Managing Emergency Situations with Lean and Advanced Manufacturing Technologies: An Empirical Study on the Rumbia Typhoon Disaster

Abstract

Purpose – This study examines the impact of lean manufacturing (LM) on the financial performance of companies affected by emergency situations. It additionally explores the role of advanced manufacturing technologies (AMTs) in complementing LM to enhance financial performance in emergency and non-emergency situations.

Design/methodology/approach – Both survey and archival data were collected from 219 manufacturing companies in China. With longitudinal data collected before and after an emergency situation (i.e., Typhoon Rumbia), regression analysis was conducted to investigate the effects of LM and AMTs on financial performance in different contexts.

Findings – Our results reveal an inverted U-shaped relationship between LM and financial performance in the context of emergency. We also found AMTs exerted a positive moderation effect on the inverted U-shaped relationship, indicating high levels of AMTs mitigated the inefficiency of LM in coping with supply chain emergency.

Originality – This study illuminates how AMTs support LM practices in facilitating organizational performance in different contexts. Specifically, this study unravels the interaction mechanisms between AMTs and LM in influencing financial performance in emergency and non-emergency situations.

Research implications – Through simultaneous investigation of LM and AMTs as bundles of practices and their fit with different contexts, this study takes a systems approach to fit that advances the application of contingency theory in the Operations Management literature to more complex patterns of fit.

Keywords: lean manufacturing, advanced manufacturing technologies, supply chain disruption, emergency, financial performance

Article classification: Research paper

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1. Introduction

The COVID-19 pandemic has significantly highlighted the vulnerability of the global supply chain in the face of worldwide catastrophe. It is the culmination of emergency situations more frequently induced by climate hazards related to floods, heat waves, and storms, all of which have risen almost 35% since the 1990s (IFRC, 2020). Such emergency situations have proven detrimental to manufacturing operations due to the disruptions in supply chain caused by closed ports, cancelled cargo flights, and postponed deliveries (Macdonald and Corsi, 2013). To cope with these unexpected events, an increasing number of studies have highlighted the importance of developing resilient operations by building buffers in stock, equipment, and labor (Papadopoulos *et al.*, 2017). However, such endeavors contradict the central tenet of lean manufacturing (LM) to minimize buffers (Shah and Ward, 2003; Fullerton *et al.*, 2014). Companies adopting LM practices must thus contend with the tension between prioritizing cost-efficiency and emergency-readiness (Pettit *et al.*, 2019).

Originally derived from Toyota's operating model in the 1950s, LM has been widely implemented by manufacturers across various industries in today's highly competitive and volatile market environment (Primo *et al.*, 2020). It aims to continuously reduce non-value-added activities and eliminate waste by streamlining operational processes (Yang *et al.*, 2011; Vinodh and Joy, 2012). As LM practices (e.g., small lot sizes and short lead times) align well with the current market need for diversified and on-demand products, substantial profits have been made through their use (Fullerton and Wempe, 2009). Companies' financial performances can be improved via waste elimination initiatives, such as reducing inventory and shortening set-up times (Shah and Ward, 2003; Shah and Ward, 2007).

Although LM has been touted as a set of universal best practices for superior performance (Sousa and Voss, 2008), more than 60% of studies have reported its mixed or insignificant impact on financial performance (Camacho-Miñano *et al.*, 2013). The inconclusive relationship between LM and financial performance could thus mainly be attributed to LM's dependence on context (Sousa and Voss, 2008; Azadegan *et al.*, 2013). There is an increasing awareness in the literature that attaining LM's purported benefits often requires the support of a stable external environment free of emergency situations (Doolen and Hacker, 2005; Cox *et al.*, 2007; Azadegan *et al.*, 2013). When the external environment is disrupted by an emergency, LM may not be effective in addressing increased environmental uncertainty and dynamism.

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Due to the elimination of waste, then, scholars have claimed there will be less organizational slack, which has been widely considered an important resource in coping with external uncertainty (Saurin, 2017). Without adequate organizational slack as a buffer, firms may be more likely to suffer from a lack of stock in emergencies. Natural disasters may severely interrupt the flow of goods and ultimately lead to a critical shortage of key materials, which disrupts production processes, delays product delivery (Christopher, 2005), and suppresses financial performance through the reduction of sales and increased costs. The 2011 earthquake and tsunami in Japan is a prime example of how LM created excessive supply chain disruptions and financial loss in an emergency situation (Carey *et al.*, 2011). The inappropriate implementation of LM has been claimed as a bottleneck in this case that increased the cost of re-designing manufacturing processes and organizational structures to be more responsive to external shocks (Ghobakhloo and Hong, 2014). Given LM's potential risks in emergency situations, there is a dearth of research on the relationship between LM and financial performance. This study addresses this gap with the following research question:

RQ1. *How do LM practices influence companies' financial performance in emergency situations?*

Although emergency situations have revealed weaknesses in contemporary lean supply chains, they have also presented valuable opportunities for companies to re-evaluate and re-position their processes and capabilities to better cope with future emergencies and ensure long-term survival. The key driver of change is the implementation of advanced manufacturing technologies (AMTs) to support and complement lean processes (Buer *et al.*, 2018; Buer *et al.*, 2020). By providing accurate and timely operations information and facilitating the synchronization of production processes, AMTs (e.g., computer–aided manufacturing, manufacturing resource planning, and big data analytics) can help realize the potential of LM practices as well as determine LM inefficiencies in turbulent environments (Fosso Wamba and Mishra, 2017; Buer *et al.*, 2018; Fosso Wamba *et al.*, 2020). The importance of AMTs has particularly attracted attention from researchers who have documented AMTs' facilitation of LM efficiency (Powell, 2013; Kolberg and Zühlke, 2015; Tortorella and Fettermann, 2018).

Yet, despite the purported benefits of AMTs, such as real-time data access and process synchronization (Fosso Wamba *et al.*, 2020), these benefits have been insufficiently adopted or under-utilized in manufacturing environments. It was reported, for instance, that only 17%

of manufacturers implemented AMTs to support key production functions, while more than 50% of manufacturers had not yet adopted AMTs (Peters, 2019). The main reason for this has been a marked lack of understanding regarding AMT mechanisms, especially the knowledge gap in AMTs' role in enhancing LM in different contexts. Given the significant investment and complexity of implementation, leveraging AMTs to support LM practices should be conducted with caution, as highlighted by the diverging moderating effects of Industry 4.0 on the effectuation of LM practices (Tortorella *et al.*, 2019). Buer *et al.* (2020) have further advocated that, "*[f]uture research should continue to investigate how technology affects lean organizations and how lean implementation frameworks are affected*" (p.13)." Accordingly, this study addresses the following research question:

RQ2. *How do AMTs moderate the relationship between LM practices and financial performance?*

To answer these questions, this study draws on contingency theory (CT) to investigate the effects of LM and AMTs on the financial performance of manufacturers who were both affected and unaffected by an emergency (i.e., Typhoon Rumbia). Longitudinal data was collected from a sample pool of 1,200 manufacturing firms in 16 cities located in the Anhui province of China. Data were collected before and after the catastrophic typhoon of August 2018 that affected nine of the 16 cities. The first wave of data collection took place in November 2016 via a questionnaire survey that measured LM practices, AMTs, and demographic variables. In the second round, archival data was collected on financial performance after the typhoon in March 2019. After matching and screening, the data of 219 firms were analyzed, 114 firms of which were affected by the typhoon and 105 firms of which were unaffected. Our analytical results indicate an inverted U-shaped relationship between LM and financial performance under emergency conditions, which suggests high levels of LM might be detrimental to financial performance in emergency situations. The results also highlight the importance of AMTs, which reveals their different mechanisms in complementing LM in emergency and non-emergency contexts.

2. Contingency Theory

Literature in operations management (OM) has increasingly highlighted the importance of contextual factors in investigating OM practices and their associated performance outcomes

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(Ketokivi, 2006; Sousa and Voss, 2008; Tortorella *et al.*, 2018). It has specifically been suggested that OM practices are context-dependent and that studies applying a "universal view" without consideration of contextual factors may lead to incomplete or biased understandings of the relationships between organizational performance and OM practices. To advance current knowledge on the value of LM and AMTs, it is imperative to adopt a contingency approach to analyzing these practices in different environmental contexts (Azadegan *et al.*, 2013). CT contends that a fit between organizational practices and contextual factors will result in high performance (Donaldson, 2001). Given this, CT also contends that an emergency (e.g., a natural disaster) will result in a misfit due to changes in contingencies, which can motivate organizations to reshape the practices of LM and AMTs to fit the new contingencies to avoid the loss of organizational performance (Donaldson, 2001).

Studies applying CT generally involve three types of variables: (1) contingency variables, or the situational factors exogenous to a focal organization; (2) response variables, or an organization's actions and strategies in response to contingencies like LM practices; and (3) performance variables, which reflect the level of effectiveness derived from the fit between contingency and response variables (Donaldson, 2001). Past studies adopting a contingency approach have investigated the effects of various contingency factors on the relationship between LM and performance (Azadegan *et al.*, 2013). However, most studies have concentrated on the effects of internal contingency factors, such as plant age, firm size, product type, and technology adoption (e.g., Shah and Ward, 2003; Bonavia and Marin, 2006; Olhager and Prajogo, 2012; Tortorella and Fettermann, 2018). Seldom have external contingency factors (e.g., uncertainty and environmental dynamism) been considered in the extant literature (Azadegan *et al.*, 2013). Moreover, scholars have called for careful consideration of external contingencies when implementing LM practices to better align with external environments to create more value (Galeazzo and Furlan, 2018).

The exaggeration of the rate and volume of change in emergency situations can distort external environments and disrupt information, financial, and product flows (Pagell and Krause, 2004). Given this, the resulting increases in environmental dynamism can restrict and negatively impact LM's effectiveness because they diminish the organizational slack necessary for coping with uncertainties (Azadegan *et al.*, 2013; Saurin, 2017). Several studies have confirmed this deficit in LM, demonstrating LM's incapability of responding to oscillating marketplace demands (Katayama and Bennett, 1996; Lewis, 2000; Kolberg and Zühlke, 2015).

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As such, scholars have advocated for the necessity of incorporating external context in investigations of LM effectuation (Cooney, 2002; Rymaszewska, 2014). To develop a granular understanding of LM's influencing mechanism, a contingency approach must be applied to analyzing and comparing the effects of LM for companies that are affected and unaffected by emergency situations.

In particular, this study adopts a systems approach to fit, which enables consideration of bundles of OM practices and their fit with contingencies (Drazin and Van de Ven, 1985). This approach treats fit as the internal consistency of multiple response variables and contingencies that jointly affect organizational performance (Miller, 1981; Sousa and Voss, 2008; Flynn *et al.*, 2010). Scholars have supported the systems approach because it can address the limitations of reductionism that collapse organizations into independent elements. This reductionist approach fails to account for the aggregated effects of the aforementioned elements in an organization system (Drazin and Van de Ven, 1985). In spite of this, few studies in OM research have applied the systems approach (Sousa and Voss, 2008). Past studies employing CT have instead focused on the relationship between a single contingency factor and a single response variable (Sousa and Voss, 2008). This has greatly constrained knowledge development on the dynamism among OM practices and their relationships with a given context. The current study expands the systems approach to fit by considering the interaction effect of LM and the implementation of AMTs under different contexts (i.e., with and without emergencies). It thereby provides a more in-depth analysis of conflicting contingencies for manufacturers that are affected and unaffected by emergencies. Our conceptual framework is depicted in Figure 1.

<Figure 1 around here>

3. Literature Review and Hypotheses Development

3.1 Effects of LM and AMTs in an Emergency

The concept of lean manufacturing (LM) is based on the Toyota Production System (TPS) that works to continuously minimize waste and maximize flow (Womack *et al.*, 1990; Vinodh and Joy, 2012). It accounts for a company's internal and external operations, including product design, manufacturing, supply chain management, customer relationship management, and enterprise management (Womack *et al.*, 1990). Lamming (1993) has further shown that LM reshapes the relationships between customers and suppliers by improving information

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exchange, joint decision-making, joint planning, quality management, and R&D. In general, LM refers to a set of practices for eliminating waste and non-value-added activities from a firm's manufacturing operations (Shah and Ward, 2007; Yang *et al.*, 2011; Fullerton *et al.*, 2014). It is a multifaceted approach made up of different bundles of practices, including standardization, manufacturing cells, reduced setup times, Kanban, one-piece flow, reduced lot sizes, reduced buffer inventories, 5S, and Kaizen (continuous improvement) (Fullerton *et al.*, 2014). To attain the goal of fulfilling customer demand with minimum waste, these practices must be implemented in a unified, coherent system that streamlines the business processes and functions of a firm (Shah and Ward, 2007; Buer *et al.*, 2020). Meanwhile, LM practices (e.g., Kanban and 5S) require firms to improve integration between physical and information flows to ensure the acquisition and transfer of real-time manufacturing information (Sullivan *et al.*, 2002).

Due to its merits of productivity and profitability, LM has been widely adopted in various industry sectors, such as the automobile and electronics industries (Primo *et al.*, 2020). In adopting LM practices, it has been found firms can enjoy a 30% to 70% increase in resource utilization through the elimination of different types of wastes (Nallusamy, 2016). Existing studies have also attested to the positive role of LM in improving financial performance by improving cost efficiency, operational processes, and labor productivity (Yang *et al.*, 2011; Fullerton *et al.*, 2014).

While the relationship between LM and organizational performance has been widely studied and empirically examined, most studies are conducted with the implicit assumption that the external environment is stable. This elides the fact that performance benefits from LM are contingent on environment and context (Jayaram *et al.*, 2010). According to CT, LM may therefore not be a universal solution for all firms in all contexts (Buer *et al.*, 2018; Kamble *et al.*, 2020). Cusumano (1994) has demonstrated that the pursuit of continuous improvement and waste elimination places pressure on suppliers and induces additional costs related to product variety, environment, and recycling. In other words, external factors beyond firms' control can negatively affect the effectiveness of LM (Cooney, 2002).

As indicated by Benders and Slomp (2009), LM is a long and arduous process that can exert positive and negative effects that are contingent upon contextual factors. Lewis (2000) has suggested firms should be more cautious when adopting LM practices by carefully considering external contingencies. While LM can generate direct performance benefits for companies in stable environments wherein environmental dynamism is low, it is not clear how the degree by which LM approaches are implemented by an organization affects firm performance in the event of a supply chain disruption or disaster. On one hand, LM activities like reduced lead times can, to some extent, enhance a firm's production flexibility in response to disruptive events. On the other hand, LM can dramatically increase supply chain vulnerability to emergencies that result from the elimination of supply chain waste. These effects can compete with each other, creating a tension that complicates the relationship between LM and firm performance. It is therefore imperative to develop a more granular understanding of the performance effects of LM in the event of emergencies. This is especially important to consider given the increasingly frequent emergency events impacting global supply chains, such as Hurricane Katrina, floods in Thailand, the earthquake and tsunami in Japan, and the recent COVID-19 pandemic. As we have seen, firms are more likely to suffer supply chain disruptions when impacted by these events.

Although LM can create significant performance benefits for companies, lower inventory and a dependence on outsourcing expose them to greater risks during supply chain disruptions. A company adopting LM practices may, for example, source materials and inputs from different suppliers in multiple countries, resulting in a supply chain that is highly sensitive to unexpected events. If such a supplier suffers operational issues and natural disasters, the flow of goods can be severely interrupted and ultimately lead to a critical shortage of key materials, which disrupts production processes, delays product delivery (Christopher, 2005), and suppresses financial performance through the reduction of sales and increased costs. The risk can be further aggregated in a LM production environment, wherein there is less organizational slack and stock for coping with external uncertainties given the minimization of inventory and suppliers (Ivanov, 2017; Saurin, 2017). Whenever a supplier defaults, inventory can easily run out and cause an immediate interruption in production processes (MacKenzie *et al.*, 2014).

Some companies implementing LM practices are inclined to outsource periphery business, leading to a high risk of supply chain disruption during emergencies (Mohammed *et al.*, 2008; König and Spinler, 2016). A typical example of this is the Ericsson crisis in 2000, in which a fire accidently hit the plant of its major chip supplier. Unable to locate alternative supply sources, it took months for Ericsson to recover its production, which ultimately resulted in a loss of around 1.68 billion dollars in its mobile phone division (Latour, 2001). The impact of

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an unexpected event can even propagate and cascade along the supply chain, creating a ripple effect that impacts global supply chains (Ivanov, 2017). For example, as the major production hubs of input materials, the 2011 earthquake and tsunami in Japan and the severe flood in Thailand crippled global electronic and automotive supply chains, causing the production suspension of many factories and significant delays in product delivery (MacKenzie *et al.*, 2014).

The above exemplifies the vulnerability and fragility of lean supply chains. Specifically, removing "waste" and simplifying a supply chain also means the absence of buffers (e.g., extra capacity and high inventory) for absorbing and dealing with unexpected interruptions (Melnyk, 2007). Without resilience, lean supply chains can be over-exposed to surprises and shocks that can severely damage organizational performance (McCann *et al.*, 2009). With an emphasis on standardization in the supply chain, LM has the potential to induce organizational rigidity because it requires adherence to fixed rules at the expense of adaptability to external changes (Fredriksson and Gadde, 2005), which can hamper a firm's adaptability to effectively respond to emergencies. For lean supply chains, this disruptive effect is not only immediate, but can also linger in the long-term because more time is required to develop resources to recover (Hendricks and Singhal, 2005). Given this, the vulnerability of lean supply chains highlights the importance of keeping the degree to which LM approaches are implemented at an appropriate level to avoid a drastic increase in risks (Jüttner, 2005). Indeed, it is important to maintain a certain level of leanness during emergencies to ensure necessary production flexibility and process efficiency. However, being too lean can create negative consequences instead of improved performance when organizations do not have extra resources for coping with external shocks. This will change the linear relationship between LM approaches and financial performance in emergency contexts such that the direct positive effect becomes negative when the degree of LM implementation exceeds a certain level, which leads to the following hypothesis:

H1. *For companies affected by emergencies, there exists an inverted U-shaped relationship between LM and financial performance, such that LM will improve financial performance at first and then impede performance after it reaches to a certain level.*

AMTs have been broadly defined as "a variety of both hard and soft technologies developed to improve manufacturing capabilities" (Chung and Swink, 2009, p.533). Scholars

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have contended that, when properly implemented, AMTs improve firms' flexibility and efficiency (Bai and Sarkis, 2017; Ghobakhloo and Azar, 2018). They contribute to low-cost, differentiation strategies (Kotha and Swamidass, 2000) by boosting manufacturing functions like product development, manufacturing process, logistics planning, and information exchange (Kotha and Swamidass, 2000). Specifically, the product development function can be improved with a product data management (PDM) system that stores and analyzes data on product development projects, product structures, documents, and quality. It assists product developers in design and refinement based on data-driven reports (Kropsu - Vehkapera *et al.*, 2009). For instance, additive manufacturing is an emerging technology that provides rapid prototyping for expediting product development cycles with high precision product details (Ahmed, 2019; Holmström *et al.*, 2019). The recent development of scalable additive manufacturing also provides the tools necessary for the fast manufacturing of serialized production volumes. This technology facilitates the implementation of LM practices by removing redundant production steps, reducing raw material usage, and enhancing customer responsiveness (Roscoe *et al.*, 2019).

In addition, the manufacturing process can be monitored and adjusted by computer-aided manufacturing (CAM) and computer-aided process planning (CAPP) that involve users in decision-making by considering their preferences in developing solutions (Xu *et al.*, 2011). Flexible manufacturing systems (FMS) similarly enhance the adaptability of manufacturing processes by providing capacity for highly varied automatically manufactured products (Candan and Yazgan, 2015). Logistics planning can also be optimized via advanced manufacturing resource planning (MRP) systems that integrate material flow with logistical information (Miclo *et al.*, 2019). In addition, AMTs play a significant role in improving information exchange functions within and across firms. Electronic data interchange (EDI) as well offers technical standards of data transfer, which enhances information flow throughout supply chains (Hill and Scudder, 2002). Moreover, advanced cloud storage and retrieval systems make it possible to collect, manage, and process large scale manufacturing and logistical data in real time (Roodbergen and Vis, 2009).

Given the above, AMTs can complement lean practices and principles to deliver better performance by enhancing efficiency and creating resilience in a supply chain. In emergency situations, AMTs can reduce hazardous impacts on lean supply chains with optimal preparedness, response, and recovery. In terms of preparedness, advanced planning and

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scheduling AMTs and early warning systems can be proactive measures for the efficient discovery and preparation for potential disruptions (Ivanov *et al.*, 2019). Through monitoring systems enabled by Internet of Things, the sharing of accurate, real-time data can boost a supply chain network and improve information visibility to expedite the identification of disruptions (Chen *et al.*, 2019). In lean supply chains, the risk and the impact of a contingency can be alleviated through detection and even forecasted in advance so companies can better implement emergency responses and recover from disruptive circumstances (Blackhurst *et al.*, 2005).

In the response and recovery stages, AMTs can facilitate resource mobilization and allocation to restore and stabilize disrupted processes and ensure the continuity of lean supply chains (Ivanov *et al.*, 2019). For example, decision support systems integrating real-time data analytics are capable of generating proactive disruption simulations of various scenarios for the development of resilient design and lean processes. With supply chain event management systems and RFID-enabled feedback control technologies, supply chain partners can more effectively and more rapidly design contingency plans and initiate mitigation activities during emergencies (Ivanov *et al.*, 2019). Therefore, AMTs can offset the potential negative impacts of high levels of LM implementation during emergencies, which leads us to the following hypothesis:

H2. *For companies affected by emergencies, the level of AMTs will moderate the inverted U-shaped relationship between LM and financial performance, such that the relationship will be less pronounced among companies with more AMTs compared to companies with less ATMs.*

3.2 Effects of LM and AMTs in Non-Emergency Situations

Extant literature has widely examined and evidenced the direct positive impact of LM on organizational performance in contexts free of supply chain disruptions (Fullerton and McWatters, 2001; Olhager and Prajogo, 2012). These positive effects can be further enhanced by implementing AMTs in the creation of supply chain synergies (Buer *et al.*, 2020). For instance, Khanchanapong *et al.* (2014) has attested the interaction effect between LM practices and AMTs in enhancing cost, quality, lead time, and performance flexibility. Rossini *et al.* (2019) found a positive correlation between technology and LM practices, indicating that a high level of technology adoption can facilitate the implementation of LM practices and vice versa. In addition, Buer *et al.* (2020) revealed the imperative role of technology in realizing the

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potential of LM practices by suggesting that the positive impact of LM practices on operational performance is contingent on the level of factory digitalization.

With low-level work-in-process inventories, LM practices rely heavily on supplier cooperation for the timely delivery of inputs and components (Moyano-Fuentes *et al.*, 2012), necessitating stability in supply of materials. Technology now enables material and logistics information exchange via synchronization during the manufacturing process (Roodbergen and Vis, 2009; Buer *et al.*, 2020). The development of AMTs thus aligns with the LM tenet that requires the seamless, real-time integration of physical and information flow (Buer *et al.*, 2018). As such, AMTs can enhance process alignment and information visibility, which facilitates closer interfirm collaborations and greater supply chain stability. Such technologies can also enable companies to better monitor suppliers for the prevention of supplier opportunism (Pu *et al.*, 2018), which can further stabilize input flow and create favorable LM conditions (Azadegan *et al.*, 2013). Moreover, web technologies and external IT systems can alleviate the drawbacks of low inventory and single supplier policies by providing easier and more efficient online access to alternative sources of supply (Moyano-Fuentes *et al.*, 2012).

Through an emphasis on early problem detection and solution development, LM is more effective in reliable, AMT-supported environments, such as production monitoring systems, sensors, and IoTs that enable the automatic discovery, analysis, and solving of abnormal signals and process failures (Oborski, 2014). LM performance can also be improved with quality control and process management systems that support the smoother synchronization of LM practices, such as Kanban, small lot sizes, and product leveling (Moyano-Fuentes *et al.*, 2012). The removal of non-value-added activities emphasizes set-up time optimization, inspection, and maintenance; processes that can be highly complex due to process interdependency. Better optimization can therefore be supported by maintenance planning and decision-making technologies (Riezebos *et al.*, 2009) in generating more value creation probabilities. Additionally, on-time delivery and lead time reductions can be further optimized with the help of smart sensors and cyber-physical systems that streamline set-up and production with incoming orders (Theorin *et al.*, 2017). In the absence of external emergencies, the additional efficiency and resilience AMTs provide LM can be easily translated into financial performance, which leads us to the following hypothesis:

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H3. *For companies unaffected by emergencies, AMTs will positively interact with LM to enhance financial performance.*

4. Methodology

Based on contingency theory, we applied a deductive approach (Forza, 2002) to examining the hypotheses. We specifically used Typhoon Rumbia to contextualize an emergency situation and collected both archival and survey data to test the proposed hypotheses.

4.1 The context of the study

The hypotheses were examined in the empirical context of the disastrous Typhoon Rumbia (ID no. 1818) that devastated China's Anhui province in August 2018.[1] The Anhui province is located in East China and is one of the country's most economically active regions. Of the 16 municipal cities in Anhui, nine were severely affected by Rumbia, disrupting the lives of 2.632 million people while causing 3.363 billion RMB in economic damage.[2] Rumbia's heavy winds, rainstorms, and flooding caused severe damage to regional infrastructures, such as power grids, roads, railways, and buildings, and firms were plunged into a state of emergency that required them to restore disrupted operations.

As this context suggests, natural disasters often result in emergencies that dramatically affect firms' economic environments. Such disasters create unexpected, localized, and exogenous distress to economic circumstances and thereby greatly affect how firms operate (Salvato *et al.*, 2020). In the setting of our study, Rumbia provided an opportunity to explore the role of LM and AMTs in mass emergencies.

4.2 Sample and data collection

Both survey and archival data were collected to examine the hypotheses. The survey data were collected in November 2016 in coordination with a local administrative agency responsible for economic development, informatization, and policy recommendations for the Anhui provincial government. The agency provided contact information for a sample pool of 1,200 manufacturing firms in 16 municipal cities. An online questionnaire was distributed to each

[1] http://www.xinhuanet.com/english/2018-08/19/c_137402426.htm
[2] http://mz.ah.gov.cn/xwzx/mzyw/114049931.html

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firm's production managers to collect information on LM, AMTs, and related controls. We received completed surveys from 219 firms, with a response rate of 18.25%.

In August 2018, Rumbia hit nine municipal cities (i.e., Bozhou, Lu'an, Anqing, Suzhou, Huaibei, Huainan, Chuzhou, Bengbu, and Ma'anshan) in the Anhui Province. Among the 219 sampled firms, 114 firms are located in these nine municipal cities. There are 105 firms located seven other municipal cities that were unaffected by Rumbia (i.e., Hefei, Xuancheng, Chizhou, Wuhu, Tongling, Fuyang, and Huangshan). Given this, archival firm data (e.g., financial performance and demographic information) were also obtained. We collected the 2017 and 2018 archival data in March 2019 by contacting the administrative agency. Based on said data, we computed firm performance and related control variables. Table I presents the demographic information of the sample.

<Table I about here>

4.3 Key variables and measures

Previously validated scales were adapted to the context of our study (Fullerton and Wempe, 2009; Fullerton *et al.*, 2014). To collect data on independent variables, we developed a questionnaire in Chinese that was then back-translated to ensure the accuracy and conceptual equivalence between the Chinese and English versions of the questionnaire (Peng and Luo, 2000). Three academic experts reviewed the questionnaire and provided feedback on the flow of the questions and the appropriateness of the measures. It was then revised and pilot tested with 30 executive MBA students. Finally, the questionnaire was minorly modified based on student feedback.

Financial performance was measured with ROA (Return on Assets) computed as the ratio of earnings before interest and taxes divided by the average total assets. ROA is a standard accounting measure of financial performance and focuses on a firm's overall performance (Xie *et al.*, 2016). In this study, a time lag was incorporated between the dependent and the independent variables.

Lean manufacturing (LM) practices refer to the extent to which a manufacturing firm implements lean manufacturing tools (Fullerton *et al.*, 2014). Eight items were adapted from

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Fullerton *et al.* (2014) to measure these practices. The items were designed to capture a firm's implementation of standardization, reduced setup time, Kanban, one-piece flow, reduced lot sizes, reduced buffer inventories, 5S, and Kaizen.

Advanced manufacturing technologies (AMTs) refer to the application of both hard and soft technologies to improving a firm's manufacturing capabilities (Chung and Swink, 2009). Eight items were adapted from Chung and Swink (2009) to measure AMTs, all of which reflected a firm's utilization of CAM, FMS, CAPP, MRP Ⅱ, PDM, EDI, rapid prototyping, and storage/retrieval systems.

Control variables. To limit the estimation bias of potential endogeneity issues from omitted variables, we controlled for nine variables that could influence firm performance. First, we controlled *prior performance* as measured by a firm's ROA in the year 2017 because firm performance is historically oriented and current performance is affected by prior performance. Second, we controlled for well recognized firm characteristics commonly employed as controls. We controlled *firm age* as the natural logarithm of the number of years since a firm's founding to 2017; *firm size* as measured by the natural logarithm of the number of employees in 2017; and *R&D intensity* computed as R&D expenses divided by sales in 2016. Third, we controlled the influence of strategic compatibility with partners and government support for firm performance. Strategic compatibility with partners (i.e., a firm's congruence in organizational goals and objectives with partners) has been shown to play a critical role in organizational performance (Rajaguru and Matanda, 2013). We thus adapted a four-item scale from Rajaguru and Matanda (2013) to measure strategic compatibility with partners. We also controlled government support as proxied by government subsidies divided by sales in 2016 (Chen *et al.*, 2018). Firms can use government subsidies to obtain governmental support, such as financial resources, political legitimacy, and favorable treatment, all of which contribute to firm performance (Chen *et al.*, 2018). Finally, we controlled for industry effects. Four industry dummy variables (shown in Table I) with other industries as the baseline were included in our model.

As measures of LM practices, AMTs and strategic compatibility consisted of multiple items that were tested for reliability and validity (see Table II). A factor analysis indicated the values of Cronbach's α were higher than 0.70, indicating good reliability of the measures. Furthermore, the values of factor loading were higher than 0.60, the values of composite reliability (CR) were higher than 0.70, and the values of AVE were higher than 0.50, indicating good convergent validity of the measures (Hair *et al.*, 2010). In addition, the square root of the AVE was greater than the value of the correlation coefficients for the perceptual variable (Fornell and Larcker, 1981), which confirmed good discriminant validity (Table III).

<Table II about here>

<Table III about here>

4.4 Common method bias and nonresponse bias

It is unlikely that common method bias was a serious concern in this study. One reason for this is that we included procedural remedies in our research design. We particularly elaborated the questionnaire to reduce item ambiguity and put conceptually adjacent variables on different pages (Podsakoff *et al.*, 2003). Second, while our key independent variable and moderator were measured with subjective data, our dependent variable was measured with objective data. Third, Harman's single factor test indicated only 24.99% of the variance in the subjective variables could be explained by one factor, which was lower than the rule-of-thumb level (i.e., 50%) (Podsakoff *et al.*, 2003). Moreover, our analysis indicated nonresponse bias is unlikely to be a concern because the results show no significant difference between the early response group (N=50 in the first 4 days) and the late response group (N=41 in the last 5 days) in terms of firm age (*t*-test: $p = 0.232$), firm size (*t*-test: $p = 0.351$), and industry type ($\chi^2(4) = 3.729$, $p = 0.444$).

5. Results

5.1 Descriptive statistics and correlation analysis

Table IV presents the means, standard deviations, minimum, and maximum values for the main variables in the full sample for firms that were affected and unaffected by the Rumbia typhoon. The results show the mean values of the main variables were nearly the same between the affected and unaffected samples.

<Table IV about here>

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The pairwise correlations between the variables in the full sample are shown in Table III. Despite the correlation coefficient between ROA and prior performance, the correlation coefficients were lower than the cutoff value of 0.6 (Hair *et al.*, 2010). A multicollinearity test was conducted and the results indicated the variables' variance inflation factors (VIF) values ranged from 1.02 to 1.83, indicating multicollinearity was not a serious concern in this study (Hair *et al.*, 2010).

Hierarchical regressions were employed to test the hypotheses. We first examined the hypotheses related to firms unaffected by Rumbia and then the hypotheses related to affected firms.

5.3 Firms affected by Rumbia

Table V shows the regression results for firms affected by Rumbia. Model 1 is a baseline model that only includes controls. The results indicated prior performance (b = 0.441, $p < 0.001$) was positively related to firm performance, whereas firm size (b = –0.025, $p < 0.01$) and strategic compatibility (b = –0.019, $p < 0.10$) had negative relationship with firm performance. Model 2 examines the potential linear relationship between LM and firm performance. However, the results showed an insignificant linear relationship between them (b = –0.006, $p > 0.10$). Model 3 shows the curvilinear relationship between LM and firm performance. The coefficient for LM was positive and significant (b = 0.360, $p < 0.05$) and its squared term was negative and significant (b = –0.047, $p < 0.01$). This confirmed H1, which posited the existence of an inverted U-shaped relationship between LM and firm performance for firms affected by natural disasters.

<Table V about here>

To further validate this inverted U-shaped relationship, we followed Lind and Mehlum (2010) to examine the turning point and slope at the minimum and maximum values of LM. The overall test of the U-shaped relationship was significant (*t*-value = 2.20, $P > |t| = 0.015$). The turning point of the inverted U-shaped relationship occurred at LM = 3.810, with a 95% Filler confidence interval of [2.869, 4.184], which was well within the data range of LM [2.375, 5.000]. The slope at the lowest LM was positive and significant (b = 0.136, $p < 0.05$), whereas that at the highest LM was negative and significant (b = −0.112, $p < 0.01$). These results provide

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strong support for the inverted U-shaped relationship between LM and firm performance. Figure 2 (a) depicts this relationship.

<Figure 2 about here>

Model 3 examines the moderating effects of AMTs on the inverted U-shaped relationship between LM and firm performance. The results indicated the coefficient for the interaction term between LM squared and AMTs was positive and significant (b = 0.027, $p < 0.05$), supporting H2. Figure 2 (b) confirms this moderation effect.

5.2 Firms unaffected by Rumbia

Table Ⅵ presents the regression results for firms unaffected by Rumbia. Model 1 is the baseline model that examined the effects of control variables on firm performance. The results showed prior performance was significantly related to firm performance (b = 1.753, $p < 0.001$). Model 2 presents the performance effect of LM. However, the results demonstrated an insignificant relationship between LM and firm performance (b = –0.012, $p > 0.10$). What's more, considering the potential curvilinear relationship between LM and firm performance, the squared term of LM was included in the model. Model 3, however, shows the coefficient of LM square was insignificant (b = 0.026, $p > 0.10$), disproving the potential curvilinear relationship between LM and firm performance.

Model 4 examines the moderating effect of AMTs on the linear relationship between LM and firm performance. According to the results, the interaction term for LM and AMTs was positive and significant (b = 0.118, $p < 0.05$), confirming H3. Figure 3 shows how low, mean, and high levels of AMTs moderated the LM-firm performance relationship[3] (Wang *et al.*, 2018). The results specifically showed the relationship between LM and firm performance was negative and significant at a low level (b = –0.184, $p < 0.05$), insignificant at a mean level (b = –0.006, $p > 0.05$), and positive and significant at a high level (b = 0.125, $p < 0.05$) of ATMs. These findings further support H3 in that the positive relationship between LM and firm performance for firms unaffected by a natural disaster was stronger when the level of AMTs was higher.

[3] The low, mean, and high values of AMTs were identified according to the minimum, mean, and maximum values of the variable, respectively.

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<Table VI about here>

<Figure 3 about here>

5.4 Robustness tests

While our sample size is adequate for firm-level empirical analysis, it is relatively small. We thus reran the model with the bootstrapping resampling method (size = 1000) to test the robustness of beta coefficients and the significance of the proposed relationships. We chose this method because bootstrapping is a viable option for small sample sizes and can estimate confidence intervals in the absence of assumptions on the distribution (Chernick, 2008). The bootstrapping analysis provided largely consistent results with our main analysis, which indicated the overall robustness of our results. These results can be provided upon request.

6. Discussion, Implications, and Limitations

6.1 Discussion

Extending prior LM literature in which research has been conducted in stable supply chain environments, this study investigates how LM practices affect supply chains' financial performance during emergencies. Using data collected from manufacturers in Anhui (China) that were both affected and unaffected by Typhoon Rumbia in 2018, this study empirically confirms the existence of an inverted U-shaped relationship between lean manufacturing and financial performance (i.e., ROA) for companies affected by emergency situations. In particular, for companies adopting a low level of LM practices, increasing said level will enhance financial performance in the case of an emergency by way of additional process efficiency and production flexibility. However, if a company adopts excessive LM practices, there will not be adequate resources or resilience to effectively address an emergency and its attendant disruptions, which will reduce or even invert the positive effect of lean manufacturing on financial performance. The results thus suggest that firms should adopt an optimal level of LM to balance the benefits and risks of lean supply chains, especially when considering the increasingly turbulent global business environment. Overall, these findings offer support to Jayaram *et al.* (2010), who have argued that the benefits of LM depend on the external environment. In addition, the non-linear relationship further advances Azadegan *et al.* (2013),

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who found the positive effect of lean operations on firm performance is undermined when the external environment is unstable and unpredictable.

Although excessive LM practices can deteriorate financial performance in an emergency, implementing AMTs can mitigate this negative impact because AMTs better equip companies to prepare for, respond to, and recover from disruptions. The findings of this study indicate a positive moderation effect of AMTs on the inverted U-shaped relationship between lean manufacturing and financial performance. More specifically, Figure 2 (b) shows that, when a firm implements a high level of AMTs, the right-hand tail of the inverted U-shaped relationship will flatten and the inflection point that turns into a downward trend starts will emerge later. This suggests that, even for companies adopting relatively greater levels of LM practices, it is unlikely financial performance will be affected by supply chain disruption if they implement high levels of ATMs.

Figure 2 (b) further illustrates the importance of AMTs by showing that companies with low levels of AMTs will experience a drastic decrease in financial performance when their LM reaches an intermediate level. This is because these companies do not have adequate complementary resources for lean supply chains to effectively address disruptions. In such cases, the inflection point emerges earlier for companies with low levels of AMTs, highlighting that, without adequate technology to manage lean processes, even a relatively lower level of LM could induce supply chain rigidity and fragility, resulting in deteriorated financial performance. This finding resonates with the assertion of the indispensable role of AMTs in developing preparedness for unexpected events (Chen *et al.*, 2019; Dubey *et al.*, 2021).

When equipped with a high level of AMTs, companies can sense and respond to external market changes rapidly and effectively, thereby ensuring the value creation of LM in emergencies. Specifically, EDI with advanced cloud storage and retrieval systems can help companies attain credible real-time information from partners by facilitating standard, real-time, and large-scale information flow within collaboration networks. Companies can thus rapidly sense external market changes and take action accordingly. With the help of AMTs, a company's response to product development, manufacturing, and distribution can be effectively implemented to respond to emergency situations. PDM systems and additive manufacturing are conducive to rapid product development for catering to customer needs induced by market change. The adapted product design can be substantialized via

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manufacturing processes empowered by various AMTs, such as CAM, CAPP, and FMS. These technologies provide rapid and adjustable manufacturing processes to fulfil changing market demand in terms of product type and volume. A firm's overall resource allocation and orchestration can be gauged by MRP, which ensures companies leveraging LM can optimize financial value in emergencies.

To further understand the interplay between LM and AMTs, this study examined their interaction effect for companies that were both affected and unaffected by a natural disaster (i.e., Typhoon Rumbia) and confirms that they positively interact to enhance a firm's financial performance. Figure 3 shows the relationship between LM and financial performance was only positive when a high level of AMT is adopted. At an average level of AMT implementation, companies' financial performance was not enhanced by the adoption of further LM practices.

Surprisingly, a negative relationship between LM and financial performance was observed for companies adopting a low level of AMTs. This could be because without adequate AMTs to coordinate and optimize lean processes, the efficiency of lean supply chains cannot exceed the costs associated with LM (e.g., maintenance, monitoring, and supplier coordination). Such cases would result in a negative impact on financial performance. This negative relationship at low levels of AMT implementation further demonstrates the risk of only adopting LM as a primary strategy. The findings on companies unaffected by emergencies confirms the indispensable role of AMTs in complementing LM to ensure superior performance goals, which extends Tortorella *et al.* (2019) and Buer *et al.* (2020)'s studies by confirming the synergies between LM practices and AMTs on supply chain performance in scenarios absent of external disruptions. It also provides a more granular understanding of AMT mechanisms by revealing the difference between emergency and non-emergency scenarios.

6.2 Theoretical Implications

This study uses the contingency theory to understand the impacts of LM and AMTs on financial performance in emergency and non-emergency contexts (i.e., manufacturers affected and unaffected by Typhoon Rumbia). The Contingency theory highlights the fit between organizational practices and contexts (Donaldson, 2001), which challenges the universal view of best OM practices and offers possible explanations for the reported difficulties in implementing best OM practices (Sousa and Voss, 2008). While the importance of contextual

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factors has been widely acknowledged in OM literature, existing studies have mainly adopted reductionist approaches to contingency theory that treat organizational practices as independent elements and limit investigation to the effect of a single contextual factor on a single organizational practice (e.g., Bonavia and Marin, 2006; Demeter and Matyusz, 2011; Azadegan *et al.*, 2013). This trend has limited the development and application of contingency theory in OM literature and constrained our understandings of the complex interactions among different OM practices, variables, and contexts.

By simultaneously investigating LM and AMTs as bundles of practices as well as their fit with different contexts, this study adopts a systems approach to fit that advances the application of contingency theory to better understanding conflicting contingencies. Specifically, this study clarifies: (1) a high level of LM and AMTs as fit in a non-emergency context; (2) the U-shaped relationship indicating a moderate level of LM; and (3) a high level of AMTs as fit in an emergency context. As such, this study answers the call for more OM studies to adopt a systems approach to fit (Sousa and Voss, 2008) and reveals the potential for employing contingency theory to understanding more complex patterns of fit.

In general, this study contributes to extant studies on three fronts. First, it extends literature on LM to emergency situations, thereby analyzing the inverted U-shaped relationship between LM and financial performance. Indeed, the benefits exerted by LM have been widely advocated by prior research (Shah and Ward, 2003; Vinodh and Joy, 2012). Yet, few scholars have considered that the costs generated by LM can be detrimental to financial performance (Fullerton and Wempe, 2009). Although recent studies have highlighted that LM can generate favorable outcomes in some situations, such as misfit with organizational culture and misalignment with strategic objective (Buer *et al.*, 2018; Negrão *et al.*, 2020), there is a dearth of research on how LM effectuates in emergency situations. In light of the recent COVID-19 pandemic, emergency situations are becoming increasingly more prevalent and important to consider. In bridging this gap, this study responds to the call of considering contexts when investigating the influence of LM on performance (Bellisario and Pavlov, 2018). Our results also reveal that LM exerts a negative effect on financial performance when it exceeds a certain level, which echoes prior concerns regarding buffer elimination and undermines manufacturing resilience (Melnyk, 2007; Fullerton *et al.*, 2014).

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Second, this study contributes to manufacturing technology literature by clarifying its role in emergency situations. Recent studies have postulated the importance of implementing technologies to support LM (Kamble *et al.*, 2020). This study extends this stream of research by scrutinizing the effectuation of AMTs in emergency situations. It was found that LM drawbacks can be overcome with a high level of AMTs, which turns the LM and financial performance relationship from an inverted U-shaped to a positive one. This finding aligns with the assertion regarding the role of technology in ensuring resilience in turbulent environments (Chen *et al.*, 2019). Advanced technologies further bring opportunities for lean manufacturers to effectively cope with emergency situations and help them achieve competitive advantages.

Third, this study sheds light on how to jointly leverage LM and AMTs to create financial value in non-emergency situations. Although some controversial findings on the relationship between LM and financial performance have been reported (Camacho-Miñano *et al.*, 2013), few studies have investigated how to deal with this situation by better leveraging LM. The current study thus addresses this gap by identifying how orchestration between LM and AMTs can generate favorable financial return. It additionally provides empirical evidence on the supporting role of technology in realizing the financial benefit of LM and contributes to the current debate on whether to invest in AMTs that are valuable but costly (Buer *et al.*, 2020). Our results also indicate investment in AMTs will pay off due to the financial benefits of well-supported LM.

6.3 Practical Implications

The findings from this study yield several practical implications. First, they highlight the importance of implementing AMTs in a lean manufacturing environment. With the wide diffusion of LM in various industries, companies are less likely to gain competitive advantage by only adopting LM. Instead, a firm’s competitiveness lies in its ability to integrate LM with AMTs to configure unique, inimitable skill sets. This not only ensures efficiency but can also alleviate operational risks. Despite the difficulty of implementing complementary AMTs in the LM process, performance gains can justify such investments.

Second, the contingency knowledge of this study can provide practitioners with guidelines for selecting the most appropriate set of LM practices and AMTs for their given contexts. For companies operating in stable environments with low possibilities of experiencing external

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disruptions, our results suggest a high level of LM implementation and AMTs for fully leveraging the performance benefits of LM. The results for emergency contexts specify a moderate level of LM and AMTs to fit with unstable external environments. This offers practical insights on how manufacturers can respond to the increasingly volatile global business environment, wherein there is a rising frequency of political instability, economic turbulence and natural disasters.

However, due to intensive competition, most companies have focused on maximizing profits by minimizing "wastes" in the production process, resulting in highly lean supply chains that are extremely vulnerable to external shocks. The U-shaped relationship between LM and financial performance in emergencies further show that a high level of leanness is a deviation from fit in emergency contexts, which may lead to inferior performance. For companies with major partners in areas subject to frequent natural disasters as well as political and economic turmoil, our study suggests carefully evaluating current and future plans for implementing LM to avoid misfit with their specific contexts. We advise that, in unstable environments, manufacturers restrain the degree of LM implementation to an optimal level to attain superior performance goals. In addition, this study highlights the importance of AMTs, demonstrating their power in alleviating LM vulnerabilities in external disruptions.

6.4 Limitations

This study has three limitations that provide important opportunities for future research. First, as this study was based on Typhoon Rumbia, it may partially limit the external validity of the findings to other emergency situations, such as disease outbreaks (e.g., COVID-19), terrorism, and climate changes. The threat of these emergencies to firm operations can differ significantly according to the sphere and severity of their impacts. Future studies should thus extend this research to other emergency situations to provide a more nuanced understanding of how firms deploy advanced technologies in differential emergencies. Second, our measures of LM and AMTs were operationalized via a single respondent survey. Although this method has been widely used in existing studies, collecting secondary data on the implementation of LM and the usage of AMTs may enhance the richness of data. Third, while archival data was collected to measure a firm's overall financial performance, we were unable to obtain data on firms' monetary damages and losses caused by Rumbia. Future research should evaluate the financial

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loss caused by emergencies and examine the effect of LM and AMTs in buffering the damage of such emergencies.

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Table I. Profile of firms and respondents

	Full sample (N=219)	Affected (114)	Unaffected (105)
	Obs (%)	Obs (%)	Obs (%)
Firm characteristics			
Firm age (years)			
<5	3 (1.37%)	1(0.88%)	2(1.9%)
5–9	66 (30.14%)	33(28.95%)	33(31.43%)
10–14	80 (36.53%)	45(39.47%)	35(33.33%)
15–19	50 (22.83%)	27(23.68%)	23(21.9%)
>=20	20 (9.13%)	8(7.02%)	12(11.43%)
Employee numbers			
<50	18 (8.22%)	8(7.02%)	10(9.52%)
50–99	59 (26.94%)	30(26.32%)	29(27.62%)
100–199	70 (31.96%)	43(37.72%)	27(25.71%)
200–299	32 (14.61%)	15(13.16%)	17(16.19%)
>=300	40 (18.26%)	18(15.79%)	22(20.95%)
Industry type			
Consumer products	44 (20.09%)	25(21.93%)	19(18.1%)
Petroleum and chemical	55 (25.11%)	32(28.07%)	23(21.9%)
Machinery	56 (25.57%)	30(26.32%)	26(24.76%)
Electronics	47(21.46%)	19(16.67%)	28(26.67%)
Others	17(7.76%)	8(7.02%)	9(8.57%)
Production manager characteristics			
Gender			
Male	202(92.24%)	103(90.35%)	99(94.29%)
Female	17(7.76%)	11(9.65%)	6(5.71%)
Age (years)			
<30	8 (3.65%)	4(3.51%)	4(3.81%)
30–39	62 (28.31%)	33(28.95%)	29(27.62%)
40–59	88 (40.18%)	49(42.98%)	39(37.14%)
>60	37 (16.89%)	17(14.91%)	20(19.05%)
Missing	24 (10.96%)	11(9.65%)	13(12.38%)
Education			
High school or lower	6 (2.74%)	4(3.51%)	2(1.9%)
College and bachelor	197(89.95%)	102(89.47%)	95(90.48%)
Graduate degree	16 (7.31%)	8(7.02%)	8(7.62%)
Employment at the current firm (years)			
<3	12(5.48%)	4(3.51%)	8(7.62%)
3–7	82(37.44%)	45(39.47%)	37(35.24%)
8–14	63(28.77%)	32(28.07%)	31(29.52%)
>15	37 (16.89%)	21(18.42%)	16(15.24%)
Missing	25 (11.42%)	12(10.53%)	13(12.38%)

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Table II. Measurement items

Construct/items	Factor loadings
Lean Manufacturing (LM) Practices:	
Cronbach's α = 0.897, CR=0.920, AVE=0.592	
To what extent has your firm implemented the following (five-point scale):	
1. Standardization	0.779
2. Reduced setup times	0.832
3. Kanban system	0.768
4. One-piece flow	0.684
5. Reduced lot sizes	0.766
6. Reduced buffer inventories	0.771
7. 5S	0.767
8. Kaizen (continuous improvement)	0.779
Advanced Manufacturing Technologies (AMTs):	
Cronbach's α = 0.918, CR=0.934, AVE=0.638	
Comparing your firm to the standard or average in your industry, indicate the extent to which the following technology practices are used (five-point scale)	
1. Computer-aided manufacturing (CAM) technology practice	0.745
2. Flexible manufacturing systems (FMS) technology practice	0.794
3. Computer-aided process planning (CAPP) technology practices	0.801
4. Advanced MRP II systems	0.834
5. Product data management (PDM) system	0.841
6. EDI links to customers and suppliers	0.792
7. Rapid prototyping methods	0.810
8. Advanced storage/retrieval systems	0.770
Strategic Compatibility:	
Cronbach's α = 0.908, CR=0.936, AVE=0.787	
Please indicate your agreement with the following (five-point scale):	
1. Our firm's procedures are compatible with our supply chain partners' business procedures.	0.877
2. The goals and objectives of our firm are compatible with supply chain partners.	0.877
3. Managers from our firm and those of our supply chain partners have compatible approaches in business dealings.	0.906
4. Our firm's business procedures are compatible with supply chain partner's skills.	0.887

Table Ⅲ. Descriptive statistics

	Full sample (N = 219)				Affected by Rumbia (N = 114)				Unaffected by Rumbia (N = 105)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Financial performance	0.092	0.108	–0.085	0.745	0.093	0.089	–0.078	0.439	0.091	0.125	–0.085	0.745
LM	3.990	0.501	2.375	5.000	3.988	0.548	2.375	5.000	3.992	0.448	3.000	5.000
AMT	3.230	0.705	1.000	5.000	3.200	0.839	1.000	5.000	3.263	0.524	1.750	4.375
Prior performance	0.107	0.111	–0.059	0.637	0.106	0.105	–0.041	0.438	0.109	0.118	–0.059	0.637
Firm age	2.526	0.396	1.099	3.664	2.525	0.379	1.099	3.526	2.527	0.416	1.609	3.664
Firm size	4.983	0.852	3.045	7.272	4.973	0.844	3.258	7.272	4.994	0.866	3.045	6.934
R&D intensity	0.041	0.066	0.000	0.700	0.041	0.048	0.000	0.257	0.042	0.082	0.000	0.700
Strategic compatibility	3.897	0.596	2.000	5.000	3.906	0.649	2.250	5.000	3.888	0.536	2.000	5.000
Government support	0.010	0.020	0.000	0.152	0.009	0.019	0.000	0.097	0.011	0.020	0.000	0.152

Note: Industry types are dummy variables and are not included in the descriptive analysis.

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Table Ⅳ. Correlation matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) Financial performance	1.000														
(2) LM	–0.160	1.000													
(3) AMT	–0.128	0.520	1.000												
(4) Prior performance	0.610	–0.084	–0.026	1.000											
(5) Firm age	–0.077	–0.124	–0.161	–0.121	1.000										
(6) Firm size	–0.149	0.024	0.082	0.006	0.174	1.000									
(7) R&D intensity	–0.042	0.157	0.045	–0.106	–0.010	–0.002	1.000								
(8) Strategic compatibility	–0.093	0.562	0.361	–0.025	0.013	–0.030	0.113	1.000							
(9) Government support	–0.019	–0.012	–0.032	0.014	0.022	0.114	0.066	–0.062	1.000						
(10) Mineral and others	0.037	0.113	0.084	0.124	–0.193	0.075	0.021	0.100	–0.050	1.000					
(11) Consumer products	–0.000	–0.078	0.035	0.031	–0.107	0.039	–0.126	–0.091	–0.018	–0.145	1.000				
(12) Petroleum and chemic	0.139	–0.093	–0.219	0.037	0.158	–0.107	–0.042	–0.099	–0.028	–0.168	–0.290	1.000			
(13) Machinery	–0.091	0.051	0.141	–0.083	0.043	0.011	0.096	0.062	–0.086	–0.170	–0.294	–0.339	1.000		
(14) Electronics	–0.075	0.047	–0.007	–0.063	0.017	0.014	0.052	0.062	0.171	–0.152	–0.262	–0.303	–0.306	1.000	
(15) Affected by Rumbia	0.009	–0.004	–0.045	–0.012	–0.003	–0.012	–0.009	0.015	–0.050	–0.029	0.048	0.071	0.018	–0.122	1.000
Square root of AVE	-	0.769	0.799	-	-	-	-	0.887	-	-	-	-	-	-	-

Note: Correlation coefficients with a magnitude greater than 0.139 are significant at the 0.05 level.

Table V. Results of firms affected by Rumbia

	Model 1	Model 2	Model 3	Model 4
LM		–0.015	0.360*	1.178***
		[0.019]	[0.146]	[0.321]
AMT		–0.006	–0.009	0.246
		[0.013]	[0.012]	[0.215]
LM^2			**–0.047****	–0.166***
			[0.018]	[0.046]
LM*AMT				–0.176†
				[0.100]
$LM^{2*}AMT$				**0.027***
				[0.012]
Prior performance	0.441***	0.438***	0.431***	0.451***
	[0.078]	[0.078]	[0.077]	[0.073]
Firm age	0.001	–0.004	–0.007	–0.013
	[0.028]	[0.027]	[0.027]	[0.026]
Firm size	–0.025**	–0.024*	–0.023*	–0.024*
	[0.009]	[0.009]	[0.009]	[0.009]
RD intensity	0.288	0.302	0.357†	0.323†
	[0.209]	[0.200]	[0.187]	[0.188]
Strategic Compatibility	–0.019†	–0.007	–0.002	0.000
	[0.011]	[0.012]	[0.012]	[0.012]
Government support	0.017	0.016	–0.009	–0.022
	[0.210]	[0.209]	[0.235]	[0.245]
Consumer products	–0.016	–0.021	–0.034	–0.035
	[0.037]	[0.036]	[0.035]	[0.034]
Petroleum and chemical	–0.008	–0.013	–0.017	–0.019
	[0.041]	[0.041]	[0.039]	[0.038]
Machinery	–0.005	–0.009	–0.019	–0.017
	[0.039]	[0.039]	[0.037]	[0.036]
Electronics	–0.010	–0.015	–0.031	–0.031
	[0.040]	[0.039]	[0.038]	[0.038]
Constant	0.244**	0.283**	–0.446	–1.746**
	[0.089]	[0.104]	[0.280]	[0.522]
R^2	0.339	0.347	0.391	0.427
Adjusted R^2	0.274	0.270	0.312	0.340
F value	4.634	3.754	4.593	4.678

*Note: N=114; † p < 0.10; * p < 0.05; ** p < 0.01; *** p < 0.001; Robust standard errors in bracket*

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Table Ⅵ. Results of firms unaffected by Rumbia

	(1)	(2)	(3)	(4)
LM		–0.012	–0.227	–0.390*
		[0.030]	[0.342]	[0.182]
AMT		0.004	0.006	–0.470*
		[0.019]	[0.018]	[0.222]
LM*AMT				**0.118***
				[0.054]
LM^2			0.026	
			[0.039]	
Prior performance	0.753***	0.746***	0.742***	0.748***
	[0.194]	[0.196]	[0.196]	[0.186]
Firm age	0.016	0.014	0.013	0.007
	[0.024]	[0.024]	[0.024]	[0.023]
Firm size	–0.006	–0.007	–0.008	–0.005
	[0.013]	[0.012]	[0.012]	[0.013]
RD intensity	–0.017	–0.010	–0.030	–0.059
	[0.061]	[0.061]	[0.065]	[0.081]
Strategic compatibility	–0.009	–0.005	–0.006	0.005
	[0.018]	[0.024]	[0.024]	[0.025]
Government support	–0.323	–0.319	–0.274	–0.305
	[0.335]	[0.340]	[0.336]	[0.333]
Consumer products	0.003	0.002	–0.002	0.010
	[0.025]	[0.026]	[0.028]	[0.026]
Petroleum and chemical	0.044†	0.046†	0.041	0.042
	[0.025]	[0.027]	[0.024]	[0.026]
Machinery	–0.023	–0.023	–0.026	–0.019
	[0.023]	[0.023]	[0.023]	[0.024]
Electronics	–0.012	–0.011	–0.016	–0.009
	[0.018]	[0.018]	[0.019]	[0.020]
Constant	0.038	0.069	0.507	1.546*
	[0.106]	[0.090]	[0.700]	[0.689]
R^2	0.544	0.546	0.549	0.592
Adjusted R^2	0.496	0.486	0.484	0.534
F value	4.205	3.964	3.622	4.402

*Note: N=105; † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; Robust standard errors in bracket*

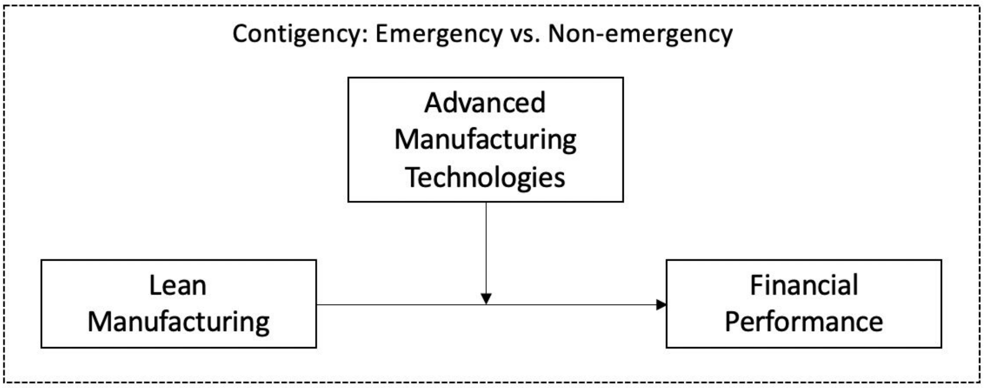

Figure 1. Conceptual Framework

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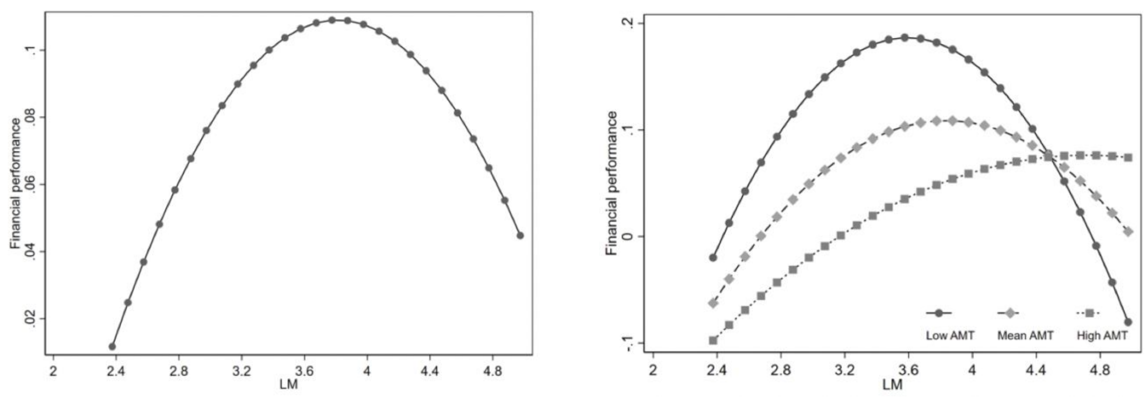

a. Inverted U-shaped relationship between LM and firm performance

b. Moderating effect of AMT

Figure 2. Effects of LM and AMT for firms affected by Rumbia

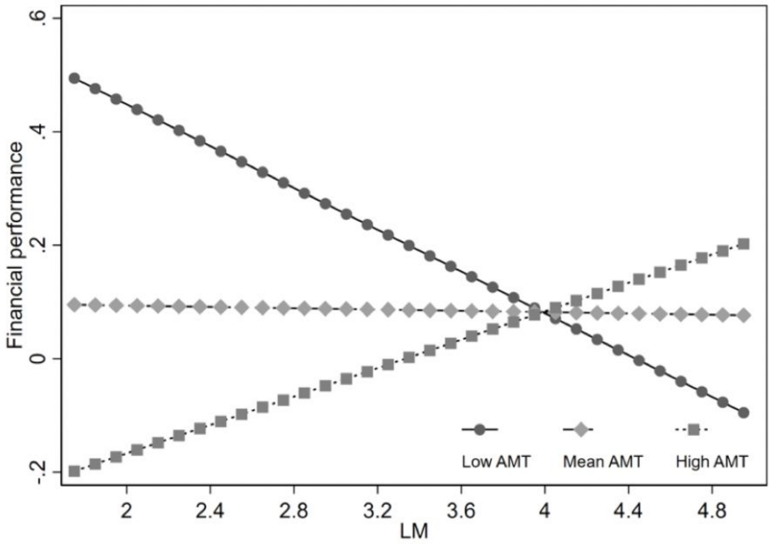

Figure 3. Moderating effect of AMT for firms unaffected by Rumbia

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