# Examining the Impact of Resilience Strategies in Mitigating Medicine Shortages in the United Kingdom's (UK) Pharmaceutical Supply Chain (PSC)


## Abstract

### Purpose

Medicine shortages have a detrimental impact on stakeholders in the PSC. Existing studies suggest that building resilience strategies can mitigate the effects of these shortages. As such, this research examined if resilience strategies can reduce the impact of medicine shortages in the United Kingdom's (UK) pharmaceutical supply chain (PSC).

### Methodology

A sequential mixed-methods approach that involved qualitative and quantitative research enquiry was employed in this study. The data were collected using semi-structured interviews with 23 key UK PSC actors at the qualitative stage. During the quantitative phase, 106 respondents completed the survey questionnaires. The data were analysed using partial least square structural equation modelling (PLS-SEM).

### Findings

The results revealed that reactive and proactive elements of resilience strategies helped tackle medicine shortages. Reactive strategies increased relational issues such as behavioural uncertainty, while proactive strategies mitigated them.

### Practical implications

The findings suggest that PSC managers and decision-makers can benefit from adopting structural flexibility and proactive strategies, which are cost-effective measures to tackle medicine shortages. Also, engaging in strategic alliances as a proactive strategy mitigates relational issues that may arise in a complex SC.

### Originality

This study is the first to provide empirical evidence of the impact of resilience strategies in mitigating medicine shortages in the UK's PSC.



**Keywords:** Behavioural uncertainty, supply chain disruptions, product design, pharmaceutical supply chain, mixed method, supply chain resilience, drug shortages, medicine shortages

## 1. Introduction

Over the last two decades, the global pharmaceutical industry has witnessed considerable growth, with a sixfold increase in traded global value (McKinsey, 2020; Mikulic, 2021). In 2020, its revenue was estimated at $1.27 trillion. However, medicines' unavailability is still increasing and is detrimental to effective healthcare operations (Phuong et al., 2019; Chen et al., 2020). For instance, in 2022, the UK and the US recorded 206 and 166 new cases, respectively, of medicine shortages (ASHP, 2022; Wickware, 2022). Instances of medicine shortages have hindered patients' treatment continuity, increased staff workloads and, in some cases, resulted in the death of patients (Phuong et al., 2019). Some documented causes of medicine unavailability include globalisation, manufacturing issues, natural disasters, pandemics, pharmaceutical supply chain (PSC) complexities and regulatory requirements (Tucker et al., 2020; Vann Yaroson et al., 2021). The covid pandemic also disrupted medicine availability because of issues in the supply chain of raw materials (KPMG, 2021). These causes of medicine unavailability highlight the dynamic and disruptive nature of medicine shortages and create concerns about tackling them effectively.

Supply chain (SC) resilience has been identified as critical in tackling disruption issues in the SC (in this case, medicine shortages) (Aldrighetti et al., 2021; Katsaliaki et al., 2021). Proponents advocate for its propensity to address inherent SC weaknesses (vulnerabilities), thus mitigating the impact of disruptions (Ozdemir et al., 2022). Following SC resilience tenets, organisations must build timely and cost-effective strategies to prepare, respond, and recover from a disruption (Hendry et al., 2019; Scala and Lindsay, 2021). These strategies include flexibility, visibility, and collaborative practices and can either be reactive and/or proactive (Tukamuhabwa et al., 2015; Kamalahmadi et al., 2022).

However, the PSC's unique nature may affect resilience strategies' effectiveness in mitigating disruptions. Researchers argue that medicines differ from other products due to their pertinence for survival and the requirement for safety and reliability while meeting consumers' needs (Chen et al., 2020). It makes the PSC very complex due to the multifaceted processes that facilitate medicine discovery, manufacturing, and distribution. The PSC is also characterised by its manufacturing processes, cost intensity and limited suppliers (Narayana et al., 2014; Sazvar et al., 2021). To this end, the peculiarities of the PSC may affect the desired impact of resilience strategies in mitigating medicine shortages. For instance, PSC actors who engage in flexible operations to reduce the effects of medicine shortages may further increase the SC's complexity due to the limited number of suppliers. Moreover, approaching SC resilience as a systemic concept requiring interactions and decision-making processes among SC actors (Vann Yaroson et al., 2021) may affect the possible strategies employed. Therefore, it is imperative to understand if resilience strategies can mitigate medicine shortages in the PSC and address the corresponding outcomes if any.

The potential of resilience in the PSC has been examined (Sabouhi et al., 2018; Bastani et al., 2021; Tucker et al., 2019; Vann Yaroson et al., 2023). However, there is limited knowledge of resilience strategies in the face of highly disruptive events such as medicine shortages and their impact on the PSC. Given the frequency of these events globally, a greater understanding of the effects of SC resilience elements, including flexibility and collaboration, when tackling medicine shortages is warranted. Thus, this study addresses the gap by examining if resilience strategies mitigate medicine shortages' impact on the PSC. The study intends to shed more light on the following research questions (RQ):

RQ1. What resilience strategies mitigate the impact of medicine shortages in the PSC?

RQ2. What is the impact of resilience strategies on the PSC when mitigating medicine shortages?

Similarly, the main objective of this study is to understand how resilience strategies are used to tackle medicine shortages and the corresponding impact on the PSC. A conceptual model was developed based on the findings from qualitative interviews and tested with three hypotheses using partial least square equation modelling (PLS-SEM). The results offer insights into the effect of medicine shortages when resilience strategies are adopted. Therefore, this paper addresses a gap in the literature by providing empirical evidence of SC resilience and medicine shortages. It also considers the corresponding effect of adopted resilience strategies on the PSC. In addition, this paper is among the first to provide empirical evidence that considers medicine shortage mitigation from a resilience strategy perspective. Finally, the study offers managers guidance on resource allocation when tackling shortages. It also provides a basis to inform best practices for adopting PSC resilience and the practical implications of applying proposed resilience strategies when addressing shortages. The following section, Section two, presents an overview of the literature on the research phenomenon. Section three presents the methodology adopted in the study alongside the findings from the qualitative phase and hypothesis development. Sections four, five and six present the findings from the quantitative phase of the study, a discussion of results and concluding remarks.

## 2. Literature Review

### 2.1. Supply chain disruptions: medicine shortages

There have been extensive studies on SC disruptions over the last decade. Disruptive activities impede the flow of goods and services within a supply chain, adversely affecting firms' financial and operational performance (Hendricks et al., 2020; Baghersad and Zobel, 2021). Disruptions are referred to as realised risks. They denote the actualisation of unfavourable events (Melnyk et al., 2014; Bode and Wagner, 2015; Habermann et al., 2015). These events may be planned and/or unanticipated. It includes natural disasters, pandemics, union strikes, geopolitical issues and terrorism, amongst others (Craighead et al., 2007; Ellis et al., 2010; Bode and Wagner, 2015; Ivanov, 2020). Queiroz et al. (2020a) referred to supply chain risk as extraordinary and highly damaging events. To this end, medicine shortages are categorised as PSC disruption since they inhibit healthcare operations that may lead to patients' death.

The factors that lead to medicine shortages are multifaceted, including quality defects, natural disasters, pandemics, pricing fluctuation, supplier defaults, and labour strikes (Fox et al., 2014; Iyengar et al., 2016; DeWeerdt et al., 2017; Beck et al. 2019). These causes can be anticipated (quota systems and price manipulation) and unanticipated (natural disasters). For this reason, medicine shortages are defined as dynamic disruptions.

The dynamic nature of medicine shortages lends itself to discrepancies in its definition and composition among supply chain actors (Miljković et al., 2020). Some studies focus on the manufacturing issues that result in shortages; others concentrate on stock out at the pharmacy level (ASHP, 2021) or timing (Miljkovic et al., 2020). Reimbursement policies (De Weerdt et al., 2015), quotas versus rationing, and tender systems have also been documented to impact shortages (Gloor et al., 2013). For instance, reimbursement occurs after a product is dispensed

in the UK based on the drug tariff or the manufacturers' price list (Ranson et al., 2019). On occasion, products may be procured at a much higher cost than the drug tariff or manufacturer's shortage list, which may increase the impact of the shortage. These issues hinder the ability to determine practical strategies to curb the effects of medicine shortages (Vann Yaroson et al., 2021). The above-identified factors denote the need to address medicine shortages from an operations and supply chain management perspective, which has received limited scrutiny in existing studies.

### 2.2. Supply chain resilience: Complex adaptive system perspective of proactive and reactive capabilities

The concept of SC resilience within literature has been posited to curb the impact of disruptive activities (Brandon-Jones et al., 2014; Pettit et al., 2019; Polyviou et al., 2019). It is based on its adaptive capacity to continue operations in the presence of disruptions. Antecedents of SC resilience have been broadly identified to include flexible operations, visibility, and collaboration (Sabahi and Parsast, 2020). These antecedents can be either reactive, employed after a disruption, or proactive in anticipation of a disruption (Kamalahmadi et al., 2022).

Flexibility refers to a firm's ability to adjust to the needs of stakeholders and the environment with minimum effort and reduced time. It has been emphasised as the critical driver of SC resilience (Fayezi et al., 2017). In most cases, this may entail speeding up production processes, ramping supply, and reducing lead times. However, the supply chain's configuration (number of suppliers, buyers, competition among suppliers) may not make this strategy effective. For instance, with limited suppliers, as in the case of the pharmaceutical supply chain (Iyengar et al., 2016), flexible operations may not be effective. Adopting flexible processes may encroach on alternate supply chains, thus increasing complexity. In the same vein, Kamalahmadi et al. (2022) showed that flexible operations were less effective in cost reduction and service level improvement.

SC collaboration requires firms to work successfully together for mutual benefits. This strategy encourages trust-building, information, resource, and joint decision-making. Empirical evidence suggests incorporating collaborative practices as a reactive strategy to reap its efficacy (Hendry et al., 2019; Silva and Reul, 2022). An example of PSC collaboration is the Serious Shortages Protocol (SSP) (PSNC, 2019) set up in the UK to tackle medicine shortages. The SSP facilitates a collaborative decision process where inputs from PSC actors are required to curb the impact of medicine shortages. It provides an avenue to respond to a shortage by rationing quantities through more dialogue between the government, health professionals, and suppliers to inform the nature and longevity of the SSP. SC visibility entails sharing information across the SC and is emphasised as an outcome of collaborative efforts (Vann Yaroson et al., 2021). Visibility implies that manufacturers have complete information about the position of their assets within a SC environment. It is pertinent to mitigate unproductive decisions, risky and unnecessary interventions, and in other cases, overreactions. These antecedents (flexible operations, visibility, and collaboration) can be either proactive or reactive (Jia et al., 2020; Shekarian and Parast, 2020; Ozdemir et al., 2022). However, the literature is evasive on what constitutes proactive and reactive capabilities.

Some studies have focused on SC resilience's proactive capabilities, which follow the SC's ability to prepare and plan for a disruption. It involves developing the capacity to recognise, anticipate, defend, and resist adverse consequences that may occur (Sa et al., 2019). Adopting these strategies allows the supply chain to recover from or resist disruption by containment or

avoidance. Other studies examine SC resilience reactive elements, which include stabilising disruptive impacts and returning to normal operations. Some disadvantages may be the costs associated with these strategies. Also, some reactive strategies are time-bound and may be unable to manage the impact of the disruption. It may lead to adverse effects, as in the case of PSC, which may lead to a patient's death. However, there are limited empirical studies to identify when supply chain resilience strategies are either reactive or proactive (Hendry et al., 2019). Integrating these perspectives may be pertinent in a unique SC, such as the PSC (Wieland and Durach, 2021; Queiroz et al., 2022). From this lens, Vann Yaroson et al. (2021) reported that PSC resilience should be approached from a complex adaptive system perspective where resilience involves adaptability to disruptions. The building of resilience strategies in SCs has been viewed through CAS lens (Tukamuhabwa et al. 2017; Vann Yaroson et al. 2021). CAS are depicted as complex systems made up of multiple dimensions and resources including the adaptive capacities of stakeholders (Choi et al., 2001; Holland, 2006). It implies that interactions with stakeholders in tumultuous environments may produce unintended outcomes.

### 2.3. The outcomes of resilience strategies

Relational practices also affect SC resilience outcomes (Wieland and Wallenburg, 2013). A SCs' relational quality features include trust, commitment, joint decision-making, and mutual risk-sharing (Chowdhury et al., 2019). Conversely, weak relational capabilities among SC actors foster partner dissatisfaction and behavioural uncertainty. SC partner satisfaction refers to feeling equity within a supply chain relationship (Essig and Amann, 2009). Partner dissatisfaction impedes collaborative practices and affects SC resilience impact. For instance, increased partner satisfaction increases collaboration, an essential ingredient of SC resilience. In the same view, partner dissatisfaction may inhibit resilience. Therefore, understanding elements that breed partner dissatisfaction is essential in SC resilience discussions. Benton and Maloni (2005) showed that partner asymmetry increased partner dissatisfaction through control.

Similarly, strategic alliance as a multi-dimensional concept denotes a relationship between two or more firms in the SC (He et al., 2020). It is formed based on the agreed degree of integration and underlying contractual agreements. Strategic alliances are suggested to facilitate SC resilience since they increase trust and facilitate information sharing through agreed mutual goals (Chen et al., 2019 ). Strategic partnerships offer significant benefits. It also induces relationship dissatisfaction and opportunistic behaviours (Gallear et al., 2015). It may be particularly evident when building resilience strategies influenced by the complexities of product design.

Product design requires configuring products and their components to provide function, aesthetics and durability (Walsh et al., 1988; Khan et al., 2008). Product design is critical in supply decisions (Wagner et al., 2012) and may affect the outcome of SC resilience. For instance, Khan et al. (2008) highlighted the importance of product design in examining supply chain risk. However, other studies consider product design an element of supply chain complexity (Wagner and Bode, 2006; Macdonald and Wagner, 2017). In such scenarios, building SC resilience mitigates associated product design complexities (Tukamuhabwa et al., 2017). As such, this study also examines the capacity of product design to influence resilience strategies when tackling medicine shortages.

### 2.4. Empirical evidence linking disruptions and SC resilience

The tenets of SC resilience suggest that the impacts of disruptive events can be mitigated if SCs possess the capability to prepare, plan, resist, recover and/or return to regular operation (Ponomarov and Holcomb, 2009; Jüttner and Maklan, 2011; Tukamuhabwa et al. 2017; Hendry et al. 2019). Following a systematic approach, a summary of the literature examining the link between SC resilience and disruptive activities, the methodological approaches and relevant elements of SC resilience are presented in Table 1. The table showed that research conducted on SC resilience and disruptive events included terrorism (Steecke and Kumar, 2009), financial crises (Juttner and Maklan, 2011), rare-harvest disruptions (Behzadi et al., 2017); constitutional changes (Hendry et al., 2019) and more recently Covid-19 pandemic (El-Baz and Ruel, 2021; Ramanathan et al., 2021; Queiroz et al., 2022; Silva and Ruel, 2022). Limited studies have investigated the effect of resilience strategies in a specialised SC, such as the PSC, with a specific interest in medicine shortages. Ward and Hargaden (2019) and Tucker et al. (2019) examined what resilience strategies could mitigate medicine shortages without considering their effect. Existing studies broadly categorise resilience strategies as flexibility, collaboration, and velocity (Juttner and Maklan, 2011; Purvis et al., 2016). However, research reporting the impact of reactive and proactive elements of SC resilience on outcomes is limited (Thun and Hoeing, 2011; Butt and Shah, 2021).

Table 1 also shows the limited use of the mixed-method approach in the existing studies. This study considers the mixed-method technique robust. It provides breadth, depth, and more rounded information (Creswell, 2013). This study extends empirical literature by examining the outcome of SC resilience strategies in mitigating medicine shortages using a mixed-methods approach.

Table 1 Empirical evidence examining the link between disruptions and supply chain resilience
Source: Adapted from Yaroson et al. (2019)

Despite the body of SC resilience literature discussed above, no studies address the effect of these resilience strategies (flexibility, collaboration and strategic alliances) (Tukamuhabwa et al., 2017). This research thus contributes to this aspect of SC resilience literature.

The following section provides an overview of the methodology employed in answering our research questions.

## 3. Methodology

This study examined the forms of PSC resilience strategies adopted in mitigating medicine shortages and the impact of these strategies. A mixed-method approach which involved the use of qualitative and quantitative methods within a single study (Creswell, 2013), was used to answer the questions posed in this study. The mixed-method approach was chosen as it provides a rigorous methodology and additional empirical insights into PSC resilience. For instance, the qualitative methods enabled an in-depth exploration of how resilience strategies were used in combating the impact of medicine shortages. In addition, qualitative techniques are appropriate for exploring emerging concepts (Creswell, 2013), as seen in PSC resilience. The quantitative method confirmed these findings from a broader perspective and enabled triangulation to ensure the validity of the results. Thus, the identified outcomes of resilience strategies in this study were explored and explained by gathering information from multiple sources (Golicic and Davis, 2012; Creswell, 2013; Venkatesh et al., 2016).

This study involved a two-phased sequential exploratory research process using qualitative followed by quantitative techniques to collect and analyse the data. The research approach was conducted under the pragmatism paradigm, which posits that social reality can be explained based on information (Creswell and Poth, 2016). A summary of the research process is provided in Figure 1.

Figure 1. Research Process

### 3.1. Qualitative research design

The first phase involved qualitative research design. Here, data were collected using semi-structured interviews with 23 actors of managerial capacity at various UK PSC levels. The aim was to explore the forms of resilience strategies used to mitigate medicine shortages and the corresponding outcomes. The nature of the sample was based on UK's PSC design, where there are limited manufacturers and wholesalers as compared to hospital and community pharmacists. It was also pertinent that interviews were conducted across the various levels of the PSC to examine and determine the interrelatedness of resilience strategies across the PSC. The sample size comprised five manufacturers, one pre-wholesaler, two logistic service providers, five hospital pharmacists, six community pharmacists, one pharmacist working in a General Practitioner (GP) practice and three participants representing various regulatory bodies. No additional information was generated after the 23$^{rd}$ response. As such, information saturation was reached by the 23$^{rd}$ respondent (Morse, 1994). The interviews were collected between June and September 2018. A summary of research respondents is provided in Table 2.

Table 2 Profile of participants in the qualitative data collection phase

An interview protocol developed from existing studies guided the data collection process at this stage. The protocol contained twenty (20) questions about medicine shortages, disruptions, vulnerabilities, and resilience strategies. The interviews lasted between 30-60 mins. Digitally recorded and subsequently transcribed data were analysed using thematic analyses following a six-step process by Braun and Clarke (2014). The lead researcher generated the initial themes. Various researchers across Pharmacy and Operations Management disciplines further validated these. This approach minimised bias and improved the study's validity (Corbin and Strauss, 2014). Secondly, these themes supported by established literature were used to design the quantitative phase's survey instrument.

### 3.2. Qualitative data analysis and hypothesis development

The analysed data showed that the resilience strategies used to mitigate the impact of medicine shortages were either reactive and/or proactive strategies. The reactive approach included flexible operations, increased visibility, and collaborative decision-making, while proactive strategies involved strategic alliances. A summary of the impact of resilience strategies adopted in the UK PSC and the corresponding results are presented in Table 3.

Table 3 Impact of resilience strategies in addressing medicine shortages
*Source: Adapted from Yaroson et al. (2021)*

### 3.2.1. Product design influences resilience strategies

Also highlighted in the analysis were the characteristics of pharmaceutical products that influenced how resilience strategies curbed medicine shortages. For instance, a research respondent explained the challenges faced in stockpiling pharmaceutical products due to shorter shelf lives, cost intensity, and/ or changing patients' treatment regimens. Another respondent explained that the manufacturing of pharmaceutical products required a high level of expertise and investment, which limited the number of manufacturers. It was also pointed out by Narayana et al. (2014) and Rahman et al. (2020). Similarly, if decisions around pharmaceutical products are treated as other commodities, their quality may be undermined (de Rima et al. 2018). Thus, the development of PSC resilience strategies was primarily defined by the design of pharmaceutical products; understanding the criticality and nature of pharmaceutical companies is essential. To this end, the study proposes that:

*H1a: Product design significantly influences reactive strategies in the PSC*
*H1b: Product design significantly influences proactive strategies in the PSC*

### 3.2.2. Reactive strategies influence relational capabilities

In discussing flexible operations, respondents often mentioned their need to seek alternative products (product flexibility) when a shortage occurred. It was either in form, volume, or presentation (tablets/injections). At other times they sought alternative suppliers (supplier flexibility). Flexible operations also differed at various levels in the PSC. For example, the community and hospital pharmacists (patient-facing PSC actors) demonstrated flexibility by substituting alternative medicinal products, while manufacturers sought alternative suppliers. However, all PSC actors echoed the ineffective ability of this strategy to meet patients' demands. It was because substituting medicines sometimes led to patients' having adverse drug reactions, exerted pressure on alternative supply chains and increased PSC complexity. As well as this, the need to source and trade with backup suppliers was a costly alternative.

Our analysis identified visibility as another element of the reactive strategy employed to curb medicine shortages. Visibility in these instances included product and information visibility, where information sharing increased visibility. Information technology (IT) platforms enhanced product visibility. The respondents from our sample explained that information about shortages was often shared through national alert websites, joint decision-making meetings, and conference bulletins.

> *"If manufacturing plants have an issue, or our safety stock is depleting, we manage this as quickly as possible through national alerts on products". MFC3*

Our respondents also highlighted issues regarding information sharing, which included the timing and the quality of information shared, which were often insufficient to facilitate effective planning. As explained in the supporting statement below:

> *"Manufacturers are not allowed to talk to each other… it is anti-competitive and has room for potential collusion. We cannot talk to others regarding anything commercial. What we have is an honest broker, such as the Commercial Medicines Unit. However, you get a lot of misinformation and confusion. I think many people feel frustrated because they get blamed for the action of others". MFC1*

The IT platforms permitted PSC actors to view where their products were in the supply chain, thus enabling them to plan for and respond to a disruption. However, information sharing was sometimes detrimental to building resilience strategies because it could lead to PSC actors engaging in unethical business practices such as stockpiling. Detrimental outcomes such as stockpiling generated mistrust and hindered future information sharing.

> *"If we notice a gap in supply, then we may do several things. The first one is to control the number of stocks in the UK, which will mean bringing the stock to a central point so we can manage the stock". MFC1*

Another argument regarding adopting reactive strategies is the inability of supply chain partners to understand market demand.

> *"The downside is that these manufacturers do not understand market demand. So, it is highly variable and volatile. This leads to problems of forecasting and visibility". HOSP3*

Collaborative decision-making involved joint meetings with PSC actors to decide on collaborative strategies to meet demand, including sourcing alternatives, production ramp-up, and strategy delegation. However, the meetings could lead to panic buying, conflict, and partner dissatisfaction. For instance, the patient-facing PSC actors explained that they engaged in stockpiling to meet patient demand when they were notified of shortages. Upstream PSC actors, as interview respondents, explained that panic buying/stockpiling was avoided by adopting rationing/quota strategies resulting in conflicts and partner dissatisfaction. All PSC actors argued that they engaged in such practices to ensure patient treatment continuity, as presented in the statement below.

> *"A lot of time, manufacturers try not to tell you there will be a problem because if they inform us, we tend to buy up all the stock. It is a selfish process, and panic buys as they assume a shortage will create shortages". COMM 2*

Following this analysis, we propose that:
*H2a: Reactive strategies significantly increased partner dissatisfaction in the PSC*
*H2b: Reactive strategies significantly increased behavioural uncertainty in the PSC*

**3.2.3. Proactive strategies influenced relational capabilities in the PSC**
Our findings also identified resource sharing facilitated through strategic alliances as a PSC proactive resilience strategy.

*"We find out that we have not been hit with these shortages as other companies would have because we have contacts with our suppliers who give us heads up... a lot of smaller independent companies struggle". LSP1*

Proactive strategies depicted through resource sharing facilitated PSC actors' capability to plan and prepare for medicine shortages. These alliances permitted infrastructure sharing, such as warehouses and technological know-how. It was evident that trust existed between supply chain partners as they were allowed to stockpile. The qualitative phase findings also showed that resilience strategies' impact on medicine shortages might be altered if opportunistic behaviours occur, which may lead to behavioural uncertainties. The theory of opportunism suggests dysfunctional activities within a supply chain. The complexity of the product design and the number of suppliers in the PSC was attributed to the increased monopolistic behaviours when strategic alliances were formed. It is supported by extant literature which suggests possible adverse behaviours in complex strategic partnerships (He et al., 2020; 2021). Also, smaller individual firms suffered, thus leading to partner dissatisfaction.

Similarly, as a result of the complex adaptive system, mistrust occurred when information was shared strictly with strategic partners, leading to unpredictable behaviours among SC actors. Following these, we propose that:

*H3a: Proactive strategies significantly increased partner dissatisfaction in the PSC*
*H3b: Proactive strategies significantly increased behavioural uncertainty in the PSC*

A summary of the hypothesised relationships in this study is presented in Figure 2.

*Insert Figure 2 here. Structural Model and Hypothesis Development*

### 3.3. Quantitative research design and hypothesis testing

The study sought to confirm the findings from the qualitative interview stage in the quantitative phase of this study. The survey instrument measured resilience constructs such as flexibility, visibility, and some aspects of collaborative practices identified from the qualitative phase. Ten experts conversant with the UK's PSC pre-assessed the reliability and validity of the survey instrument. Participants were accessed using snowballing and purposive sampling techniques. These sampling techniques were chosen because participants needed to fulfil specific criteria. (i) an in-depth knowledge of the strategies employed to curb medicine shortages' impact and (ii) the capacity to employ these strategies (Saunders et al., 2019). When participants who met these criteria were identified, they received a web survey link. Due to the niche area of this research, which aimed to investigate if resilience strategies aided in mitigating medicine shortages, a reduced number of participants met the study criteria. Several channels were used to distribute the survey, including social media platforms and professional bodies' bulletins. A total of 106 actors at various stages of the PSC participated in the study.

Data analyses were carried out using a two-step approach on SPSS and SmartPLS. First, simple statistics such as frequencies identified the patterns and outliers of the data. The Cronbach's alpha, composite reliability and Average Variance Extracted (AVE) were used to assess the measurement models in the study. Second, the discriminant validity test (Heterotrait-Monotrait Ratio (HTMT) approach) was used to validate the identified structural paths. Our structural model analysis used the partial least square method (PLS: PLS-SEM), a variance-based

predictive approach employed, dealing with complex models (Sarstedt et al., 2019). The data were triangulated using meta-inferences. The theoretical statements offered holistic explanations of the research phenomenon from the qualitative and quantitative findings (Venkatesh et al., 2016). The study's findings and analysis are presented in the next section.

### 3.4. Quantitative phase and data analysis

This study phase sought to confirm the results from the qualitative phase and address the second research question. As such, a literature-based model augmented with findings from the qualitative phase of the study was adopted. The survey questionnaire was used to collect data from 106 respondents within five categories of respondents of the PSC as used in the qualitative phase. The respondents who completed the questionnaire needed to oversee the decision-making process within their organisation. This study employed the two-step technique to analyse the quantitative data collected with SPSS 25.0 and SmartPLS (v.3.2.6) (Talwar et al., 2020a, b; Dhir et al., 2021). Following the recommendations by Hair et al. (2019), the data were cleaned and coded, bringing the final dataset to 106 responses. Thus, the study involved ten manufacturers, five pre/wholesalers, four regulators, 57 secondary care and 30 primary care pharmacists. The disparity in the number of PSC actors' responses was expected since there are fewer manufacturers and regulators than primary and secondary care pharmacists in the PSC.

## 4. Results

### 4.1. Nonresponse bias and Common method bias (CMB)

The t-test assessed the nonresponse bias between early and late respondents (Tsou and Hsu, 2015). The lack of statistical differences among the scale items demonstrated the absence of nonresponse bias. Using a single respondent in a cross-sectional survey generates CMB. In these instances, the link between the exogenous and endogenous variables is inflated, which may bias the results (Podsakoff and Organ, 1986). The possibility of CMB occurring was assessed using the complete collinearity variance inflation factors (VIF) (Kock, 2015, 2020; Hair et al., 2019; Queiroz et al., 2021) and the Harmans' single factor test (Harman, 1976; Fuller et al., 2016). The values for the VIF were all under 5, and the 27.5% cumulative average for Harman's single-factor test depicted the absence of CMB.

### 4.1. Reliability and Validation of Measurement Scales

Existing literature on SC resilience suggests using a reflective measurement model to measure resilience antecedents (Wieland and Wallenburg, 2013; Golgeci et al., 2018; Ivanov and Dolgui, 2020). These propositions were validated by testing for item loadings. We established the reliability and validity of the variables using the overall Cronbach alpha scores, composite reliability test and the Average Variance Extracted (AVE). As depicted in Table 4, the outer loadings, the overall Cronbach alpha score, and composite reliability stood above the recommended 0.60 thresholds (Vaske et al., 2017; Hair et al., 2019).

The test scores suggest that this study's measurements of resilience outcomes were a good fit.

Table 4 Reliability and validity tests

The discriminant validity test was also validated for the structural path (Fornell and Larcker, 1981). The requirement here is that the Average Variance Extracted (AVE) square root for

each construct should be higher than its correlation, and these values are less than 0.95. As shown in Table 5, the values are below 0.95, reflecting that these study's items measured their intended constructs.

Table 5 Structural path measurements

*Values in bold depict discriminant validity

### 4.2. Hypothesis testing

The hypotheses were tested using the variance-based structural equation modelling: partial least square method (PLS: PLS-SEM). The PLS-SEM approach was considered suitable due to its predictive nature, ability to deal with complex models and suitability for studies with small sample sizes (Nitzl, 2018; Hair et al., 2019; Sarstedt et al., 2019). These criteria reflected our research aim, which was geared to achieve predictability and our small sample size of 106. Thus, following our assessment of the reliability and validity of the measurement model, the structural model was examined to test the proposed hypothesis (Nitzl, 2018). The PLS-SEM path coefficient of 500 replications was used to investigate the relationship among the variables using SmartPLS. The statistical data of the hypothesis testing are presented in Table 6.

Table 6. Hypothesis testing

According to the analysis, product design significantly affects proactive and reactive strategies ($\beta$ = 0.551, $p$ = 0.000; $\beta$ = 0.656, $p$ = 0.000). Thus, *H1a* and *H1b* are supported, indicating the influence of product design on PSC resilience. The findings do not support *H3a* and H3b ($\beta$ =0.124, $p$ =0.422; $\beta$ =-0.148, $p$ = 0.433), where proactive strategies do not significantly influence behavioural uncertainty and partner dissatisfaction. The relationship between reactive strategies and PSC partner dissatisfaction is positive and significant ($\beta$ =0.574, $p$ = 0.000). Also, higher reactive strategies increase behavioural uncertainty ($\beta$ =0.545, $p$ =0.000), thus supporting (*H2a)*. From Table 6, the structural path results confirm some of our qualitative phase findings. These findings depict the influence of PSC product design in developing resilience strategies which invariably affects the PSC. A summary of our hypothesis testing is provided in Figure 3.

*Figure 3 Summary of hypothesis testing.*

## 5. Discussion and Implications

This research examined the outcomes of resilience strategies when managing medicine shortages. The analysed data from the qualitative and quantitative phases showed that PSC actors adopted reactive and proactive strategies to tackle medicine shortages. Flexible operations, collaborative practices, and visibility were categorised as reactive strategies and employed after shortages. Flexibility helped PSC actors promptly address the supply gap to meet patients' needs. The prevalent flexibility types identified involved using an alternative formulation or strength, a generic equivalent, or a therapeutic equivalent referred to as form/volume flexibility. This finding aligns with studies highlighting flexibility as an antecedent of resilience (Sabahi and Parsast, 2020; Kamalahmadi et al., 2022). It demonstrates the need for flexibility in curbing critical disruptions (Quieroz et al., 2021).

The findings establish flexible operations as a short term-solution to resilience in the PSC. It is not sustainable due to the cost of sourcing an alternative product, structure or supplier (Fayezi et al. 2017; Kamalahmadi et al. 2022). Similarly, due to the peculiarity of pharmaceutical products, flexible operations can apply pressure on substitute products or supply chains. It can also put additional stress on human resources, defeating the purpose of resilience (Tukamuhabwa et al., 2017; Bodie et al., 2018). The hypothesised relationship in this study confirmed that partner dissatisfaction is an implication for flexible operations. It may emanate from increased medication errors and the additional workload for PSC actors.

Joint decision-making as a collaborative practice was also necessary for addressing the impact of medicine shortages. In these instances, PSC actors jointly decided on ways to increase production, engage idle capacity, and delegate strategies to address shortages and meet patients' demands. However, these activities bred panic buying and increased PSC partner dissatisfaction and conflict. The threat of an adverse reaction from PSC actors concerning information on impending shortages restricted the timing and quality of information shared. This action created a potential barrier to information visibility, as vulnerable firms could regard the release of information as a threat to their survival (Katsaliaki et al., 2021). It provides possible explanations for the behavioural uncertainties of PSC actors.

In addition, the time required to pass on information to the relevant stakeholders and the dissemination of actions to curb the disruption may impact resilience abilities. Take, for instance, the case of the Serious Shortages Protocol (SSP) in the UK (PSNC, 2019). The SSP facilitates a collaborative decision process to curb the impact of medicine shortages. It is cumbersome as the inputs required from several SC actors may be time-consuming. Thus, before deciding on how to handle a shortage jointly, there may have been whispers of the impending shortage. These whispers might lead to panic buying by SC actors. Hence, for joint decision-making to effectively mitigate the impact of medicine shortages, it has to be timely (Ponomarov and Holcomb, 2009; Tukamuhabwa et al., 2017; Hendry et al., 2019).

Similarly, the findings identified proactive strategies as a necessary resilience capability for curbing medicine shortages. It involved forming strategic alliances with PSC actors before the disruption. These formed strategic alliances included sharing tangible and intangible resources. It facilitated information sharing, increased trust, enhanced goal alignment, and satisfaction with partners, which helped curb the impact of medicine shortages. The hypothesised link (*H3a and H3b)* of a positive influence of strategic alliances on opportunistic behaviours and partnership satisfaction was rejected ($\beta$ =0.124, $p$ =0.422; $\beta$ =-0.148, $p$ = 0.433). It implies that strategic alliances mitigate medicine shortages and do not increase opportunistic behaviours and partner dissatisfaction. These findings contradict the studies by He et al. (2021), who suggest possible adverse outcomes when strategic alliances are employed in complex situations. It demonstrates the benefits associated with strategic partnerships in building PSC resilience and tackling medicine shortages. These findings corroborate a prior study by Min (2015), who showed that strategic alliances based on joint decisions helped firms achieve agreed goals, share resources, information, profits, knowledge, and risks.

Also, the results showed that pharmaceutical product design influenced the resilience strategies adopted to tackle medicine shortages. It follows the argument that the resilience strategies adopted in managing disruptions are limited due to the nature of pharmaceutical products (Vann Yaroson et al., 2021). Therefore, more efforts should be considered when designing pharmaceutical products to ensure resilience. These include developing and using blockbuster technologies to manufacture pharmaceuticals, such as 3D and additive manufacturing. These can reduce lead time and be more cost-effective.

A closer scrutiny of the analysed data showed that, in most cases, PSC resilience resulted from SC actors' interactions and decision-making processes in response to medicine shortages. These interactions suggest developing resilience strategies systemically (throughout the supply chain) and not in parts (individual firms) (Sa et al., 2019; Vann Yaroson et al., 2021). Also, the decision of a PSC actor to build resilience strategies in response to disruption could result in further exposure of the PSC to the impact of disruption. These responses to decisions by PSC actors are influenced mainly by the PSC's complex production process and stringent regulations.

### 5.1.Theoretical implications

Theoretically, this research extends the literature on medicine shortages and SC resilience. First, it provides empirical evidence of resilience strategies' contribution to mitigating medicine shortages' impact. The findings also strengthen the arguments for the presence of reactive and proactive resilience strategies as complex adaptive systems. Similarly, some reactive strategies, such as flexibility, were temporary solutions with little long-term resilience-building capacity. In particular, the study highlights the detrimental effect building resilience strategies could sometimes have on the PSC. For instance, joint decision-making as a reactive strategy led to uncertain behaviours, which had detrimental impact on the PSC. The findings thus extend PSC resilience literature by highlighting the benefits and detriments of building resilience strategies when mitigating medicine shortages.

Secondly, this study advocates for structural rather than volume or supplier flexibility in tackling medicine shortages. Structural flexibility includes being prepared to share assets such as factories, distribution centres and transportation with other companies to create economies of scale. Also, developing flexible labour arrangements with little or no penalty will increase structural flexibility and help meet demand swings at every given time.

Thirdly, the findings also extend the debate on strategic alliances in building SC resilience to show its ability to tackle monopolistic behaviours, especially in complex SC settings.

Finally, this research offers a methodological contribution to SC resilience literature by adopting a mixed methods approach to investigate the complex relationship between resilience strategies and medicine shortages mitigation. Due to the lack of literature, this study provides empirical evidence through a mixed methods approach in SC resilience literature.

### 5.2. Practical implications

Regarding practical implications, the findings highlighted the importance of reactive and proactive strategies in building the UK's PSC resilience to medicine shortages. The complexities and added costs of employing reactive strategies make this a short-term endeavour. It implies that in mitigating medicine shortages, proactive dimensions are critical. In this respect, managers and PSC actors should build proactive capacities and dedicate resources to sustaining them. For instance, integrating IT systems across PSC actors would facilitate information sharing and increase the alertness of impending threats and transparency of stock levels. As such, it would help reduce behavioural uncertainty and partner dissatisfaction. Business analytics tools such as big data and artificial intelligence can predict disruptions and the outcomes of decision-making processes. These tools can also prescribe techniques necessary for increasing resilience strategies. However, SC actors' willingness to develop and implement this information technology is critical to its success.

The findings also suggest that when tackling medicine shortages, managers and decision-makers are strongly advised to manage firms' resources in ways that support partner satisfaction. It is particularly critical in relational transactions to mitigate behavioural uncertainty and partner dissatisfaction incidences. Specifically, a more systematic and formal way of strategic alliances should be adopted to check monopolistic behaviours and facilitate trust, commitment, and collaborative practices. The findings demonstrate the importance of managers and decision-makers in building PSC resilience. Thus, in tackling medicine shortages, PSC actors, including managers, directors, and VPs, need to consider how adopted resilience impacts PSC resilience. To this effect, the impact of decisions should be appraised through decision models that permit the examination of actions' impact on underlying PSC features. Also, a centralised information broker should be set up to help information sharing among PSC actors. The broker's role should be to analyse the actions and decisions of PSC actors and prompt information disbursement. For instance, when manufacturers make decisions to use flexible operations in tackling medicine shortages, the centralised broker should analyse the impact of this decision on patient safety and make recommendations. Also, when regulatory bodies develop regulations, the centralised broker could analyse these regulations by forecasting the impending impact on medicine flow. They also offer necessary steps to ensure it does not disrupt the medicine flow. It can be achieved by circulating informative materials about the consequences of their actions. It will also serve as a form of checking and balance of the excesses of actors in the PSC.

## 6. Concluding remarks, limitations and opportunities for further research

### 6.1.Conclusion

This study investigated the contributions and effect of resilience strategies in mitigating medicine shortages in the UK's PSC. It adopted a mixed-method research design. Data were generated using semi-structured interviews and questionnaires from 23 and 106 SC actors. The findings addressed the two main research questions posed at the beginning of this study. First, reactive and proactive strategies were identified as significant resilience strategies used in mitigating the impact of medicine shortages. Secondly, these strategies produced mixed outcomes in the PSC. For instance, when flexible operations were used to increase the medicine supply, PSC resilience was temporarily increased. However, it propelled partner dissatisfaction.

In the same way, joint decision-making among SC actors enhanced information sharing. It also fostered behavioural uncertainty, such as panic buying. This study contributes to PSC resilience research by (i) providing empirical evidence on the forms of resilience strategies used to mitigate dynamic disruptions such as medicine shortages' impact and (ii) highlighting how these strategies impact the PSC.

### 6.2. Limitations and opportunities for future research

This study, like most other studies, has its limitations. These limitations, however, paradoxically present opportunities for future research. For instance, this study focused on the relationship between resilience and medicine shortages' impact, with a particular focus on the UK PSC, which may be limiting. Future studies should replicate our study while considering different PSCs to highlight patterns that may have been overlooked.

Further, the data collected in this study was for a fixed period. A longitudinal study examining PSC resilience over several disruptive activities may provide in-depth insight into PSC resilience. This study is also limited as there was no consideration for various medicine classifications. It would be desirable if the study were extended to focus on medicines like biosimilars or vaccines to understand the outcomes of resilience strategies when disruptions happen.

Finally, although data for this study were collected from PSC actors at various levels, the focus was on manufacturers, wholesalers, pharmacists and regulatory bodies. Future research should consider other PSC actors, including packaging, pricing, logistic service providers, and warehousing. This study's approach may be constrained as it failed to capture the interrelatedness and complexity of the PSC.

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