). Furthermore, our study shows that firms with a high level of firm uncertainty suffer greater loss of abnormal stock returns in VR-enabled marketing practices. This finding is also in line with existing studies that have highlighted the importance of reducing firm uncertainty, especially in the implementation of high-risk strategic practices (Martin et al., 2015; Bstieler, 2005). Our findings also indicate that firms with an emphasis on value appropriation will suffer less loss of abnormal stock returns from VR-enabled marketing practices than those with an emphasis on value creation. This finding is consistent with prior studies which emphasised the role of strategic fit in supporting firms' strategic practices (Avison, 2004; Swaminathan et al., 2008) and the positive impact of value appropriation emphasis on firms' financial performance (Healey and Mintz, 2021).

It should be noted that technological capability was not found to significantly buffer the negative impact of VR-enabled marketing practices on firm value. In fact, the evidence for technology capability having a positive impact on firms is inconclusive. For example, Chae et al. (2018), Chae et al. (2014), and Liang et al. (2010) all failed to find a significant bearing of technology capability on firms' financial performance. A possible explanation for this is that a superior technological capability also accompanies inherent risks and challenges. Specifically, firms with high technological capability are subject to incorrect identification and deployment of resources, complex implementation processes, and irrecoverable deployment costs (Chae et al., 2018; Wang and Alam, 2007). A superior technological capability will also lead to inflexible legacy systems, which increase the switching costs of adopting new technologies and impede firms' ability to respond to changing business environments (Chae et al., 2018).

Therefore, these inherent risks and inflexible legacy systems may neutralise the advantages of a high technological capability in implementing VR-enabled marketing practices. In this way, technological capability cannot mitigate shareholders' concerns or increase their earnings expectations in VR-enabled marketing practices.

In addition, our post-hoc analysis showed that applying VR in the pre-purchase and intra-purchase stages would cause a significant loss of firm value. However, applying VR in the post-purchase stage would cause a negative but insignificant change in firm value. Based on our previous theoretical explanations of the impacts of VR-enabled marketing practices, applying VR in the post-purchase stage may allow firms to achieve more marketing innovations while experiencing less uncertainty. In the post-purchase stage, VR allows firms to differentiate their new products and services from those of competitors, thus expanding their market share and increasing cash flows. However, VR applications in the pre-purchase and intra-purchase stages are more easily imitated by competitors due to weak marketing innovations and low resource commitment, thus leading to increased risks and uncertainties regarding the net returns from these applications.

Taken together, our results not only empirically examine the impacts of VR-enabled marketing practices on firm value but also reveal how firms can reap more value (or suffer less loss) from the use of these practices by taking their characteristics (i.e., formulating alliances, levels of firm uncertainty, and strategic emphasis types) and the VR application areas (i.e., pre-purchase stage, intra-purchase stage, or post-purchase stage) into consideration.

3.5.1 Implications for Research

This paper has several important implications for research. First, most previous studies (e.g., Laurell et al., 2019; Tussyadiah et al., 2018) investigated the consequence of VR-enabled marketing practices from the stance of consumer-level outcomes (e.g., cognition, attitude and behavioural intentions), making it difficult to quantify the financial benefits of VR-enabled marketing practices for firms. Our research extends this line of research by using the event study approach to examine the impact of VR-enabled marketing practices on firm value from a corporate-level perspective. The event study results show that the firms which have implemented VR-enabled marketing practices will experience an average loss of 0.53% abnormal stock returns over a three-day event window. By doing so, our research contributes to an emerging research stream in marketing studies which aims to quantify the impact of marketing practices on firm value (Beckers et al., 2018; Boyd et al., 2019; Sadovnikova and Pujari, 2017). Our study inspires future research to examine the impact of VR marketing on other firm-level performance metrics (i.e., market share and return on assets) to gain a holistic view of the value creation of VR-enabled marketing practices in organisations.

Second, our study adds to an increasingly vital body of literature on investigating the tension and opportunity as the result of adopting disruptive technology in marketing practices. As stated by Li and Chen (2019), VR is a double-edged sword for firms' marketing practices. Although previous marketing studies examined the advantages and opportunities of VR in marketing practices (Huang et al., 2016; Kim et al., 2020b), recent studies argued that VR-enabled marketing practices bring negative impacts to firms (Deng et al., 2019; Li and Chen, 2019). Our study provides empirical evidence that VR marketing indeed results in negative stock market reactions. This result confirms the argument of prior studies that adopting VR in marketing practices may not always be positive as firm expect them to be. In this way, our study contributes to the divergent views about VR-enabled marketing practices and offers a new angle to investigate the value creation of VR in marketing practices. Our research also provides important theoretical guidance for future studies to comprehensively understand the impacts of VR-enabled marketing practices on both firms and consumers.

Third, the results emerging from our cross-sectional regression indicate that the negative stock reaction to VR-enabled marketing practices is contingent on firm characteristics, including marketing alliance, firm uncertainty and strategic emphasis. The results demonstrate that marketing alliance and value appropriation emphasis tend to increase the firm value associated with VR-enabled marketing practices. Conversely, firm uncertainty leads to a decrease in the firm value arising from VR-enabled marketing practices. Our findings contribute to existing research which has examined the effects of certain contextual factors on the value creation linked to marketing practices that are supported by disruptive technology. Lastly, our post-hoc analysis identified that the stock market would significantly react to different types of VR-enabled marketing practices. These important results also inspired future studies to examine the moderating effects of specific application areas (e.g., displaying, selling, and consumption) on the relationship between disruptive technology adoption and firm value.

3.5.2 Implications for Managers

Our findings have important managerial implications, the first being that while previous studies (Kang et al., 2020; Lin, 2017; Wang and Chen, 2019) have demonstrated how VR-enabled marketing practices can benefit consumers, our study reveals an unexpected negative impact on firm value. The average abnormal stock returns over a three-day event window surrounding VR-enabled marketing practices are -0.53%, representing an average loss of US $299 million in firm value for these firms. The results indicate that shareholders tend to view the costs and risks of VR-enabled marketing practices as outweighing the benefits.

Second, our study provides clear guidelines about how managers can effectively employ VR in marketing practices. We revealed that stock market reaction is more favourable (or at least less negative) if there is a high level of marketing alliance and a strategic emphasis on value appropriation. This is because marketing alliances enable companies to share risks and complement resources, thereby reducing the uncertainty associated with VR-enabled marketing practices. We recommend that managers seek partnerships or alliances in VR-enabled marketing practices or other risky technology-related marketing activities. Meanwhile, managers should always pay attention to the strategic alignment between their new marketing practices and current strategic emphasis.

Third, the abnormal stock returns arising from VR-enabled marketing practices are more negative when accompanied by a high level of firm uncertainty. Therefore, it is necessary for managers to consider adoption timing and reduce internal firm uncertainty prior to the implementation of VR-enabled marketing practices. Finally, we urge managers to prioritise considering the applications of VR in the development of new products or services since applying VR in the post-purchase stage would not cause significant firm value decreases.

3.6 Limitations and Future Research

This study is not without limitations. First, due to the limitations of having access to secondary data, the sample in our research includes only publicly traded firms. We thus cannot be certain that our results generalise to private firms. Future research can adopt other methodologies such as surveys and interviews to explore whether VR-enabled marketing practices affect firm performances in the context of small and medium enterprises. Second, our research focuses on stock market reactions. Future studies can explore other financial indicators (e.g., sales and net profit). Third, our research scope focuses on the application of VR in marketing activities. It is possible that different results would be obtained when VR is implemented for other business purposes. Future research may consider the application of VR in other scopes, such as employee training and product manufacturing.

Chapter 4.

The Effect of Virtual Reality-Enabled Manufacturing Practices on Production Efficiency

Abstract: Firms have been increasingly adopting virtual reality (VR) technologies for manufacturing purposes, but it is still unclear whether and how such VR-enabled manufacturing practices can help firms improve production efficiency. Analysing a sample of 87 US treatment firms that have adopted VR-enabled manufacturing practices and 87 matched control firms without such adoption over the period of 2010–2020, our difference-in-differences estimation suggests that the treatment firms gain more production efficiency improvement when compared with the matched control firms. The production efficiency improvement depends on the internal operating environment and external industry environment. In particular, the increased production efficiency is more pronounced in the context of high labour volatility and high market dynamism. In addition, we find that the improvement in production efficiency varies across different VR application fields and industry sectors. Overall, our study demonstrates the positive effect of VR-enabled manufacturing practices on production efficiency but also reveals the moderating roles of firms' internal and external operating environments, VR application fields and industry sectors.

Keywords: VR, manufacturing practices, production efficiency, difference-in-differences model

4.1 Introduction

The emergence of virtual reality (VR) has attracted the attention of managers. Nowadays, the market value of VR was USD 4.42 billion in 2020 and is expected to increase to USD 87.0 billion by 2030 (Yahoo Finance, 2021; Bloomberg, 2022). The number of VR adopters (including individual customers and business customers) has been estimated at 74 million worldwide in 2022, which is much higher than other immersive technologies (Statista, 2022). VR refers to a disruptive technology that creates a virtual environment in which individuals can interact or manipulate virtual objects without spatial and physical constraints (Hoedt et al., 2017; Ivanov et al., 2019; Okulicz, 2004). VR has been adopted by businesses to various manufacturing practices, including new product design, prototyping, planning, worker skills training, machining, assembly, and inspection (Aurich et al., 2009; Abidi et al., 2019). For example, Northrop Grumman applied VR to new product development to shorten development times and reduce production costs (Business Wire, 2015; Northrop Grumman, 2018). Walmart developed a VR-based training program to onboard and train staff (Walmart, 2018). Aptar Group, a US consumer packaging manufacturer, provided manufacturing process designers with VR to enable them to engage in production related tasks, including the construction of machinery, the reorganization of workspace, and the identification of employee safety risks (Aptar, 2017).

The prevailing application of VR in manufacturing practices, or VR-enabled manufacturing practices, has also attracted the attention of researchers. A major research theme related to VR-enabled manufacturing practices is the identification of the future applications and directions of VR in manufacturing practices (Lawson et al., 2016; Turner et al., 2016). Another research stream concerning VR-enabled manufacturing practices involves conceptual discussions about how firms can effectively integrate VR-enabled manufacturing practices into their operational systems (Chandra Sekaran et al., 2021; Hamurcu et al., 2020; Guo et al., 2020).

Although a few operations and managements studies have started to explore how VR-enabled manufacturing practices can enhance firms' operational performances (Abidi et al., 2019; Azizi et al., 2019; Gong et al., 2019), they are still based on conceptual discussion and have documented limited empirical evidence (Barhorst et al., 2021; Dammacco et al., 2022; Gong et al., 2019; Guo et al., 2020; Guo et al., 2022; Pérez et al., 2019). Therefore, the empirical research into the operational outcomes associated with VR-enabled manufacturing practices remain nascent. Miandar et al. (2020) and Núñez-Merino et al. (2020) also stress the need to empirically examine the performance outcomes of industry technology 4.0 applications such as VR-enabled manufacturing practices.

The above observations from practice and research motivate our study to provide an empirical investigation of the effect of VR-enabled manufacturing practices on firms' operational outcomes, or more specifically, production efficiency. We focus on production efficiency because it is concerned with how effectively firms transform their inputs into economic outputs and has direct implications for operations management (Grönroos and Ojasalo 2004; Modi and Mishra, 2011). Firms with a higher production efficiency can manufacture goods and provide services more cost-effectively and promptly (Hsieh and Lin, 2010; Shou et al., 2021). However, it is unlikely that all firms will gain the same production efficiency improvement from their VR-enabled manufacturing practices. We thus will further examine how the VR-enabled manufacturing practices-induced production efficiency improvement might vary across firms depending on their internal and external operating environments (e.g., labour volatility and market dynamism). Taken together, our study aims to answer the following questions:

1) What is the effect of VR-enabled manufacturing practices on production efficiency?
2) How do labour volatility and market dynamism moderate the relationship between VR-enabled manufacturing practices and production efficiency?

We answer these questions empirically with a sample of 87 US treatment firms that have adopted VR-enabled manufacturing practices and 87 matched control firms without such adoption over the period of 2010–2020. We identify the treatment firms based on their VR-enabled manufacturing practices announcements in the Factiva news database and perform propensity score matching (PSM) to match each treatment firms to a control firm without adopting VR-enabled manufacturing practices. Our difference-in-differences (DID) analysis of these treatment and control firms suggests that VR-enabled manufacturing practices do improve production efficiency. We find that the increased production efficiency due to VR-enabled manufacturing practices is more pronounced in the context of high labour volatility and high market dynamism. In addition, our post-hoc analysis shows that applying VR only in pre-manufacturing training and intra-manufacturing activities can significantly improve production efficiency. In contrast, applying VR to pre-planning and scheduling activities and post-manufacturing activities does not significantly impact production efficiency. Furthermore, compared with the service industry sector, non-service industry sectors (e.g., manufacturing, mining and construction) achieve greater production efficiency improvements through VR-enabled manufacturing practices.

Our research makes several contributions. First, our study quantifies the impact of VR-enabled manufacturing practices on production efficiency empirically, which directly answers the calls by Ivanov et al. (2021a), Ivanov et al. (2021b) and Dalenogare et al. (2019) to examine the possible outcomes of digital technology supported manufacturing practices. To the best of our knowledge, our study is among the first to empirically test the impact of VR-enabled manufacturing practices on production efficiency. This enhances our understanding about the outcomes of VR adoption in manufacturing operations context and also provides empirical support for firms to adopt VR-enabled manufacturing practices.

Moreover, our research further explores the interplay between VR-enabled manufacturing practices and contextual factors. Specifically, our study demonstrates that VR-enabled manufacturing practices is more beneficial to firms operating under conditions of high labour volatility and high market dynamism. This extends an emerging research stream that focuses on examining the moderating role of environmental dynamism in the relationship between digital technology-enabled operations practices and firm performance (Li et al., 2020; Wamba et al., 2020). These contextual factors also provide important implications for firms to determine when to adopt VR-enabled manufacturing practices to gain more efficiency benefits.

Lastly, our study advances the literature by highlighting moderating effects of the VR application areas and industry sector types. Such a consideration also provides essential and detailed guidance for firms considering VR-enabled manufacturing practices implementation.

4.2 Literature Review and Hypothesis Development

4.2.1 VR Applications in Manufacturing Practices

Based on the perspective of the 'reality-virtuality continuum', the types of immersive technologies can be classified into augmented reality (AR), mixed reality (MR) and VR (Flavián et al., 2019). AR places virtual objectives into the real-world environment to generate a composite view in which virtuality overlaps reality (Barhorst et al., 2021). MR generates an environment where virtual objects coexist and interact with real-world objects, merging virtuality and reality (Flavián et al., 2019). Unlike AR and MR, VR creates a fully virtual environment in which users can navigate, interact and receive feedback based on their manipulations of virtual objectives (Kim et al., 2021). In this way, VR gives users the feeling of being present in another world by incorporating enhanced sensory elements to elicit telepresence in high-involvement situations (Cowan and Ketron, 2019). In essence, the high-involvement and interactive virtual environment created by VR offers greater potential to revolutionise firms' business practices than other immersive technologies. The application fields of VR in manufacturing practices can be categorised into four types within three manufacturing stages, as shown in Table 4.1.

Table 4.1. Summary of VR Application Fields in Manufacturing Practices

Pre-Manufacturing Stage	**VR Application Example**	**Source**
Planning and Scheduling	Using VR to simulate and optimize manufacturing-related planning and scheduling activities, such as factory layout design and workflow optimization	Eswaran and Bahubalendruni (2022)
Manufacturing Training	Using VR to create virtual workplace environments for employees to practice their manufacturing skills and learn new techniques	Bahubalendruni (2022)
Intra-Manufacturing Stage	**VR Application Example**	**Source**
Product Design and Production	Using VR to create prototypes, design products, and evaluate production workflow stages (e.g., machining, shearing, assembly, and production) in virtual environments	Corallo et al. (2020)
Post-Manufacturing Stage	**VR Application Example**	**Source**
Inspection and Maintenance	Using VR to simulate inspection and maintenance activities, including equipment damage detection and repair	Burova et al. (2022)

First, in terms of the pre-manufacturing stage, VR is widely integrated into planning and scheduling activities and manufacturing training (Chang, 2021; De Lorenzis et al., 2023). The key difference between these two activity types is that the former is decision-maker planning-centric, while the latter is employee skills training-centric. For planning and scheduling activities, VR allows firms to visualise and optimise their factory and facility design layouts and simulate complex scheduling activities and tasks (Eswaran and Bahubalendruni, 2022). Additionally, VR is used to facilitate effective manufacturing training: in particular, VR enables employees to learn manufacturing skills, practise them in a safe and interactive virtual workplace and receive immediate feedback (Chang, 2021; Shamsuzzoha et al., 2021).

Second, in the intra-manufacturing stage, VR is used to support actual manufacturing process activities (e.g., prototyping, product design, machining, and assembly). For example, firms use VR to develop virtual prototypes, test product quality and simulate machining and assembly processes in simulated manufacturing environments (Corallo et al., 2020; Dammacco et al., 2022). VR-supported manufacturing process activities allow firms to lower manufacturing costs, facilitate production workflows, and accelerate production. Third, in the post-manufacturing stage, VR can be applied to firms' inspection and maintenance activities. VR offers technicians a remote inspection and maintenance environment for manufacturing equipment and facilities instead of needing to be physically present in hazardous environments (Kwegyir-Afful, 2022). Such VR-enabled inspection and maintenance activities can improve employee safety and reduce downtime requirements due to the reduced need for physical inspections and maintenance.

The field of VR-enabled manufacturing practices has received significant attention in recent years due to the advances in VR and its potential value creation for firms' manufacturing systems. The existing literature on VR-enabled manufacturing practices mainly focuses on conceptual discussions (e.g., Eswaran and Bahubalendruni, 2022) and case study-oriented empirical research (e.g., Burova et al, 2022; Corallo et al., 2020). For instance, Eswaran and Bahubalendruni (2022) presented a conceptual discussion about the challenges and opportunities of applying VR in manufacturing systems. Similarly, Andrushchenko et al. (2019) provided a general conceptual discussion of how VR technologies can improve enterprise competitiveness. In terms of qualitative empirical studies, Dammacco et al. (2022) employed the case study method to propose a novel approach that helps firms to use VR for designing complex manufacturing systems. Similarly, based on case studies, both Burova et al. (2022) and Guo et al. (2022) provided insights into how VR can be used to assist and optimise maintenance methods. Additionally, Corallo et al. (2020) adopted the action research method to investigate how VR improves product and process design.

Although existing studies have yielded important insights into the implications of VR-enabled manufacturing practices, a notable research gap is the lack of empirical studies that explicitly quantify the efficiency or performance associated with VR adoption in a manufacturing and operations context. In particular, the limited empirical evidence concerning the outcomes of VR-enabled manufacturing practices has exacerbated polarisation of the debate over the value creation of VR, which has been both heralded as a new paradigm by some industry voices and criticised by others as over-hyped (Wakefield, 2023). To fill this important research gap, our work aims to conduct a quantitative empirical study to examine whether VR-enabled manufacturing practices affect firms' production efficiency and determine the situations in which firms can reap more benefits from VR-enabled manufacturing practices. Figure 4.1 presents the conceptual framework. Our study can expand the frontiers of knowledge in the VR adoption and manufacturing operations disciplines by providing new insights into VR-enabled manufacturing practices implementation. Table 4.2 summarises how our study differs from previous studies and contributes to the literature and managerial practices.

Figure 4.1 Conceptual Framework of Third Study

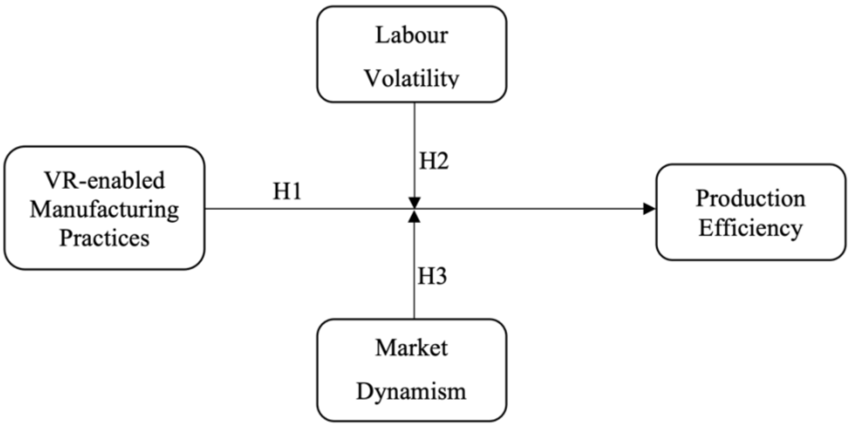


Table 4.2 Relevant VR-enabled Manufacturing Practices Literature

Study	Research Focus	Method	Contribution
Andrushchenko et al. (2019)	Conceptualize VR and its applications in business	Conceptual Discussion	Discusses how VR can be integrated into enterprise practices and used to enhance competitiveness
Corallo et al. (2020)	Understand how VR improves the manufacturing process	Action Research	Conducts qualitative studies to explain how VR improves product and process design
Eswaran and Bahubalendruni (2022)	Identify the challenges and opportunities of VR adoption in manufacturing systems	Conceptual Discussion	Proposes several frameworks for explaining how VR can be applied to different manufacturing systems and the associated key challenges
Burova et al. (2022)	Explore the applications of VR to maintenance practices	Case study	Provide guidelines on how to develop a VR-supported maintenance method
Dammacco et al. (2022)	Explore approaches for applying VR to manufacturing systems	Case study	Propose a model to help firms use VR to design complex manufacturing systems
Guo et al. (2022)	Evaluate how to use VR to optimize ergonomic design in manual assembly and maintenance scenarios	Case study	Propose an integrated VR-based method for the ergonomic optimization of manual operations
Our research	Examine the outcomes of VR-enabled manufacturing practices and related boundary conditions	Quantitative Empirical Study	Provide empirical evidence on the impacts of VR-enabled manufacturing practices on production efficiency and related implementation guidelines.

4.2.2 The Impact of VR-enabled Manufacturing Practices on Production Efficiency

Our study uses the perspective of the Practice-Based View (PBV) to understand the impact of VR-enabled manufacturing practices on production efficiency. The PBV was developed by Bromiley and Rau (2014) based on the Resource-Based View (RBV). PBV argues that a firm's imitable practices (i.e., activities executed by companies) can improve the firm's performance (Bromiley and Rau, 2016; Carter et al., 2017). There are two key differences in the main perspectives of PBV and RBV (Bromiley and Rau, 2014; Bromiley and Rau, 2016). First, in terms of strategic outcomes, PBV emphasizes the impact of imitable practices on relatively short-term tangible firm performance, such as profitability and efficiency, rather than the long-term sustainable competitive advantages emphasized by RBV. Second, from the perspective of isolating mechanisms (i.e., resource heterogeneity and resource immobility), RBV focuses on explaining how these mechanisms enable firms to outperform their competitors; in contrast, PBV focuses on exploring the effect of the practices with weak or no isolating mechanisms on firm performance.

Applying the PBV logic in the context of our study, we argue that VR-enabled manufacturing practices are important imitable practices in organizations rather than rare and inimitable resources because VR is an accessible immersive technology which can be adopted by firms and easily transferred to their manufacturing practices (Bag et al., 2021). Our argument is also in line with the empirical study of Liu et al. (2016), which applies PBV to explain how supply chain technology adoption as a transferable practice contributes to firm performance. Furthermore, the focused outcome for VR-enabled manufacturing practices in our study is production efficiency, which represents an important operational performance indicator for organizations. Thus, using the PBV perspective to investigate the effect of VR-enabled manufacturing practices aligns with our research focus.

Using the theoretical lens of PBV, our study argues that VR-enabled manufacturing practices as a firm's transferrable practices contribute to production efficiency through enhanced manufacturing flexibility and manufacturing innovation. First, VR-enabled manufacturing practices improve firms' labour flexibility and process flexibility, which are the core dimensions of manufacturing flexibility as suggested by prior studies (Ivanov et al., 2018;

Jain et al., 2013; Rogers et al., 2011). Labour is the most essential element of organizational production systems (Okulicz, 2004). Labour flexibility refers to the extent to which employees quickly assimilate the required professional skills and can perform manufacturing tasks effectively in response to unpredictable and ambiguous work-related changes (Rogers et al., 2011; Solberg et al., 2021). A firm with a high level of labour flexibility can more effectively address uncertainties emerging from the production process and respond to changes in demand by redeploying the workforce as required (Bhattacharya et al., 2005; Zhang et al., 2003). In this way, labour flexibility promotes manufacturing and operations activities by facilitating firms to pursue more business opportunities in turbulent market environments.

An example of increased labour flexibility arising from VR-enabled manufacturing practices is VR-enabled employee training, which can replicate the full manufacturing process and activities in a virtual environment where employees can learn new professional skills and perform work tasks without any risk to themselves or equipment (Hoedt et al., 2017; Karambelkar and Bhattacharya, 2017). Moreover, VR-enabled employee training can simulate employees' actual movements within the working environment (e.g., carrying and walking) to optimize employee productivity (Okulicz, 2004). For instance, the Ford company applied VR in their manufacturing facilities to train new employees and allow existing employees to practise new tasks in the manufacturing process; this resulted in a 70% reduction in production line injuries and a 90% decrease in ergonomic issues such as overextended movements, difficult hand clearance, and tasks involving hard-to-install parts (Business Wire, 2015). Accordingly, the increased labour flexibility arising from VR-enabled manufacturing practices enables firms to decrease employee onboarding and manufacturing training time, optimize employee productivity, and reduce inputs costs, which all improve production efficiency.

Second, VR-enabled manufacturing practices contribute to the overall process flexibility, which allows firms to eliminate wastes during the manufacturing process and decrease the probability of production disruption. Process flexibility represents a firm's ability to adjust to changes in the manufacturing process (i.e., machining and assembly) and accommodate to potential production disruption (D'Souza and Williams, 2000). A complex and varied manufacturing process helps companies to cope with the dynamic market demands, but it also makes them susceptible to production operations risks (Bergs et al., 2021). VR-enabled manufacturing practices allow firms to more efficiently update their manufacturing processes and reduce associated costs and disruption risks. To be more specific, VR-enabled manufacturing practices enable employees to investigate the assembly process, test products' features and details, and examine potential defects in a virtual environment (Aurich et al., 2009; Lawson et al., 2016; Turner, 2016). For example, Sikorsky used VR assembly to identify the potential gaps in a new product assembly process, thereby avoiding these problems in the real manufacturing process and further reducing costs and wastes (PRNewswire, 2018).

Third, VR-enabled manufacturing practices enhance manufacturing innovation which enables firms to increase product scopes, reduce manufacturing costs, and shorten new product development cycle. Manufacturing innovation refers to firm-specific ability to radically enhancing existing processes and products or to develop new manufacturing processes and products (Linder et al. 2019; Taques et al. 2021). VR-enabled manufacturing practices are important tools for firms promoting manufacturing innovation. Firms with VR-enabled manufacturing practices can perform virtual manufacturing and prototyping for new products, which reduces production costs and accelerates production by enabling designers to demonstrate a product's details without creating a physical prototype (Hamurcu et al., 2020; Guo et al., 2020). For instance, SEAT (2018) reported that VR-enabled manufacturing and prototyping not only helped the firm to decrease costs but also reduce prototype production time by 30%. This increased manufacturing innovation arising from VR-enabled manufacturing practices dramatically speeds up manufacturing processes for new products, helping to satisfy new market demands without significantly increasing manufacturing costs, which helps firms to transform their raw inputs more effectively into final sales.

In summary, we expect VR-enabled manufacturing practices to exert positive effects on production efficiency through increased manufacturing flexibility (i.e., labour flexibility and process flexibility) and manufacturing innovation. Hence, we propose the following hypothesis:

Hypothesis 1: VR-enabled manufacturing practices improve a firm's production efficiency.

4.2.3 The Roles of Internal and External Operating Environments

While we expect VR-enabled manufacturing practices to have a positive impact on a firm's production efficiency, the magnitude of this impact is likely to be dependent on the firm's internal and external operating environments (i.e., labour volatility and market dynamism). The labour volatility and market dynamism factors are linked to the two theoretical explanations (i.e., manufacturing flexibility and manufacturing innovation) that we use to elaborate on the main impacts of VR-enabled manufacturing practices. In particular, a high labour volatility scenario increases the need for manufacturing flexibility (Sreedevi and Saranga, 2017). Similarly, a high level of market dynamism requires firms to have greater manufacturing innovation to achieve more cost-effective and time-efficient responses to changes in external demands (Wamba et al., 2020). Given the need for flexibility and innovation under different operating environments, the main impacts of VR-enabled manufacturing practices may vary under different labour volatility and market dynamism scenarios. Therefore, our study further explores how labour volatility and market dynamism moderate the impacts of VR-enabled manufacturing practices on production efficiency.

4.2.3.1 Moderating Effect of Labour volatility

Labour volatility refers to the rate at which the labour resource in a firm increases or decreases over a specific period (De Winne et al., 2019). A high labour volatility indicates high levels of employee fluctuation and instability, with mass employee resignation and new employees joining. Labour volatility is detrimental to organizational competitiveness as it causes additional operating costs, weakens internal knowledge capital, generates operational uncertainty (Li et al., 2021; Shaw et al., 2005; Somaya et al., 2008). For instance, a high labour volatility entails considerable employee replacement and new employee training costs. Moreover, a high employee turnover as the indicator of high labour volatility leads to a significant loss of core human and knowledge capital, hampers tacit knowledge diffusion, and causes decelerated manufacturing and operational activities, thereby posing potential challenges for labour resource coordination and planning (Choi and Dickson, 2009; Li et al., 2021). To improve labour flexibility and address the inefficiencies emanating from labour volatility, many firms rely on implementing traditional soft system-embedded practices. For example, managers can foster an organisational culture that promotes employee retention or establish conventional HR training practices that enable new employees to acclimatise to their new surroundings rapidly. However, a major issue is that these traditional soft systems embedded practices (e.g., organisational culture and traditional HR training practices) remain incapable of immediately addressing the loss of core human and knowledge capital and barriers to knowledge assimilation arising from labour volatility.

Unlike traditional soft system embedded practices, VR-enabled manufacturing practices improve firms' labour flexibility, and allow them to more effectively address the potential negative impacts of labour volatility on production efficiency in a relatively short timescale. The enhanced labour flexibility arising from VR-enabled manufacturing practices enables firms to help their employees rapidly acquire essential manufacturing skills and knowledge, even if they are experiencing high employee turnover and an abundance of newcomers. A previously mentioned example is the VR-enabled manufacturing skills training program used to improve employee productivity and shorten essential training periods. We thus anticipate that VR-enabled manufacturing practices implemented by a company with high labour volatility is more potent than for firms with low labour volatility. Accordingly, the following hypothesis is proposed:

Hypothesis 2: Labour volatility positively moderates the impact of VR-enabled manufacturing practices on production efficiency.

4.2.3.2 Moderating Effects of Market Dynamism

Market dynamism refers to the dynamic changes in market demands (Beverland and Lindgreen, 2004; Chan et al., 2016). In particular, high market dynamism indicates rapid changes in customer preferences and unpredictable market development (Anand and Ward, 2004). Rapid market demand changes offer valuable opportunities for organizational development. For example, companies introduce new products to take advantage of market opportunities arising from rapidly changing market demands (Anand and Ward, 2004; Gunasekaran and Yusuf, 2002). However, many established firms neglect the potential value of dynamic market changes and are prone to catering only to their existing customers (Jansen et al., 2009). This is because firms with traditional legacy manufacturing systems lack operational flexibility, and it is thus challenging for them to respond to changes in market demands (Bernardes and Hanna, 2009).

The improved manufacturing innovation arising from VR-enabled manufacturing practices allows firms to rapidly and cost-effectively adapt their employees and production systems to new product manufacturing. Essentially, in a highly dynamic market, a firm with VR-enabled manufacturing practices can better sense and achieve a timely response to fluctuating and unpredictable consumer preferences and have more opportunities to obtain higher growths. McKinsey (2018) suggests that VR-enabled manufacturing practices enable firms to shorten the new product development cycle and more promptly meet emerging market demands. Previous studies also highlight that firms reap more benefits from innovative strategic practices when market dynamism is high (Chan et al., 2016; Lam et al., 2019). Therefore, we argue that the effectiveness of VR-enabled manufacturing practices will be more pronounced in response to high market dynamism, positing the following hypothesis:

Hypothesis 3: Market dynamism positively moderates the impact of VR-enabled manufacturing practices on production efficiency.

4.3 Methodology

Our study proposed three hypotheses. H1 assumes that VR-enabled manufacturing practices significantly improve production efficiency. Based on H1, we further postulate that the impact of VR-enabled manufacturing practices on production efficiency is contingent on labour volatility (H2) and market dynamism (H3). Our research employed the following steps to identify sample firms and test the proposed three hypotheses.

First, we used the Factiva database to search for US listed firms' public announcements about VR-enabled manufacturing practices. We carefully read each announcement and identified 87 sample firms that had implemented VR-enabled manufacturing practices from 2010 to 2020. However, a central issue at this stage was that the VR-enabled manufacturing practices were not implemented randomly. In other words, the treatment effect (i.e., the adoption of VR-enabled manufacturing practices) could be influenced by self-selection among firms. This means that firms may decide whether to adopt these practices, a decision potentially based on their unique characteristics or strategic objectives. Such non-random assignment of the treatment effect can introduce a selection bias, which may bias the study's results and lead to incorrect inferences about the effects of VR-enabled manufacturing practices on production efficiency.

Hence, this raises the possibility of sample selection bias. To address this potential sample selection bias, it is necessary to observe the counterfactual outcomes of VR-enabled manufacturing practices. In other words, we need to compare the firms' production efficiency in two scenarios, the first of which is firms' production efficiency following the implementation of VR-enabled manufacturing practices. The second scenario concerned what these same firms' production efficiency would be if they had no VR-enabled manufacturing practices. However, these two scenarios cannot be observed simultaneously.

To address the above issue, the second step of our research design is to employ propensity score matching (PSM) to match each firm with VR-enabled manufacturing practices (i.e., treatment firm) to a control firm that had a similar probability of implementing VR-enabled manufacturing practices as the treatment firm but did not do so. In this way, each matched control firm is considered as a counterfactual scenario for each treatment firm. Based on the nearest-neighbour 1:1 matching method, our study identified 87 treatment firms and 87 matched control firms.

Third, the difference in difference (DID) regression model has been used to examine whether VR-enabled manufacturing practices are able to positively influence firms' production efficiency (H1). Subsequently, we investigated the interaction effects in the DID regression model to test whether the impact of VR-enabled manufacturing practices is contingent on the levels of labour volatility (H2) and market dynamism (H3).

4.3.1 Data Collection

Following previous studies (Faramarzi and Bhattacharya, 2021; Monfort et al., 2021), we identified the sample firms by searching US listed firms' announcements of VR-enabled manufacturing practices via Factiva.

Factiva is an online archive database developed by the Dow Jones Company that covers major global newswires, industry reports and other business announcement-related sources, such as *Financial Times* and *The Wall Street Journal*. The keywords used for the search included a combination of stock market index (e.g., Nasdaq and NYSE), terms related to VR technology (e.g., virtual reality and VR), and terms related to manufacturing practices (e.g., design, prototype, planning, production, assembly, product, safety, and training). These searching terms are the key 'classifiers' we identified from previous research on VR adoption in manufacturing practices (Abidi et al., 2019; Berg and Vance, 2017; Pérez et al., 2019). As VR-enabled manufacturing practices are a relatively new phenomenon, this research was limited to a 11-year period from 2010 to 2020. We carefully read all the announcements collected and only retained those clearly mentioning applying VR into manufacturing practices rather than other business practices (e.g., product display, brand showcase, advertising, customer experience and other market communication activities). For multiple reports of the same firm, we only retained the announcement with the earliest report year. This screening process resulted in a final sample of 87 treatment firms which have implemented VR-enabled manufacturing practices from 2010 to 2020. Some examples are excerpted below.

- DTE Energy introduced a VR based technician training system which allows DTE technicians to train in several simulated work environments, including how to operate at great heights, repair down wires and perform gas line shut-offs.
- ExxonMobil adopted VR to train process operators and engineers in oil and gas production, processing and transportation facilities.
- Ford Motor launched a VR simulator to help their engineers develop new safety technologies and test vehicle performance.
- General Motors implemented VR to enable engineers to design new vehicles without the need to physically build expensive and time-consuming design prototypes.
- KVH Industries, an *American* communications and navigation equipment manufacturer, used VR to assist engineers in daily tasks and the identify safety hazards.

Figure 4.2 shows the overview of sample firms identification strategy. Panel A of Table 4.3 presents the characteristics of the sample firms with VR-enabled manufacturing practices. The average net income and current assets were USD 1690.818 million and USD 13318.471 million, respectively. The mean inventories, R&D expenditure, and number of employees were USD 5715.999 million, USD 1208.378 million and 94.728 thousand, respectively. Panel B illustrates the industry distribution of these sample firms. The vast majority of sample firms belong to the manufacturing and service industries, corresponding to 60.92% and 21.84% of the total sample size, respectively. Panel C presents the year distribution of sample firms based on their years of implementing VR-enabled manufacturing practices.

Figure 4.2 Overview of Sample Firms Identification Strategy

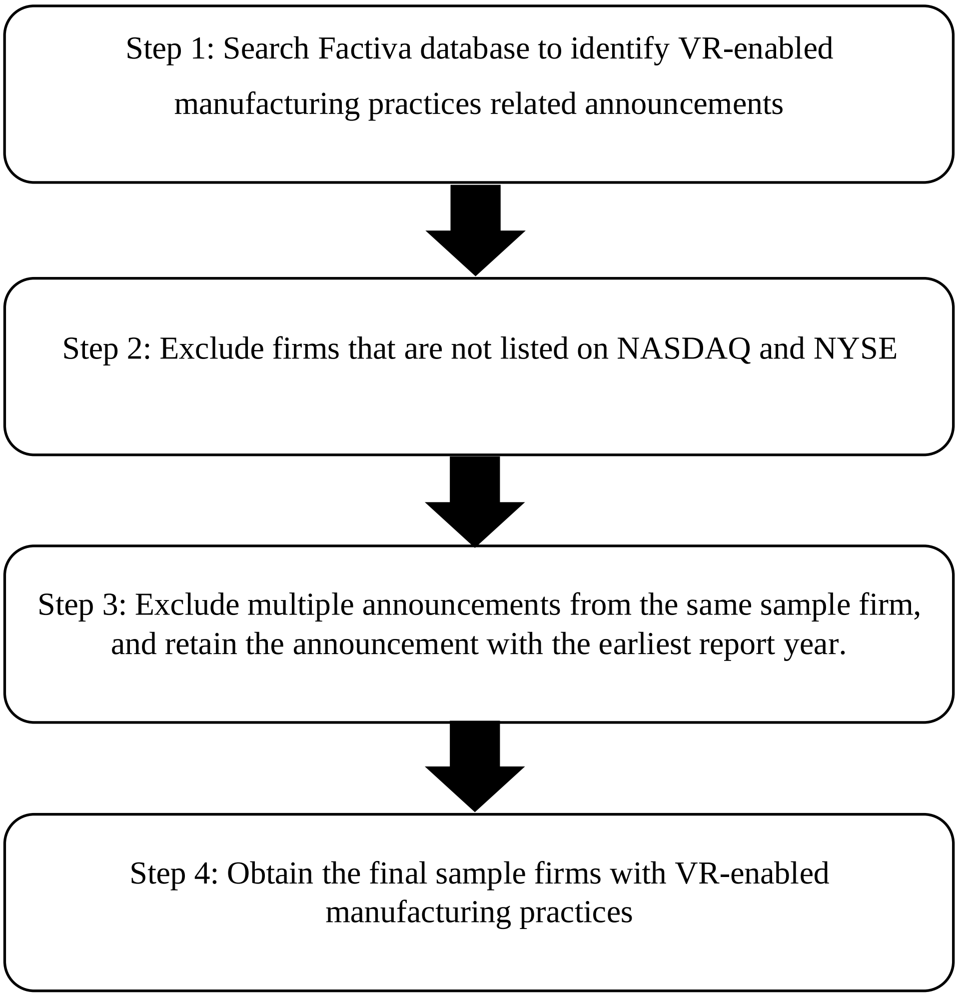


Table 4.3. Characteristics of Sample Firms with VR-enabled Manufacturing Practices

Panel A: Descriptive Statistics of Sample Firms

Variable	Unit	Mean	Std. Deviation	Min	Max
Net Income	Million US$	1690.818	4595.613	-22355.000	21053.000
Current Assets	Million US$	13318.471	24626.418	50.057	160073.000
Inventories	Million US$	5715.999	17097.061	0.000	131661.000
R&D Expenditure	Million US$	1208.378	2337.728	0.000	13543.000
Number of Employees	Thousand	94.728	247.353	0.161	2200.000

Panel B: Industry Distribution of Sample Firms

Industry	2-Digit SIC Code	Frequency	Percentage
Manufacturing	20-39	53	60.92%
Services	60-89	19	21.84%
Mining and Construction	10-17	5	5.75%
Transportation and Public Utilities	40-49	5	5.75%
Retail Trade	52-59	3	3.45%
Public Administration	91-99	2	2.29%
Total		87	100%

Panel C: Year Distribution of Sample Firms

Year	Frequency	Percentage
2010	3	3.45%
2011	2	2.30%
2012	2	2.30%
2013	3	3.45%
2014	2	2.30%
2015	7	8.04%
2016	11	12.64%
2017	22	25.29%
2018	17	19.54%
2019	10	11.49%
2020	8	9.20%
Total	87	100%

4.3.2 Propensity Score Matching

Our strategy for identifying treatment firms relies on the public announcements of US-listed companies, implying that the selection of treatment firms is not a random process and thus leading to a sample selection bias in our study. To address this potential selection bias, we adopted PSM to identify firms without VR-enabled manufacturing practices (i.e., a matched control firm group) but with very similar attributes and probabilities of implementing VR-enabled manufacturing practices to our treatment firm group. PSM has been widely used in prior technology adoption and operations management research (e.g., Lui et al., 2016; Ye et al., 2020). These matched control firms identified from PSM can be considered as a counterfactual group that allows us to observe what would happen to the treatment firms' production efficiency if they had no VR-enabled manufacturing practices. By comparing production efficiency between the treatment and matched control firm groups, we are able to achieve an unbiased estimate of the impact of VR-enabled manufacturing practices on production efficiency.

We conducted PSM by firstly creating a candidate pool comprised of all firms without VR-enabled manufacturing practices (i.e., control firms) in the same industry sector (four-digit SIC code) and the same year as the treatment firms. We then constructed multiple logistic regression models on a year-by-year basis, wherein the dependent variable is a dummy variable indicating whether firms have adopted VR-enabled manufacturing practices, and the independent variables are firm-level characteristics. These firm-level characteristics used in the matching method include financial slack, firm debt, firm profitability, firm size, R&D intensity, inventory turnover, and production efficiency. After performing the logistic regression model, we match each treatment firm to a control firm whose propensity score or predicted probability is most closed to that of the treatment firm.

The rationale for firm-level characteristics selection for performing PSM is that firms with high levels of slack resources, profitability, R&D intensity, and larger size may tend to have more resources and related infrastructures to support the implementation of VR-enabled manufacturing practices (Matzler et al., 2015; Zuo et al., 2019). Conversely, high production efficiency, inventory turnover, and firm debt ratio may decrease the likelihood that firms will use VR-enabled manufacturing practices due to the unnecessary resource investment and resource constraints (Lui et al., 2016; Xiong et al., 2021). We measure financial slack as a firm's current assets divided by their total assets (Lui et al., 2016), firm debt as total liabilities divided by total assets (Eriotis et al., 2007), firm profitability as net income divided by total assets (Appio et al., 2019), firm size as the logarithm of the number of employees (Parker and Ameen, 2018), R&D intensity as R&D expenditure divided by the total sales (Guldiken and Darendeli, 2016), inventory turnover as the total sales divided by total inventory (Wan et al., 2020), and production efficiency as an industry-standardized ratio of total sales to total plant, property, and equipment resources (Modi and Mishra, 2011). The financial and accounting data for measuring these variables are based on one year before the implementation of VR-enabled manufacturing practices to address possible simultaneity issues.

The above matching procedures identified 87 treatment firms and 87 matched control firms. Table 4 shows the balancing test results for the treatment firms and their matched control firms. We performed independent sample *t*-tests to compare the overall means of two groups (i.e., treatment firm group and matched control firm group) in different firm-level characteristics. The results of these tests show that there are no statistically significant differences across all firm-level characteristics between the two groups in the year before implementing VR-enabled manufacturing practices, thus indicating satisfactory matching quality was achieved.

Before performing the subsequent DID model, it is important to ensure that the matching procedures do not violate the parallel trend assumption. The parallel trend assumption suggests that the pre-treatment outcome trends between the treatment and control groups should be similar (Lam et al., 2022). We thus further compared the differences in production efficiency between treatment and control firms across two extra pre-treatment years (i.e., years *t*-2 and *t*-3). As shown in Table 4.4, the disparities in production efficiency between the two groups do not significantly differ from zero over the three pre-treatment years, indicating that the two groups had similar movement trends in production efficiency prior to the implementation of VR-enabled manufacturing practices. Therefore, the parallel trend assumption is unlikely to be violated.

Table 4.4 Balancing Test Results for Treatment Firms and Matched Control Firms

Variable	Treatment	Control	Difference	*t*-statistics	*p*-value
Financial Slack(*t*-1)	0.394	0.399	-0.005	-0.199	0.842
Firm Debt(*t*-1)	0.253	0.234	0.019	1.096	0.275
Firm Profitability(*t*-1)	0.039	0.056	-0.017	-1.254	0.211
Firm Size(*t*-1)	3.237	3.041	0.196	0.656	0.512
R&D Intensity(*t*-1)	0.038	0.032	0.006	0.856	0.393
Inventory Turnover(*t*-1)	42.155	145.403	-103.248	-1.262	0.208
Production Efficiency(*t*-1)	0.002	0.025	-0.023	-0.168	0.866
Production Efficiency(*t*-2)	0.091	-0.039	0.130	0.723	0.429
Production Efficiency(*t*-3)	0.071	-0.047	0.118	0.756	0.451

Note. Year *t* is the year of implementing VR-enabled manufacturing practices.

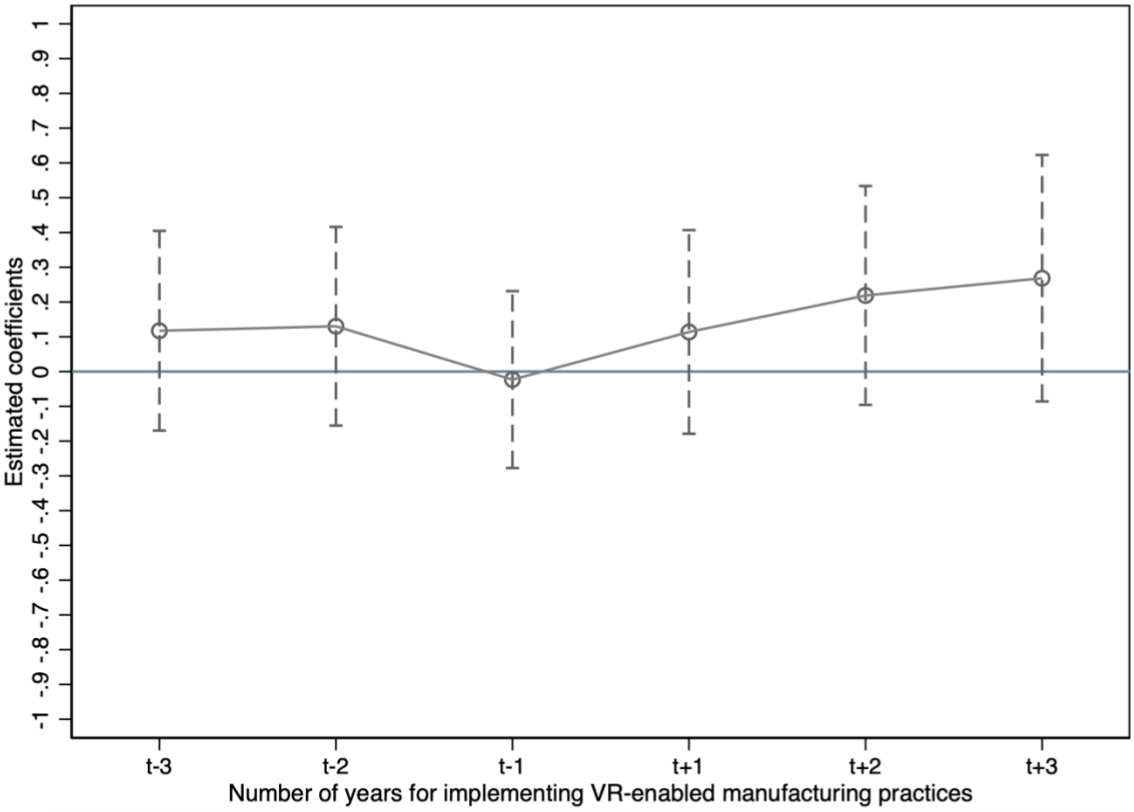
As an additional check, we also followed the study of Lam et al. (2022) to perform a parallel trend test. Specifically, we regressed the production efficiency on interaction terms between the treatment and year dummy variables. The year of VR-enabled manufacturing practices implementation was employed as the reference year. The model specification is as follows:

$$Production\ Efficiency_{i,t} = \beta_0 + \beta_1 Treatment_i \times Year_{t-3} + \beta_2\ Treatment_i \times Year_{t-2} + \beta_2\ Treatment_i \times Year_{t-1} + \beta_4\ Treatment_i \times Year_{t+1} + \beta_5\ Treatment_i \times Year_{t+2} + \beta_6\ Treatment_i \times Year_{t+3} + \delta_i + \varepsilon_{i,t}\ , \qquad \text{Equation (1)}$$

where Production Efficiency$_{i,t}$ is the production efficiency of firm *i* in year *t*. Treatment is a dummy variable, coded as “1” and “0” for treatment firms and matched control firms, respectively. Year represents the different year dummies, where Year$_t$ is the year of VR-enabled manufacturing practices implementation. δ_t indicates the year fixed effects. $\varepsilon_{i,t}$ represents the error terms.

Figure 4.3 shows all the estimated coefficients for interaction terms between treatment and year dummy variables with 95% confidence intervals. As the year of VR-enabled manufacturing practices implementation serves as the reference group, it is not shown in Figure 4.2. For the years ranging from *t*-3 to *t*-1 (i.e., the years prior to the implementation of VR-enabled manufacturing practices), we can clearly see that the points of the estimated coefficients are around the horizontal zero line with the corresponding 95% confidence intervals. There is no evidence of a significant difference in pre-trends between treatment and control firms in terms of production efficiency. This result enables us to further confirm that a parallel trend assumption is not violated in our samples during the three years prior to the implementation of VR-enabled manufacturing practices. In the following section, we describe our DID model.

Figure 4.3 Parallel Trend Test



Note: Year *t* (the year of implementing VR-enabled manufacturing practices) is the reference group.

4.3.3 The Baseline DID Model

We applied the DID model to test the hypothesized impacts of VR-enabled manufacturing practices on production efficiency. DID is a commonly used statistical technique by management researchers to examine the treatment effects of strategic practices on firm performance, such as the effect of C-TPAT certification on operational performance (Tong et al., 2022) and the impact of environmental accreditations on financial risk and sales growth (Ye et al., 2020). The DID model uses two dummy variables (i.e., treatment and post) to divide the full sample into four groups: treatment group in the pre-treatment period, treatment group in the post-treatment period, control group in the pre-treatment period, and control group in the post-treatment period (Ye et al., 2020). The first difference (D1) is the difference in the outcome variable between the pre-treatment period and the post-treatment period for the treatment group, while the second difference (D2) is the difference in the same outcome variable between the pre-treatment period and the post-treatment period for the control group. Finally, the DID model measures the treatment effect by comparing the difference between D1 and D2. This approach reduces the self-selection bias issue and eliminates the unobserved differences between the treatment and control groups (Fan et al. 2022; Lu et al., 2018). The baseline DID regression model is as follows:

$$Y_{i,t} = \beta_0 + \beta_1 Treatment_i \times Post_t + \beta_2 Treatment_i + \beta_3 Post_t + \varepsilon_{i,t} \text{ ,} \qquad \text{Equation (2)}$$

where subscripts *i* and *t* denote company i and year t, respectively. $Y_{i,t}$ indicates the production efficiency of company i in year t. $Treatment_j$ is a dummy variable, coded 1 for all treatment firms (i.e., firms with VR-enabled manufacturing practices) and 0 for all control firms (i.e., matched firms without VR-enabled manufacturing practices). $Post_t$ a dummy variable, coded 1 for every year in the post-treatment period and 0 otherwise. The interaction between treatment and post ($Treatment_j \times Post_t$) represents the treatment effect of VR-enabled manufacturing practices on production efficiency. $\varepsilon_{i,t}$ represents the error terms.

As discussed above, we used the PSM approach to construct the treatment and matched control groups. We then constructed the investigation period by using a six-year period, spanning from three years before to three years after VR-enabled manufacturing practices. Notably, we excluded the announcement year of VR-enabled manufacturing practices. A six-year period (*t*-3, *t*+3) enables us to better capture the impact of VR-enabled manufacturing practices, as the implementation is a complex process, and it may take an extended period before the impacts are revealed. In addition, the inclusion of three-year periods before VR-enabled manufacturing practices offers an adequate pre-shock benchmark.

4.3.4 The Final DID Model

Our final DID regression model is presented below as Equation (3). β_1 determines whether VR-enabled manufacturing practices have a significant impact on production efficiency (H1).

β_4 *and* β_5 indicate how this impact is contingent on different levels of labour volatility (H2), and market dynamism (H3), respectively. The measurements of these variables and related notations summarized in Table 4.5 and discussed below. Table 4.6 lists the descriptive statistics, including the mean and standard deviation values, in addition to the correlations of all variables in Equation (3).

$$\begin{aligned} Production\ Efficiency_{\ i,t} \\ &= \beta_0 + \beta_1 Treatment_i \times Post_t + \beta_2 Treatment_i + \beta_3 Post_t \\ &+ \beta_4 Treatment_i \times Post_t \times Labour\ Volatility_{i,t} \\ &+ \beta_5 Treatment_i \times Post_t \times Market\ Dynamism_{i,t} + \beta_6 Labor\ Volatility_{i,t} \\ &+ \beta_7 Market\ Dynamism_{i,t} + \ \alpha Controls_{i,t-1} + \ \eta_t + \delta_i \\ &+ \varepsilon_{i,t} \qquad\qquad \text{Equation (3)} \end{aligned}$$

where the subscripts *i* and *t* refer to firm i and year t, respectively. $Controls_{i,t-1}$ is a vector of control variables, which will be explained further in the following paragraphs. η_t and δ_i indicate the firm and year fixed effects, respectively. $\varepsilon_{i,t}$ represents the error terms. It should be noted that we have controlled for firm and year fixed effects, thus, $Treatment_j$ and $Post_t$ will be omitted in the fixed effect regression model, as shown in following Table 7.

Production Efficiency. Consistent with the study of Modi and Mishra (2011) and Shou et al. (2021), we measure production efficiency as the ratio of sales to production resources (i.e., plant, property, and equipment), which is then standardized according to the industry mean and standard deviation (four-digit SIC codes). A high value of this variable indicates the higher efficiency of companies in transforming production resources into final economic outputs.

Labour volatility. Labour volatility reflects the degree of variation in firms' employee numbers over a period (De Winne et al., 2019). Based on the study by De Winne et al. (2019), we measure labour volatility as the standard deviation of a firm's total number of employees over a five-year period before implementing VR-enabled manufacturing practices. The higher the standard deviation, the more employee fluctuation the firm has over time.

Market Dynamism. Following the study of Jacobs and Singhal (2014), we measure market dynamism as a regression of industry sales (four-digit SIC codes) on years (over the five years before implementing VR-enabled manufacturing practices), where the standard error was divided by the mean of industry sales over the same period. This metric of market dynamism indicates the instability of market demand. A high level of market dynamism reflects an unstable market environment with changing and unpredictable customer preferences (Henderson et al., 2006; Stoel and Muhanna, 2009; Lam et al., 2019). Accordingly, our measurement is able to capture the nature of market dynamism.

Control Variables. We incorporated several control variables to capture their potential impacts on production efficiency. We controlled for firm-specific factors, including financial slack (current assets divided by total assets), firm debt (total liabilities divided by total assets), firm profitability (net income divided by total assets), firm size (logarithm of the number of employees), R&D intensity (R&D expense divided by total sales), and inventory turnover (total sales divided by total inventory).

Table 4.5 Variable Measurements and Notations

Variable	Measurement	Reference	Data Source
Dependent Variable			
Production Efficiency	The ratio of sales to production resources (i.e., plant, property and equipment), and then is standardized according to the industry mean and standard-deviation (four-digit SIC codes).	Modi and Mishra (2011)	Compustat
Independent Variables			
Treatment × Post	An interaction term between treatment (coded as 1 for treatment firms and 0 for matched control firms) and post (coded as 1 if the outcome variable lies in the post-VR-enabled manufacturing practices implementation period for both treatment firms and control firms, 0 otherwise).	Tong et al. (2022)	Press Release
Labor Volatility	Standard deviation of a firm's number of employees across five years.	De Winne et al. (2019)	Compustat
Market Dynamism	Industry sales are regressed on year (per five years before the event year), and the standard error is divided by the mean of industry sales.	Jacobs and Singhal (2014)	Compustat
Control Variables			
Financial Slack	A company's current assets divided by total assets.	Lui et al. (2016)	Compustat
Firm Debt	A company's total liabilities divided by total assets.	Eriotis et al. (2007)	Compustat
Firm Profitability	A company's return on asset (ROA) ratio, calculated as "net income divided by total assets".	Appio et al. (2019)	Compustat
Firm Size	A company's number of employees (log-transformed).	Parker and Ameen (2018)	Compustat
R&D Intensity	A company's R&D expense divided by total assets.	Guldiken and Darendeli (2017)	Compustat
Inventory Turnover	A company's total sales divided by total inventory.	Wan et al., (2020)	Compustat

Notations	Explanations	Notations	Explanations
β	Coefficient of variable in regression model	η	Firm-fixed effects in regression model
ε	Error terms in regression model	δ	Year-fixed effects in regression model
t	Index for year	i	Index for firm

Table 4.6 Correlations and Descriptive Statistics

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Production Efficiency	1.000									
(2) Treatment × Post	0.060*	1.000								
(3) Labor Volatility	-0.062*	0.008	1.000							
(4) Market Dynamism	-0.102***	0.070**	-0.030	1.000						
(5) Financial Slack	0.234***	-0.007	-0.217***	-0.020	1.000					
(6) Firm Debt	0.054	0.058*	0.105***	-0.045	0.451***	1.000				
(7) Firm Profitability	0.107***	-0.082**	0.047	-0.077**	-0.041	-0.147***	1.000			
(8) Firm Size	-0.244***	0.032	0.495***	-0.052	-0.480***	0.111***	0.166***	1.000		
(9) R&D Intensity	-0.004	0.023	-0.204***	-0.103***	0.422***	0.099***	-0.238***	-0.343***	1.000	
(10) Inventory Turnover	0.025	-0.063*	-0.045	-0.048	0.110***	0.085***	-0.023	-0.108***	0.171***	1.000
Mean	0.011	0.193	6.033	0.023	0.400	0.241	0.046	3.174	0.035	54.962
Standard Deviation	0.853	0.395	11.261	0.021	0.174	0.111	0.099	1.994	0.040	328.573

Note: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$ (two-tailed tests).

4.4 Results

4.4.1 Main Findings

We constructed a panel dataset over a six-year period for all firms from three years before to three years after the implementation of VR-enabled manufacturing practices. After removing firm-year observations with missing data, our final sample comprised 794 firm-year observations, corresponding to 87 treatment firms and 87 matched control firms over the six-firm-year period. Table 7 presents the results of the DID regression analysis with production efficiency as the dependent variable. We adopted a firm-fixed-effect and year-fixed-effect regression model; hence, the time-invariant *Treatment* variable and firm-invariant *Post* variable are accordingly omitted in all models.

Model 1 is the basic model, which only includes the control variables. In Model 2, the direct effect of VR-enabled manufacturing practices (i.e., Treatment × Post) is added. The interaction effects of labour volatility and market dynamism are included in Model 3. The *F*-tests ($p < 0.05$) show that these three models are significant, with *R*-squared values ranging between 0.049 and 0.072. A multicollinearity test was carried out by calculating the variance inflation factor (VIF) values for the full model, which returned maximum and mean VIF values of 2.21 and 1.32, respectively. These are below the threshold value of 10, indicating that multicollinearity is not a major concern in our study (Kennedy, 1998).

As shown in Table 4.7, all variables' coefficients remain consistent across the three models. We therefore used the results of the full model (Model 3) for hypothesis testing. Model 3 reveals that the coefficient of Treatment × Post is significantly positive ($\beta = 0.129$, $p < 0.05$). This finding implies that VR-enabled manufacturing practices significantly improve a firm's production efficiency, supporting H1. Model 3 also shows that the coefficient corresponding to the interaction between Treatment × Post and labour volatility is positively significant (β =

0.008, p < 0.05); this finding confirms H2 that labour volatility significantly and positively moderates the relationship between VR-enabled manufacturing practices and production efficiency. Similarly, as hypothesized in H3, market dynamism significantly and positively moderates the relationship between VR-enabled manufacturing practices and production efficiency (β = 3.686, p < 0.05).

In summary, our results find support for the positive impact of VR-enabled manufacturing practices on production efficiency. Moreover, this positive impact is stronger for firms operating with high levels of labour volatility and market dynamism.

Table 4.7 DID Test Results

	Model 1	Model 2	Model 3
Treatment × Post (H1)		0.141***(2.593)	0.129***(2.369)
Treatment × Post × Labor Volatility (H2)			0.008**(2.075)
Treatment × Post × Market Dynamism (H3)			3.686**(2.130)
Labor Volatility	-0.001(-0.529)	-0.001(-0.543)	-0.002(-0.683)
Market Dynamism	0.940(0.942)	1.009(1.015)	0.663(0.665)
Financial Slack	0.143(0.656)	0.178(0.820)	0.204(0.940)
Firm Debt	0.335(1.149)	0.322(1.079)	0.297(0.997)
Firm Profitability	0.395*(1.837)	0.354*(1.648)	0.358*(1.677)
Firm Size	-0.092(-1.265)	-0.085(-1.163)	-0.070(-0.953)
R&D Intensity	-1.583*(-1.951)	-1.579**(-1.968)	-1.679**(-2.101)
Inventory Turnover	0.000(0.221)	0.000(0.270)	0.000(0.290)
Constant	0.183(0.663)	0.181(0.660)	0.134(0.487)
Firm Fixed Effect	Included	Included	Included
Year Fixed Effect	Included	Included	Included
Firm-Year Observations	794	794	794
Within R-squared	0.049	0.059	0.072
F-value	2.40***	2.73***	2.92***

Notes: *p < 0.10, **p < 0.05, and ***p <0.01(one-tailed tests for hypothesized variables and two-tailed tests for control variables). Unstandardized coefficients are reported. t-statistics are in parentheses.

4.4.2 Robustness Analysis

Following the studies of Lam et al. (2022) and Bradley et al. (2016), we performed a placebo test to examine whether the significant improvement in production efficiency was indeed caused by VR-enabled manufacturing practices rather than unobservable factors in our sample. The underlying concept of the placebo test is to perform a hypothetical VR-enabled manufacturing practices at a point in time that did not occur in reality. As the interaction term (Treatment × Post) indicates the true effect of VR-enabled manufacturing practices on production efficiency, we firstly randomly assign this interaction term to all samples — this random assignment generates a "false" VR-enabled manufacturing practices effect that should not induce a significant increase in production efficiency. If the coefficient of the interaction term becomes insignificant after this random assignment process of the interaction term, this placebo test suggests that the increase in production efficiency is indeed caused by VR-enabled manufacturing practices. However, a significant coefficient in the interaction term indicates that our results are biased due to potentially unobservable variables.

We repeated the DID regression model 1,000 times based on random assignment of the interaction term. We extracted the estimated coefficients and associated *t*-values of the falsified "Treatment × Post", which are plotted in Figures 4.4 and 4.5, respectively. Figure 4.4 shows a kernel density estimation plot for the coefficients of the falsified "Treatment × Post" based on the 1,000 regression results. As shown in Figure 4.4, the solid line indicating the average coefficients of the falsified "Treatment × Post" is centered around zero and is distant from the true estimated coefficients represented as a dashed line. Figure 4.5 shows that the *t*-values of the estimated coefficient for the falsified "Treatment × Post" are also centered around zero and exhibit a normal distribution, indicating that most of the falsified "Treatment × Post" values are insignificant. The placebo test results confirm that our findings are less sensitive to the impacts of unobservable factors.

Figure 4.4 Density Plots of the Estimated Coefficient (Placebo Test)

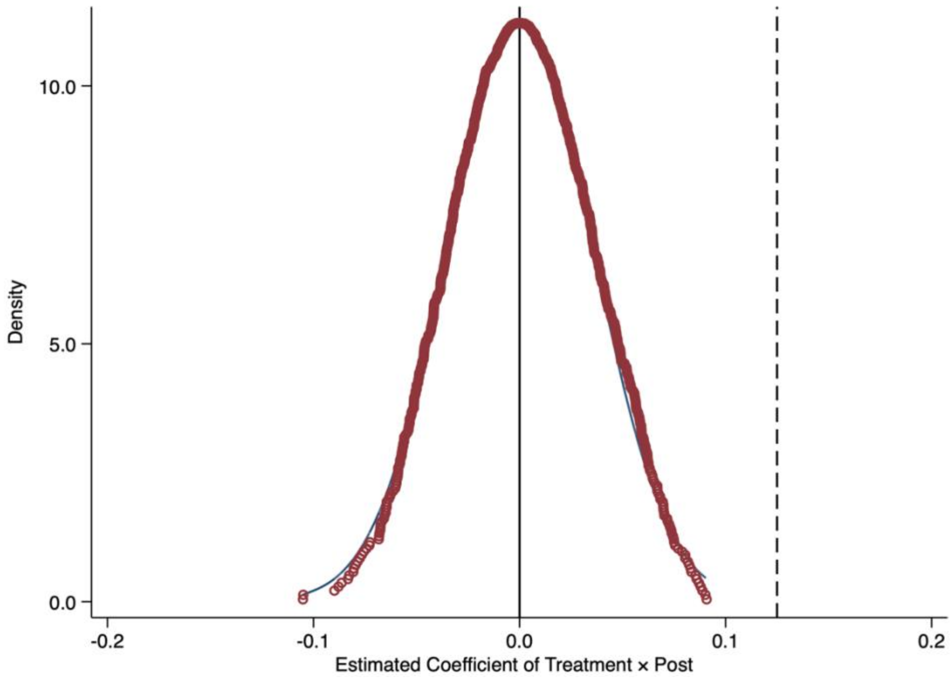
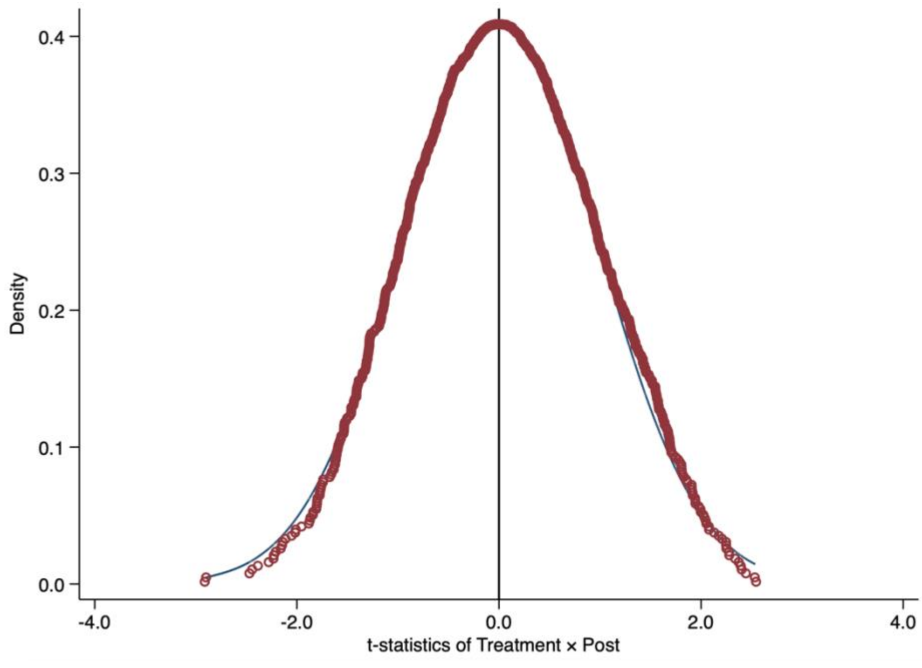


Figure 4.5 Density Plots of *t*-Statistics (Placebo Test)



4.4.3 Post-Hoc Analysis

We further performed post-hoc analysis to examine how the main impacts of VR-enabled manufacturing practices vary across different VR application fields and industry sectors. Firstly, we carefully read all treatment firms' announcements of VR-enabled manufacturing practices and identified their specific manufacturing application fields. We then documented the adoption frequency of four manufacturing-related activity types (i.e., planning and scheduling, manufacturing training, product design and production, inspection and maintenance) across three manufacturing stages. As shown in Table 4.8, firms principally leveraged VR for product design and production activities (*N*=52) and manufacturing training activities (*N*=61).

Table 4.8 Distribution of VR Applications Across Manufacturing Stages

Pre-Manufacturing Stage	Frequency
Planning and Scheduling	13
Manufacturing Training	52
Intra-Manufacturing Stage	Frequency
Product Design and Production	61
Post-Manufacturing Stage	Frequency
Inspection and Maintenance	12

We then performed a post-hoc DID analysis. As shown in Model 1 in Table 4.9, the interaction between Treatment × Post and manufacturing training is positive and significant ($p < 0.05$). Similarly, the interaction between Treatment × Post and product design and production is also positive and significant ($p < 0.05$). However, there are no significant interactions for planning and scheduling as well as inspection and maintenance. These results signify that only the application of VR in pre-manufacturing training activities and intra-manufacturing activities can significantly improve production efficiency. In contrast, applying VR to pre-manufacturing planning and scheduling activities and post-manufacturing activities does not significantly improve production efficiency.

We also further test whether the impacts of VR-enabled manufacturing practices are contingent on specific industry sectors. According to the industry distribution listed in Table 4.3, we created six industry dummies, including manufacturing, mining and construction, transportation, retail trade, public administration, and service. We then computed the interactions between Treatment × Post and the industry dummies. It should be noted that the service industry is used in the reference group and thus not included in the regression model. As shown in Model 2 in Table 4.9, we observe positive and significant coefficients for the industry dummies. These results indicate that firms within the non-service industries tend to reap more benefits from VR-enabled manufacturing practices than those in the service industries. We further explain this result in the subsequent discussion section. In addition, we performed a further robustness test by combining all variables of Model 1 and Model 2 into a full model. As shown by Model 3 in Table 4.9, our results remain consistent in the full model.

Table 4.9 Post-Hoc DID Analysis

	Model 1	Model 2	Model 3
Treatment × Post × Planning and Scheduling	0.050(0.420)		0.061(0.505)
Treatment × Post × Manufacturing Training	0.209***(2.685)		0.188**(2.473)
Treatment × Post × Product Design and Production	0.236***(3.045)		0.153*(1.957)
Treatment × Post × Inspection and Maintenance	0.098(0.757)		0.101(0.758)
Treatment × Post × Manufacturing Industry		0.892***(5.802)	0.740***(4.591)
Treatment × Post × Mining and Construction		0.729**(2.100)	0.670*(1.936)
Treatment ×Post × Transportation		1.640***(7.397)	1.559***(6.997)
Treatment × Post × Retail Trade		0.893***(3.464)	0.847***(3.287)
Treatment × Post × Public Administration		1.056***(3.791)	0.813***(2.739)
Control Variables	Included	Included	Included
Firm Fixed Effect	Included	Included	Included
Year Fixed Effect	Included	Included	Included
Firm-Year Observations	794	794	794
Within R-squared	0.080	0.132	0.150
F-value	3.07***	5.07***	4.79***

Notes: $*p < 0.10$, $**p < 0.05$, and $***p < 0.01$ (two-tailed tests). Unstandardized coefficients are reported. *t*-statistics are in parentheses. Service industry is used as the reference category for industry dummies.

4.5 Discussions and Implications

4.5.1 Implications for Research

Our research contributes to the literature on manufacturing and operations management in the following respects. First, PBV emphasizes not all practices bring expected positive outcomes, and some practices even have possible detrimental effects for firms. This argument reinforces the necessity to examine the outcomes of various practices, especially the emerging and risky technology supported strategic practices. Our study thus extends previous studies that focus on conceptualizing the value of VR in firms' manufacturing practices (Hamurcu et al., 2020; Karambelkar and Bhattacharya, 2017; Guo et al., 2020) by empirically showing that VR-enabled manufacturing practices indeed improve production efficiency. Moreover, a recent call by Ivanov et al. (2021b) urges researchers to investigate how digital technology can be utilized in operations and supply chain management to improve firms' productivity and efficiency. Our research directly responds to this call by revealing the positive impact of VR-enabled manufacturing practices on production efficiency.

Second, our study enriches the literature that investigates the interplay between environmental dynamisms, digital technology-enabled practices, and firm performance (Buer et al., 2018). Our study complements this research stream by not only focusing on the moderating effect of external dynamisms, but also taking a step further to look at how firm internal dynamism (i.e., labour volatility) and VR-enabled manufacturing practices jointly affect firm's production efficiency. The focus on labour volatility in our study indicates some fruitful lines of future research. Extant studies emphasized the important role played by external environmental dynamisms in a firm's manufacturing and operations activities but overlooked the internal dynamisms (Beverland and Lindgreen, 2004). Firms are not only confronting with the challenges from external environments but also from their internal contexts (Pache and Santos, 2010). Our study thus opens a new research avenue for exploring how both external and internal dynamisms, and digital technology supported manufacturing practices jointly shape a firm's operating performance.

Third, our findings further enrich the literature by highlighting the boundary conditions created by the VR application areas and industry sector types. Previous research discussed the general impacts of VR-enabled manufacturing practices with less attention given to differentiating between the benefits of the various VR application areas implemented by firms and applied industry types (Dammacco et al., 2022; Guo et al., 2022). Accordingly, there remains limited available guidance and knowledge on the manufacturing areas and industry sectors in which VR is more valuable or less valuable. Taking an operational perspective, our study examines firms' performance outcomes when they have applied VR in different manufacturing stages (i.e., pre-manufacturing, intra-manufacturing, and post-manufacturing) and different industry sectors. By doing so, our study improves the understanding of VR-enabled manufacturing practices' outcomes and stimulates new research avenues in the manufacturing and operations area. An important avenue for future research would be the exploration of how applications in different operations areas can moderate the performance of disruptive technology-enabled (e.g., big data and artificial intelligence) manufacturing activities.

4.5.2 Implications for Managers

Our research has several important implications for managerial practices. First, from the perspective of PBV, not all firms' strategic practices positively contribute to the firms' performances. It is challenging for managers to ensure positive net returns when applying a disruptive technology into manufacturing practices due to the associated technological complexity and uncertainty. The requirements for implementing VR-enabled manufacturing practices implementation can involve mass financial and labour resource commitments and may increase the potential risks for firms. Our results demonstrate that the extra efforts required for VR-enabled manufacturing practices implementation can be justified, as such practices do lead to significant improvements in production efficiency.

Second, our results highlight how firms' labour volatility influences the benefits of VR-enabled manufacturing practices. As shown in our test results, the positive impact of VR-enabled manufacturing practices on production efficiency is stronger for firms operating with a high level of labour volatility. We attribute this to VR-enabled manufacturing practices' capability of buffering the negative effects of labour volatility on the firms' manufacturing activities. High levels of labour volatility (i.e., mass employee resignation and many newcomers) make it challenging for companies to coordinate their labour resources with manufacturing activities, resulting in extra operational costs for firms and harming their long-term competitiveness (Ruso et al., 2021). By using VR-enabled manufacturing practices, firms with high labour volatility can offer an effective approach for new employees to rapidly undergo manufacturing training, and reduce the possibility of production disruptions. In this sense, managers should not only incorporate VR-enabled manufacturing practices as an impetus for improving production efficiency but also as a potential buffering tool to counteract labour volatility.

Third, our results provide important guidelines for firms to decide when to implement VR-enabled manufacturing practices in a dynamic industry environment. Our findings highlight that firms can achieve greater production efficiency improvement from VR-enabled manufacturing practices under the high market dynamism scenario. High levels of market dynamism pose more challenges for managers in coordinating production resources and achieving optimal inventory levels in response to rapid changes in market demands (Beverland and Lindgreen, 2004; Gunasekaran and Yusuf, 2002). VR-enabled manufacturing practices offer firms operating in more dynamic markets a better chance to counter fast-changing demands through enhanced manufacturing flexibility and innovation.

Fourth, our post-hoc analysis also provides important implications for firms considering VR-enabled manufacturing practices implementation. The results of our post-hoc analysis indicate that firms do not uniformly reap the benefits of VR-enabled manufacturing practices. In particular, the specific manufacturing activities and industry sectors in which VR are applied are crucial to determine the extent to which firms can achieve production efficiency improvement. This finding offers several aspects of meaningful managerial guidance. Although VR-enabled manufacturing practices generally improve firms' production efficiency, we found that applying VR only in pre-manufacturing training and intra-manufacturing activities can significantly improve production efficiency. In contrast, applying VR to pre-manufacturing planning and scheduling activities and post-manufacturing activities does not significantly impact production efficiency. These results indicate that the value creation of VR-enabled manufacturing practices in production efficiency is primarily driven by pre-manufacturing training and intra-manufacturing activities. We suggest that firms with production efficiency orientation should consider including VR in their manufacturing training activities and intra-manufacturing activities.

However, managers must also not underrate the benefits of VR-enabled planning and maintenance practices since these aspects may improve other operations metrics. Managers must regularly monitor and self-examine the outcomes of different VR applications in manufacturing areas. For instance, Ford company and SEAT company regularly monitor and evaluate the impacts of VR on reducing production line injury rates, prototype production times and operational costs (Business Wire, 2015; SEAT, 2018). These monitoring practices allow managers to better understand how to apply VR to manufacturing and operations activities, improve operational performance and make necessary strategic adjustments.

Lastly, our post-hoc analysis reveals that industry sectors significantly moderate the benefits of VR-enabled manufacturing practices. Compared with the service industry sector, non-service industries (e.g., manufacturing, mining and construction) achieve greater production efficiency improvements through VR-enabled manufacturing practices. This is because non-service industries typically adopt more standardised production processes, thus lowering the implementation and operations costs of VR-enabled manufacturing practices. In contrast, the processes of service production are much less standardised due to their inherent complexity and variability; accordingly, service firms need to frequently update their VR-enabled manufacturing practices, increasing their financial burdens and disrupting regular workflows. Thus, services firms are generally less able to reap value from VR-enabled manufacturing practices. One of the fundamental lessons from these findings is that managers should be aware of the importance of achieving an alignment between technology, industry sectors and manufacturing activities when implementing VR-enabled manufacturing practices.

4.6 Conclusion and Limitations

Our study employed the PSM and DID methodologies to quantify the effect of VR-enabled manufacturing practices on production efficiency empirically. Our findings show that VR-enabled manufacturing practices significantly improve firms' production efficiency. Meanwhile, firms can achieve greater production efficiency improvements by implementing VR-enabled manufacturing practices in scenarios involving high levels of employee fluctuation and high levels of market dynamism. Although our research has made important contributions to the literature and managerial practice recommendations, there are still several limitations of this work that may provide avenues for future research.

First, our study only investigates the effect of VR-enabled manufacturing practices and production efficiency. Although the industry-standardised production efficiency measurement used in our study addresses time-varying changes across industries, such a measurement cannot provide a complete perspective on the production and operations performances of VR-enabled manufacturing practices. We suggest that future studies investigate the impact of VR-enabled manufacturing practices on other important production metrics (e.g., lead time, product quality, and inventory level). Meanwhile, the measurements of explanatory variables (i.e., labour volatility and market dynamism) used in our study cannot capture relatively short-term environment dynamism. Future studies could use fiscal quarter-based data to measure the moderating role of short-term labour volatility and market dynamism in VR-enabled manufacturing practices. Such research could also examine whether VR-enabled manufacturing practices bring immediate impacts in short-term dynamism contexts. Our study does not control for VR-related characteristics (e.g., types of VR consoles and output devices) due to secondary data limitations. Therefore, we encourage future research to use a field experiment design approach to examine or control for the impacts of VR characteristics on the performance outcomes of VR-enabled manufacturing practices.

Second, owing to data limitations, our sample only focuses on publicly listed firms. It should be noted that many small and medium-sized enterprises (SMEs) are implementing VR-enabled manufacturing practices. Thus, future studies could test the generalizability of our findings by investigating how VR-enabled manufacturing practices may benefit SMEs through other datasets. In addition, it would also be worthwhile to further investigate the barriers and enablers of implementing VR-enabled manufacturing practices in SMEs, as these firms have fewer resources and less-advanced infrastructures to implement disruptive technology-supported manufacturing practices. Future research can also adopt the survey-based method to explore the theoretical mechanisms explaining the impacts of VR-enabled manufacturing practices on firm performance.

Third, although we explore the moderating effects of labour volatility and market dynamism on the relationship between VR-enabled manufacturing practices and production efficiency, it is also likely that this positive outcome of VR-enabled manufacturing practices is contingent on internal firm-specific dynamisms (e.g., financial resources uncertainty and innovation capability uncertainty). Accordingly, we highlight the roles of internal firm-specific dynamisms in moderating the effects of VR-enabled manufacturing practices on firm performance as an area worthy of future exploration.

Chapter 5. Conclusion

5.1 Summary of the Thesis

This thesis includes three studies that examine the firm-level outcomes of VR-enabled business practices with the aim of answering three important questions. Firstly, the first study leveraged the SLR method to conceptualise VR and present a comprehensive review of its applications in business practices. The first study shows that VR technologies comprise four main components (i.e., input devices, virtual environments, output devices, and VR users), which interact to form a circular chain that constitutes a complete VR system. In particular, input devices (i.e., sensation-capture equipment, computer hardware, and software) collect users' sensory information and use it to generate a virtual environment. The virtual environment, generated based on VR input devices, offers an interactive virtual space and objects that can be created or manipulated by users via simulated sensory stimuli (e.g., sight, hearing, haptic feedback, and smell). The virtual environment is then represented by several output devices such as projectors, CAVEs, and HMDs. Simultaneously, VR users employ input devices to send manipulation commands in the virtual world and, ultimately, interact with the virtual environment. Furthermore, the first study summarised that VR had been widely applied by businesses to support marketing practices (e.g., product displays, service experiences, and digital channels) and manufacturing and operations practices (e.g., product design, prototyping, planning, and employee training). The first study also identified several important research gaps and proposed various research directions for future studies. In particular, future research should consider developing VR-specific theories and using diversified methodologies to improve the understanding of the drivers and outcomes of VR adoption at both individual and firm levels.

In the second study, the event study method was used to empirically test the impact of VR-enabled marketing practices on firm value, measured as abnormal stock returns. The results show that firms that have implemented VR-enabled marketing practices will experience an average loss of 0.53% abnormal stock returns over a three-day event window. From a TR perspective, this seemingly counter-intuitive finding is because VR-enabled marketing practices are associated with high levels of uncertainty. Such practices tend to be viewed by investors as more risky marketing investments, thus diminishing the value of these practices. Furthermore, the subsequent cross-sectional regression results reveal that marketing alliances, firm uncertainty, and emphasis on value appropriation are crucial factors that drive the magnitudes of changes in firm value resulting from VR-enabled marketing practices. While VR-enabled marketing practices negatively affect firm value, firms forming marketing alliances and putting a stronger emphasis on value appropriation suffer reduced losses. In contrast, firms with high levels of firm uncertainty tend to suffer the greatest losses in terms of abnormal stock returns in VR marketing practices. Additionally, the post-hoc tests show that applying VR in the pre-purchase stage (i.e., communications and advertising) and the intra-purchase stage (i.e., retailing and selling) can cause a significant loss of firm value. However, applying VR in the post-purchase stage (i.e., creating consumption experiences) causes a negative but insignificant change in firm value. Moreover, firms that applied VR in the post-purchase stage suffered fewer firm value losses than those that applied VR in the pre-purchase stage.

The third study focuses on the applications of VR in manufacturing practices and gauges the impact of these practices on production efficiency. Based on the DID model, the third study reveals that VR-enabled manufacturing practices can positively influence firms' production efficiency. Such improvements from VR-enabled manufacturing practices are found to be contingent on the levels of labour volatility and market dynamism. The positive impact of VR-enabled manufacturing practices on production efficiency tends to be stronger for firms operating with high levels of labour volatility and market dynamism. Furthermore, the post-hoc tests show that only the application of VR in pre-manufacturing training activities and intra-manufacturing activities can significantly improve production efficiency. In contrast, applying VR to pre-manufacturing planning and scheduling activities and post-manufacturing activities does not significantly improve production efficiency. The results of post-hoc tests also indicate that firms in the non-service industries tend to reap more benefits from VR-enabled manufacturing practices than those in the service industries.

Overall, this thesis documents important empirical evidence regarding the application of VR in different business practices. The divergent outcomes from VR-enabled marketing practices (i.e., loss of firm value) and VR-enabled manufacturing practices (i.e., enhanced production efficiency) suggest that future studies should underline both the positive and negative outcomes of technology adoption at the firm level. Managers should also be cautious of applying a ‘one-size-fits-all’ approach to VR adoption. The specific outcomes of VR adoption identified in our work are contingent on firm-level characteristics (i.e., marketing alliances, firm-specific uncertainty, and strategic emphasis), environmental dynamism (i.e., employee volatility and market dynamism), application areas (e.g., marketing and manufacturing practices) and industry types.

5.2 Contribution and Implications

5.2.1 Theoretical Contribution and Implications

The theoretical implications of this thesis are threefold. First, this thesis contributes to the literature on the intersection of disruptive technology adoption, marketing, and operations management themes by examining the outcomes of VR-enabled business practices. While previous studies have conceptually discussed the impacts of VR adoption on firms and examined related consumer-level outcomes (e.g., Deng et al., 2019; Flavián et al., 2021; Kim et al., 2023; Li and Chen, 2019), only limited research to date has investigated these aspects from a firm-level perspective. By investigating the two firm-level outcomes from VR-enabled business practices, this research project addresses this important gap in the literature and directly responds to the call of Miandar et al. (2020) that increased attention should be paid to the outcomes of disruptive technology-supported practices. The proposed conceptual frameworks in the first study also offer novel insights into the components of VR and its applications in different business practices, in addition to potential outcomes derived from such technology adoption. These findings can serve as a potential cornerstone for future empirical studies of VR adoption.

Second, previous studies have failed to distinguish the value creation of VR when it is leveraged in different business practices (Kim et al., 2020a; Lin, 2017; Wang and Chen, 2019). This thesis addresses this important research gap by revealing the divergent firm-level outcomes of VR adoption in marketing practices and manufacturing practices. Although VR can significantly improve production efficiency when applied to manufacturing practices, it can significantly reduce firm value (i.e., negative abnormal stock returns) when applied to marketing practices. These empirical results indicate that although internal employees can genuinely benefit from VR-enabled business practices, external investors remain concerned about the risks and uncertainties associated with VR-enabled marketing practices. These results also provide important empirical support for the assertions in TR theory and PBV theory that argue that not all technologies and firm strategic practices will achieve the desired positive results (Blut and Wang, 2020; Bromiley and Rau, 2014; Bromiley and Rau, 2016; Parasuraman, 2000). This thesis also suggests that the focus of artificial intelligence (AI) adoption in business potentially merits investigation. Since the recent study of Lui (2022) also uncovered a negative stock market reaction to AI adoption, it would be of interest to scrutinise the outcomes of AI adoption in specific business practices (e.g., AI in marketing and AI in manufacturing).

An information asymmetry perspective can potentially explain the above contrasting results. Information asymmetry refers to a trading situation in which information acquired by two negotiating parties is unbalanced, such as one-party having access to more information than the other (Tate et al., 2010). In essence, managers have an information advantage over their investors in terms of VR adoption since the investors are not directly involved in VR adoption-related decision-making. Such an information asymmetry will result in a "lemon" issue (Naqvi et al., 2021). The investors and managers will have different incentives and expectations in terms of VR adoption. Most of these VR-enabled marketing practices may not directly or immediately create financial returns. Managers are thus typically more concerned about how to use VR to achieve long-term competitive advantages and how this technology can enable them to differentiate their brands from competitors. Unlike marketing managers, the investors prioritise immediate increases in cash flow and are more cautious about the risks embedded in these disruptive technology-supported strategic practices. The limited information about VR-enabled marketing practices will further exacerbate investors' concerns about VR adoption-related risks (e.g., enormous resources commitment and uncertain net returns). In this way, investors tend to respond negatively to VR-enabled marketing practices in the short-term. In contrast, information asymmetry is largely reduced when VR is applied to manufacturing practices. This is because internal employees are directly involved in VR-supported manufacturing practices and can perceive the applications and outcomes of such practices. These important findings highlight that operations and management scholars should further consider how information transparency and information availability will shape investors' reactions to firms' disruptive technology-supported practices.

Third, this thesis extends the literature on disruptive technology adoption, marketing, and operations management by investigating the moderating effects of firm-level characteristics (i.e., technology capability, marketing alliances, firm-specific uncertainty, and strategic emphasis) and environmental dynamism (i.e., employee volatility and market dynamism). Understanding how firm-level characteristics and environmental dynamism affect the outcomes of VR adoption is essential given that disruptive technology adoption is currently inextricably linked to dynamic internal and external environments. Future studies can build on this work to further explore how the firm-level outcomes of VR adoption are contingent on other internal and external contextual factors, such as innovation capability and market competition.

5.2.2 Practical Contribution and Implications

This thesis has several takeaways for managers who are seeking to adopt VR to foster their firms' performances. First, this thesis developed two theoretical models showing the components of VR, its applications in business practices, and the potential drivers and outcomes of VR adoption. In combination, these models provide marketing and operation managers with fundamental knowledge for implementing VR-enabled business practices.

Second, from the adoption purpose perspective, managers should be aware that the value creation of VR adoption can vary significantly across different business practices. While adopting VR in manufacturing practices allows firms to improve their production efficiency, adopting VR in marketing practices may lead to a loss of firm value, as highlighted by the results of the second study. A possible explanation is that the increased risks and uncertainties associated with VR-enabled marketing practices lower investors' expectations in terms of firms' future cash flow, leading to negative abnormal stock returns. Accordingly, there is a significant need for managerial efforts to improve information transparency and provide information updates about VR adoption-related business practices to reduce investors' concerns. Ideally, managers should continually monitor the performance of VR marketing practices and publicly offer investors related information. This thesis also highlights the roles of marketing alliances and strategic focuses, confirming their potential to reduce the losses in the form of abnormal stock returns from VR-enabled marketing practices.

Third, this thesis also reveals that the firm-level outcomes derived from VR adoption are contingent on the related firm-level characteristics and environmental factors. In terms of adopting VR in marketing practices, the adoption outcomes (i.e., abnormal stock returns) can vary depending on whether firms have marketing alliances; in addition, these outcomes can vary depending on firms' levels of internal uncertainty and strategic focus. Regarding VR adoption in manufacturing practices, the adoption outcome (i.e., enhanced production efficiency) is contingent on the levels of employee fluctuation and market dynamism. These findings offer managers valuable guidance on how to reap more benefits when adopting VR in different business practices.

In addition, our post-hoc analysis provides detailed guidance for firms considering VR adoption. For VR-enabled marketing practices, we urge managers to prioritise the applications of VR in the development of new products or services since applying VR in the post-purchase stage would not cause significant firm value decreases. For VR-enabled manufacturing practices, managers should be aware that the value creation of VR-enabled manufacturing practices in production efficiency is primarily driven by pre-manufacturing training and intra-manufacturing activities. Moreover, firms in the non-service industries tend to reap more benefits from VR enabled-manufacturing practices than those in the service industries.

5.3 Limitations and Recommendations for Future Work

Although this thesis provides a range of new insights and addresses several important research gaps, there are also certain limitations. First, the selected context for the two empirical studies is based on firms in the US. While the US focus was an ideal study context because of the high VR adoption rate among businesses and the availability of relevant data, it would also be valuable to investigate other country contexts, especially emerging markets. For instance, the VR hardware market in China ranked in the global top 5 in 2023 with a revenue of US$2,399 million (Statista, 2023b). Given the enormous increases in VR adoption rates and the lack of studies that have investigated such emerging market contexts, there are important new research opportunities for future studies. Another potential area of interest would be to conduct comparison studies across multiple countries to assess the efficacy of VR in improving business performance. Furthermore, due to data availability, I used publicly traded firms as the sample for hypothesis testing. Future research could use primary data for small and medium enterprises to offer insights with greater generalizability.

Second, this thesis only examines the outcomes of VR adoption by considering its applications in marketing and manufacturing practices. Future studies could extend this research theme in two ways. The first would be to take a more nuanced view and examine the firm-level outcomes for more specific VR-enabled business activities (e.g., product and service innovation). The second is to investigate more diverse firm-level outcomes, including firm risks, firm profitability, employee productivity, and innovation performance. In this context, more granular insights could be obtained to allow firms and researchers to distinguish the firm-level outcomes of different VR-enabled business practices.

Third, while TR theory provides an appropriate explanation in terms of the general negative impacts of VR-enabled marketing practices on firm value, it still fails to offer specific theoretical mechanisms due to the limitations of the event study. Future studies may consider a primary data-based survey approach and target investors to reveal additional theoretical mechanisms that pinpoint the negative impacts of VR-enabled marketing practices on firm value. This research direction could provide further insights into how firms can reduce the negative impacts of VR-enabled marketing practices and achieve more benefits. Similarly, this thesis offers several theoretical explanations (i.e., enhanced flexibility and innovation) of why

VR-enabled manufacturing practices benefit firms' production efficiency. Further investigations are thus required to empirically examine more theoretical mechanisms underpinning the impacts of VR-enabled manufacturing practices on firms.

Fourth, while this thesis exhaustively accounts for the moderating role of firm-level characteristics and environmental characteristics in the impacts of VR adoption on firms' performances, there are also future research opportunities. A closer examination of VR-related technology characteristics (e.g., VR investment intensity and types of VR consoles) could provide opportunities to examine the conditions under which these factors may contribute to or impede performance related to VR adoption.

Finally, disruptive technology adoption among firms continues to grow at a steady pace. A sole focus on VR adoption cannot offer a complete view of the outcomes of disruptive technology adoption in business practices. Therefore, further research into this emerging research area is warranted. In particular, this emerging research avenue should pave the way for an in-depth exploration of how different disruptive technology types (e.g., 3D printing, blockchain, big data, and cloud computing) can affect firm performance.

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Appendix. Authorship Declaration Forms

Appendix 1. Authorship Declaration Form for First Study

University of Liverpool Management School

PhD Thesis – PhD Structured as Papers

AUTHORSHIP DECLARATION – joint authored papers - Appendix B

1. Candidate

Name of the Candidate	Student number
Yangchun Xiong	201379261
Thesis Title	
Investigating the Firm-Level Outcomes of Virtual Reality-Enabled Business Practices	

2. FORMAT OF THE THESIS

Is the candidate intending to structure their thesis as papers?	Yes	If Yes, please complete Section 3 (sole authored paper) OR 4 (joint paper) If No, you do not need to complete this form

3. PAPER INCLUDED IN THE THESIS – JOINT AUTHORED PAPER

Title of the paper	Has this paper been published, presented at a conference or under review with a journal	If Yes, please complete the boxes below. If No, go to section 4
Understanding Virtual Reality Adoption in Business Practices: A Systematic Review and Future Research Agenda	No	
If the paper has already been published please refer to the University guidelines on presentation of publications within a PGR Thesis - https://www.liverpool.ac.uk/media/livacuk/tqsd/code-of-practice-on-assessment/annex-7.2-PGR-CoP.pdf		
If the paper is under review with a journal, give details of the journal, including submission dates and the review stage		

If the paper is presented at a conference, give details of the conference

4. DESCRIPTION OF ALL AUTHOR CONTRIBUTIONS (including the PhD candidate)

Name and affiliation of author	Contribution(s) (for example, conception of the project, design of methodology, data collection, analysis, drafting the manuscript, revising it critically for important intellectual content, etc.)
Yangchun Xiong University of Liverpool	Conception of The Project, Design of Methodology, Data Collection, Analysis, Drafting the Manuscript, Revision
Professor Hugo Lam University of Liverpool	Conception Of the Project, Monitoring and Supervision, Revision
Dr Sahar Karimi University of Liverpool	Conception Of the Project, Monitoring and Supervision, Revision

5. AUTHOR DECLARATIONS (including the PhD candidate)

I agree to be named as one of the authors of this work, and confirm:

that the description in Section 4 of my contribution(s) to this publication is accurate,

that there are no other authors in this paper,

that I give consent to the incorporation of this paper/publication in the candidate's PhD thesis submitted to the University of Liverpool

Name of author	Signature*	Date
Yangchun Xiong	Yang chun. Xiong	20th March 2023
Professor Hugo Lam	Hugo Lam	20th March 2023
Dr Sahar Karimi	Sahar Karimi	20th March 2023

6. OTHER CONTRIBUTOR DECLARTION

I agree to be named as a non-author contributor to this work.

Name and affiliation of contributor	Contribution	Signature* and date

Appendix 2. Authorship Declaration Form for Second Study

University of Liverpool Management School

PhD Thesis – PhD Structured as Papers

AUTHORSHIP DECLARATION – joint authored papers - Appendix B

1. Candidate

Name of the Candidate	Student number
Yangchun Xiong	201379261
Thesis Title	
Investigating the Firm-Level Outcomes of Virtual Reality-Enabled Business Practices	

2. FORMAT OF THE THESIS

Is the candidate intending to structure their thesis as papers?	Yes	If Yes, please complete Section 3 (sole authored paper) OR 4 (joint paper) If No, you do not need to complete this form

3. PAPER INCLUDED IN THE THESIS – JOINT AUTHORED PAPER

Title of the paper	Has this paper been published, presented at a conference or under review with a journal	If Yes, please complete the boxes below. If No, go to section 4
Gaining Virtual or Real Value? Exploring the Impact of Virtual Reality-Enabled Marketing Practices on Firm Value	Yes	
If the paper has already been published please refer to the University guidelines on presentation of publications within a PGR Thesis - https://www.liverpool.ac.uk/media/livacuk/tqsd/code-of-practice-on-assessment/annex-7.2-PGR-CoP.pdf		
If the paper is under review with a journal, give details of the journal, including submission dates and the review stage		

If the paper is presented at a conference, give details of the conference Accepted and presented at the 12th Production and Operations Management Society-Hong Kong (POMS)-HK International Conference.

4. DESCRIPTION OF ALL AUTHOR CONTRIBUTIONS (including the PhD candidate)

Name and affiliation of author	Contribution(s) (for example, conception of the project, design of methodology, data collection, analysis, drafting the manuscript, revising it critically for important intellectual content, etc.)
Yangchun Xiong University of Liverpool	Conception of The Project, Design of Methodology, Data Collection, Analysis, Drafting the Manuscript, Revision
Professor Hugo Lam University of Liverpool	Conception Of the Project, Monitoring and Supervision, Revision
Dr Sahar Karimi University of Liverpool	Conception Of the Project, Monitoring and Supervision, Revision

5. AUTHOR DECLARATIONS (including the PhD candidate)

I agree to be named as one of the authors of this work, and confirm:

that the description in Section 4 of my contribution(s) to this publication is accurate,

that there are no other authors in this paper, *that I give consent to the incorporation of this paper/publication in the candidate's PhD thesis submitted to the University of Liverpool*

Name of author	Signature*	Date
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Professor Hugo Lam	Hugo Lam	20th March 2023
Dr Sahar Karimi	Sahar Karimi	20th March 2023

6. OTHER CONTRIBUTOR DECLARTION

I agree to be named as a non-author contributor to this work.

Name and affiliation of contributor	Contribution	Signature* and date

Appendix 3. Authorship Declaration Form for Third Study

University of Liverpool Management School

PhD Thesis – PhD Structured as Papers

AUTHORSHIP DECLARATION – joint authored papers - Appendix B

1. Candidate

Name of the Candidate	Student number
Yangchun Xiong	201379261
Thesis Title	
Investigating the Firm-Level Outcomes of Virtual Reality-Enabled Business Practices	

2. FORMAT OF THE THESIS

Is the candidate intending to structure their thesis as papers?	Yes / No	If Yes, please complete Section 3 (sole authored paper) OR 4 (joint paper) If No, you do not need to complete this form

3. PAPER INCLUDED IN THE THESIS – JOINT AUTHORED PAPER

Title of the paper	Has this paper been published, presented at a conference or under review with a journal	If Yes, please complete the boxes below. If No, go to section 4
Investigating the Effect of Virtual Reality-Enabled Manufacturing Practices on Production Efficiency	Yes	
If the paper has already been published please refer to the University guidelines on presentation of publications within a PGR Thesis - https://www.liverpool.ac.uk/media/livacuk/tqsd/code-of-practice-on-assessment/annex-7.2-PGR-CoP.pdf		
If the paper is under review with a journal, give details of the journal, including submission dates and the review stage		

Submitted to the special issue of the International Journal of Production Economics. The current manuscript is under the second-round review stage.
If the paper is presented at a conference, give details of the conference Accepted and presented at the 32nd Annual Production and Operations Management Society (POMS) Conference.

4. DESCRIPTION OF ALL AUTHOR CONTRIBUTIONS (including the PhD candidate)

Name and affiliation of author	Contribution(s) (for example, conception of the project, design of methodology, data collection, analysis, drafting the manuscript, revising it critically for important intellectual content, etc.)
Yangchun Xiong University of Liverpool	Conception of The Project, Design of Methodology, Data Collection, Analysis, Drafting the Manuscript, Revision
Professor Hugo Lam University of Liverpool	Conception Of the Project, Monitoring and Supervision, Revision
Dr Sahar Karimi University of Liverpool	Conception Of the Project, Monitoring and Supervision, Revision

5. AUTHOR DECLARATIONS (including the PhD candidate)

I agree to be named as one of the authors of this work, and confirm:

that the description in Section 4 of my contribution(s) to this publication is accurate, *that there are no other authors in this paper,*

that I give consent to the incorporation of this paper/publication in the candidate's PhD thesis submitted to the University of Liverpool

Name of author	Signature*	Date
Yangchun Xiong	Yang chun. Xiong	20th March 2023
Professor Hugo Lam	Hugo Lam	20th March 2023
Dr Sahar Karimi	Sahar Karimi	20th March 2023

6. OTHER CONTRIBUTOR DECLARTION

I agree to be named as a non-author contributor to this work.

Name and affiliation of contributor	Contribution	Signature* and date