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Review Paper

Generative AI in Supply Chains: Utilising Opportunities, Managing Risks

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ABSTRACT

Global supply chains are under pressure. Generative artificial intelligence accelerates planning, improves forecasting and facilitates coordination. Companies are realising initial efficiency gains, but at the same time dependencies on platforms, data access and proprietary models are growing. The pharmaceutical industry is characterised by opportunities and risks, from which forecasts are derived. Existing regulatory fragmentation can lead to gaps in corporate governance. In addition, data sets and simulation-based approaches prove that efficiency and vulnerability indicators can be empirically measured and support the diagnosis of this work. The study develops an analytical model that captures efficiency and vulnerability in a common logic. It is conceptually and theoretically based and combines literature analyses with scenario-based stress tests. The results illustrate three mechanisms for improving performance. Information processing becomes more precise, routine decisions are relieved and coordination along complex networks is accelerated. In contrast, three areas of structural risks emerge. Platform concentration shifts power, model-related lock-ins make adaptation more difficult and governance gaps increase information asymmetries. The central diagnosis is clear. Efficiency gains without reconfigurability turn speed into fragility. In the long term, competitive advantages arise from the implementation of open architectures that enable networking between institutions.

Keywords: supply chain, operations management, resilience, resource-based view, dynamic capabilities, governance, platform power, interoperability, data portability, lock-in, stress test, Generative AI.

INTRODUCTION

Increasing digitalisation and shifting geopolitical power relations are bringing about lasting changes to global supply chains. This is altering the fundamentals of industrial value creation. Generative artificial intelligence is intensifying this change. It improves planning, increases forecasting accuracy and accelerates coordination. Initial companies are reporting significant efficiency gains, but at the same time new dependencies on platforms, data access and proprietary models are emerging. Although initial studies document efficiency gains through the use of AI in supply chains, a systematic link between efficiency and vulnerability perspectives is still lacking.

Existing work often focuses either on performance improvements such as forecasting accuracy and inventory management or on resilience and risk. An integrated analysis that maps both dimensions in a joint model has hardly been done so far. This work closes the gap by bringing together efficiency mechanisms and vulnerabilities and examining their dynamics using scenario-based stress tests. In addition, current empirical findings are taken into account. The pharmaceutical industry in particular provides valuable evidence, as studies document the use of AI in forecasting, monitoring and cold chain surveillance, but at the same time point to governance gaps and regulatory fragmentation. In addition, results from large-scale data sets and simulation-based approaches to risk assessment are incorporated, which make it possible to validate efficiency and vulnerability indicators in a measurable way.

The central research question is therefore which efficiency gains and vulnerabilities the use of generative AI in supply chains generates and under which conditions short-term productivity boosts are transformed into structural fragility. The hypothesis is that efficiency gains are only sustainable if they are flanked by reconfigurability and governance. The aim of the study is to develop an analytical model that captures efficiency and risk aspects together and thus create a basis for companies and policymakers to utilise the opportunities of Generative AI without increasing new systemic risks.

Theoretical framework

The investigation of Generative AI in global supply chains requires a theoretical foundation that takes into account both entrepreneurial resources and capabilities as well as political and social contexts. Recent interdisciplinary perspectives underline that generative conversational AI entails epistemic, ethical and institutional implications that shape governance and policy design (Dwivedi et al., 2023). Three approaches are central to this: the resource-based view, the dynamic capabilities approach and the political economy of global supply chains. Barney's (1991) resource-based view sees companies as bundles of heterogeneous resources. Competitive advantages arise when these resources are valuable, scarce, difficult to imitate and can be used organisationally. Applied to Generative AI, access to data, algorithms and computing capacities determines who can achieve efficiency gains. Large platform companies have these resources at their disposal, while smaller players run the risk of being structurally left behind. This not only shifts operational competitive advantages, but also global power asymmetries along the supply chains. Empirical findings from the pharmaceutical industry illustrate that critical data and monitoring processes in particular are central to ensuring forecast quality and cold chain security (Al-Hourani & Weraikat, 2025).

The dynamic capabilities approach by Teece et al. (1997) and Helfat and Peteraf (2003) complements this perspective. It makes it clear that resilience and the ability to survive are determined not only by resources, but also by the ability to adapt and reconfigure. In the logic of dynamic capabilities, the question arises as to whether companies can integrate generative AI in such a way that they can react flexibly to shocks. Studies on the resilience of supply chains show that adaptability and learning processes are crucial for survivability (Ivanov & Dolgui, 2020; Ivanov, 2023). However, if Generative AI is controlled too rigidly or exclusively, it loses its function as a dynamic resource and itself becomes a source of systemic vulnerability. This is particularly evident in pharmaceutical networks, as regulatory breaking points and dependencies on a few raw material sources place an additional burden on reconfigurability.

Finally, the political economy of global supply chains, as emphasised by the OECD (2021), focuses on distributional effects. It points out that economic structures do not have a neutral effect, but are embedded in institutional contexts. The monopolisation of companies that provide generative AI leads to a concentration of data sovereignty and the associated control. The consequences are monopoly profits and unequal treatment of costs and risks. This shift has consequences that go far beyond efficiency issues. It affects the state's ability to act, the stability of labour markets and the balance of power between global players. Gaps and the associated costs in the area of corporate governance can erode efficiency gains.

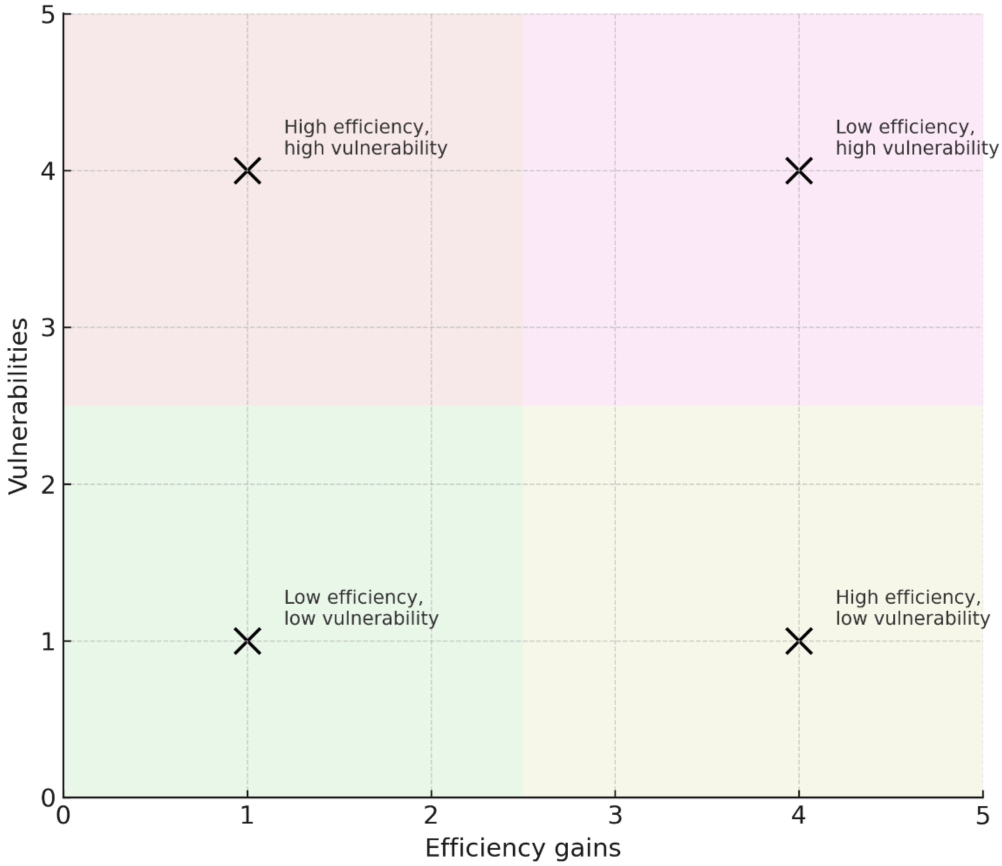

Figure 1 Efficiency-vulnerability trade-off in generative AIsupply chains.
Source: Own illustration based on Barney (1991); Teece et al. (1997); Ivanov & Dolgui (2020); Ivanov (2023); Sheffi (2023).

The interplay of these three approaches shows that Generative AI not only changes the basis of corporate strategies. It also has an impact on the systemic architecture of global supply chains. While the resource and capability logic explains who benefits, the political economy shows who bears the burdens. The theoretical challenge lies in combining both levels in order to analyse technological potentials and structural consequences in equal measure.

LITERATURE REVIEW

Research on artificial intelligence in supply chains has broadened considerably in recent years. Three strands are central to the questions posed in this paper. Firstly, the evidence on efficiency gains and performance improvements. Secondly, consideration of resilience, vulnerabilities and governance. Thirdly, the sector-specific characteristics of the automotive and pharmaceutical industries, which entail particular requirements and risks.

Efficiency and increased performance

A central expectation of the use of artificial intelligence is the improvement of forecasting capability, inventory management and operational decision-making processes. Baryannis, et al. (2019) document measurable efficiency gains in planning, transport and risk analysis in a broad overview. Brynjolfsson et al. (2023)

provide experimental evidence for significant productivity gains in knowledge-intensive tasks. Noy and Zhang (2023) show that generative processes enable efficiency gains, albeit with quality variations that need to be controlled through organisational embedding and governance. In addition, the LaDe dataset (Wu et al., 2023) industry-scale provides reference values for on-time delivery, route planning and service times and serves as a benchmark for efficiency indicators in different industries.

Resilience, vulnerabilities and governance

The insights gained from the COVID-19 pandemic have changed resilience research. Ivanov and Dolgui (2020) and Ivanov (2023) have shown in their studies that survivability and adaptability are becoming more important than pure efficiency in an organisation. Resilience therefore depends heavily on interoperability, redundancy and reconfigurability. Sheffi (2023) emphasises that platform concentration and proprietary models create lock-in effects that extend restart times and make networks more fragile. Richey, Chowdhury et al. (2023) and Wamba et al. (2023) emphasise that governance is becoming a productive factor. Without data portability, open interfaces and clear responsibilities, efficiency gains run the risk of turning into structural risks. Empirical studies such as Zhang et al. (2025) also show that generative models deliver superior results in risk assessment, particularly when it comes to identifying credit risks in supply chains. This means that vulnerability can also be measured quantitatively.

Automotive industry

With its just-in-time structures, the automotive industry is proof of interconnected global supply chains. Just-in-time and just-in-sequence processes create strong dependencies on precise planning and robust information systems. Krykavskyy et al. (2022) show that digital technologies in this sector increase transparency and efficiency, but at the same time increase complexity. Banerjee, Jain and Kumar (2024) specify the role of AI in automotive supply chain management and point to potential in inventory management and procurement. Mandala (2024) has investigated the use of generative processes in inventory management and found that the results indicate significant efficiency gains. Nevertheless, the organisation remains highly susceptible to disruptions if corporate governance requirements and interoperability are not adequately taken into account.

Pharmaceutical industry

The pharmaceutical industry is characterised by regulatory requirements, long development cycles and an increasing dependence on critical raw materials. Al-Hourani and Weraikat (2025) show in their research, using a systematic review, that AI and machine learning can increase the resilience of pharmaceutical supply chains. This is achieved through better forecasting and monitoring within the supply chain organisation. Wamba et al. (2023) document efficiency gains in demand forecasting and inventory management in their research.

In addition, the overview in the World Journal of Basic and Pharmaceutical Health Sciences (2024) emphasises that the use of AI also creates new risks, for example through dependence on proprietary platforms and governance gaps. Li, Zhang and Chen (2024) support these findings with an empirical survey of 236 companies: Generative AI improves performance when it is embedded in dynamic environments via supplier and buyer coordination. These coordination mechanisms are particularly relevant in the pharmaceutical industry, as regulatory breaking points place an additional burden on adaptability.

Common lines and differences

Although the two industries differ in some respects, they also have similarities. Improved forecasts, optimised inventory levels and faster coordination lead to increased efficiency across the board. Vulnerabilities result from platform power, proprietary models and a lack of interoperability. Network coupling and the pressure of just-in-time deliveries form critical junctions in the automotive industry. In comparison, sensitive weak points in the pharmaceutical industry are fragmented regulation and dependence on critical raw materials.

Research design and method

The research follows a qualitative-analytical multi-case study approach. This design is particularly suitable for new technologies such as Generative AI, whose effects on supply chains have not yet been conclusively empirically analysed. The approach combines the theoretical perspectives of Resource-Based View, Dynamic Capabilities and Political Economy with an explorative empirical assessment of performance gains and vulnerabilities.

Case selection and replication logic

The selection is based on a theoretical sample. Cases are selected in such a way that they exhibit contrasting conditions, such as different market roles, different types of data and platform access and diverging degrees of maturity in the embedding of AI. This increases the gain in knowledge and systematic patterns can be derived. The replication logic comprises two directions. Firstly, literal replication in cases with similar framework conditions in order to check the consistency of the results. Secondly, theoretical replication in cases with clear contrasts in order to test hypotheses about efficiency gains and vulnerabilities. The pharmaceutical industry serves as a particularly relevant test case, as empirical evidence on forecasting, monitoring and regulatory challenges is already available (Al-Hourani & Weraikat, 2025; WJBPHS, 2024).

Data collection

The study is based on two sources. Firstly, a systematic analysis of relevant literature and documents that brings together empirical findings and theoretical concepts on Generative AI in supply chains. Secondly, scenario-based stress tests that simulate external shocks and test the robustness of the findings. In addition, selected empirical studies and data sets are taken into account that make efficiency and vulnerability indicators measurable. These include the LaDe dataset with industry-scale information on last-mile efficiency (Wu et al., 2023), GAN-based simulations of credit and default risks (Zhang et al., 2025) and a survey study on generative AI utilisation and performance effects (Li et al., 2024). Interviews and key figure analyses are conceivable as future additions to further deepen the model.

Operationalisation

The efficiency perspective is made measurable with function-specific key figures. These include forecast quality, inventory turnover, on-time delivery, lead time, costs per order and productivity of knowledge-intensive tasks. The LaDe dataset provides reliable reference values for some of these indicators, particularly for on-time delivery, route planning and service times.

The vulnerability perspective captures dependencies and resilience factors. Important indicators are the concentration of providers and models, the proportion of proprietary compared to open solutions, switching barriers in contracts, data portability, technical redundancies, recovery times and the ability to reconfigure processes and models. GAN-based risk simulations allow vulnerability indicators such as recovery time or probability of failure to be quantitatively tested, while pharmaceutical evidence shows how regulatory breakpoints affect resilience.

Analysis

The analysis is carried out in three steps. First, patterns between theoretical expectations and empirically documented performance and dependency patterns are compared. This is followed by a cross-sectional case comparison in order to identify configurations that promote both efficiency and adaptability. Finally, scenario-based stress tests are carried out. Shocks and governance parameters are varied in order to test the robustness of the findings. The empirical additions LaDe as an efficiency benchmark, GANs for risk assessment and pharmaceutical evidence as a sector anchor increase the validity and provide robust indicators for the evaluation of the hypothesis.

Validity and reliability

Methodological rigour is ensured by several procedures. Construct validity is achieved through clear indicator definitions, triangulation and feedback loops. Internal validity is supported by process tracing and the testing of alternative explanations. External validity is based on analytical generalisation and not on statistical representativeness. Reliability is increased by standardised guidelines, documented coding rules and intercoder checks. The inclusion of data sets and empirical studies supports this validity by testing indicators not only theoretically but also using real-world measures.

Practical benefits

The research design delivers double added value. Companies receive manageable decision markers for make-or-buy questions, for redundancy strategies and for contract design. Politicians and regulators can derive benchmarks from this, for example for data portability, interoperability and competitive dynamics. The results are particularly relevant in the pharmaceutical sector, as regulatory breakpoints, cold chain requirements and critical raw material dependencies make it clear that efficiency gains are not sustainable without institutional safeguards.

Empirical Analysis

Efficiency and innovation potential

Generative AI opens up significant performance gains along central functions of supply chains. Three mechanisms take centre stage. Firstly, improved information processing through the integration of heterogeneous data sources, which enables more precise forecasts and more stable inventories. Secondly, the reduction of repetitive decisions, which allows specialists to focus their time on exceptions and tactical control. Thirdly, coordination gains through generative assistance in communication, which reduces throughput times and stabilises planning processes.

Empirical evidence confirms these mechanisms. Baryannis et al. (2019) document efficiency gains in planning and risk analysis. In their research, Noy and Zhang (2023) report productivity gains in knowledge-intensive tasks, albeit with differences in quality. Brynjolfsson et al. (2023) show that generative AI accelerates decision-making processes and increases efficiency. In addition, the LaDe dataset (Wu et al., 2023) provides large-scale benchmarks: 10.7 million deliveries by 21,000 couriers enable the calculation of punctuality and completeness rates, route lengths and service times. The resulting reference values clearly show that efficiency gains in complex supply chains are measurable and can also be compared across industries. In the automotive industry, Banerjee, Jain and Kumar (2024) show that AI improves planning quality and inventory management. Mandala (2024) illustrates that generative AI in inventory management reduces bottlenecks and optimises inventory turnover rates. Krykavskyy et al. (2022) describe the digital transformation pressure that enables efficiency gains but also increases network vulnerability. In the pharmaceutical industry, Wamba et al. (2023) document improvements in forecasting and monitoring. Al-Hourani and Weraikat (2025) and the World Journal of Basic and Pharmaceutical Health Sciences (2024) show that resilience strategies can be strengthened, but that new dependencies arise at the same time. Li, Zhang and Chen (2024) provide additional evidence: in a survey of 236 companies, the depth of use of generative AI increases performance, mediated via supplier and buyer coordination, and is particularly effective in dynamic environments. This is relevant for the pharmaceutical industry, as regulatory fragmentation puts a strain on adaptability and coordinative mechanisms determine success or failure. New dependencies and vulnerabilities

In addition to the efficiency gains, new risks are emerging. Four mechanisms are central. Firstly, platform concentration: those who control data and models are shifting the balance of power in their favour. Secondly, model-related lock-ins that make switching and reconfiguration more difficult. Thirdly, governance gaps that prevent transparency and traceability. Fourthly, geopolitical fault lines that make it difficult to build redundant structures across jurisdictions. These vulnerabilities are well anchored in theory. Ivanov and Dolgui (2020) and Ivanov (2023) show that a lack of reconfigurability makes supply chains unstable. Sheffi (2023) illustrates how platform power accumulates risks. Richey et al, (2023) and Wamba et al, (2023) show that governance becomes a productive factor. Empirical evidence complements these findings: Zhang et al. (2025) use a GAN-based approach to demonstrate that credit and default risks in supply chains can be predicted more precisely. In industries such as pharmaceutical distribution, this method allows stress scenarios to be realistically simulated and recovery indicators such as mean time to recover to be quantified.

Vulnerabilities vary depending on the industry. In the automotive industry, just-in-time supply chains can mean that even minor disruptions trigger chain reactions in industrial value creation. In contrast, regulatory requirements are the critical area in industrial value creation in the pharmaceutical industry. Al-Hourani and Weraikat (2025) and WJBPHS (2024) warn that without institutional safeguards, efficiency gains are quickly overshadowed by new risks.

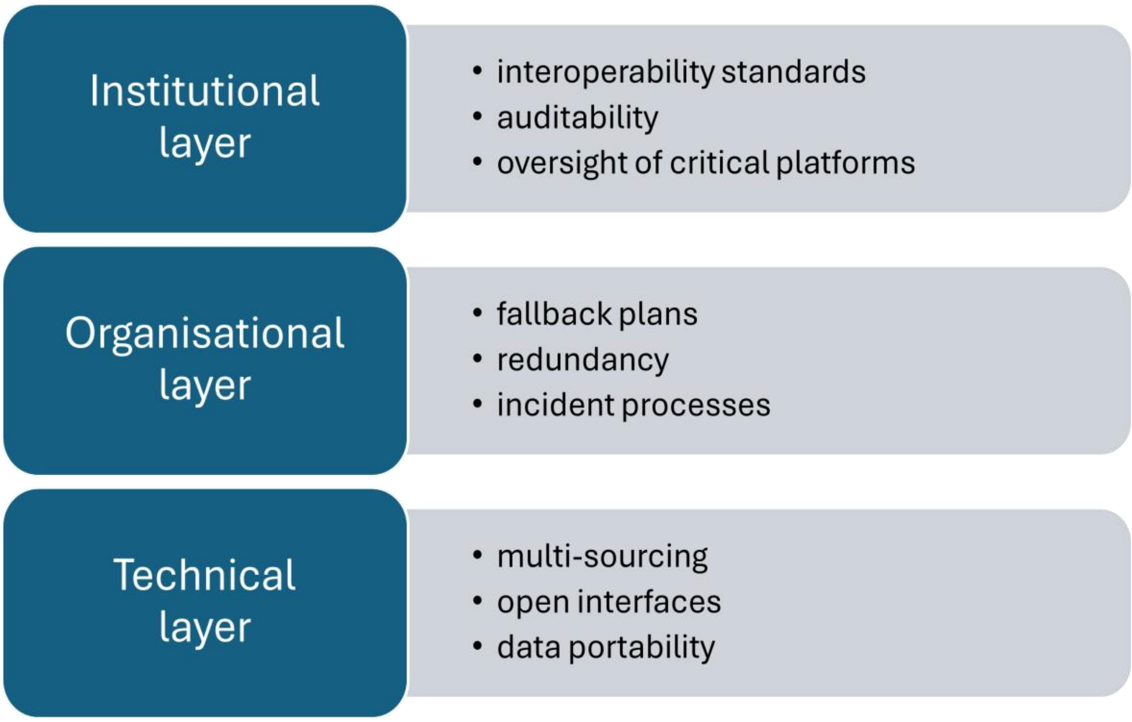

Figure 2 Protection architecture across technical, organisational, and institutional layers. Source: Own illustration based on OECD (2021); Dwivedi et al. (2023); Ivanov (2023).

Social and political repercussions

Generative AI not only affects processes, but also shifts power and distribution in value chains. Where data, models and computing capacities are bundled, economies of scale are created, which are reflected in higher margins and greater pricing power. Smaller suppliers come under pressure when dependencies on proprietary platforms grow. This corresponds to the logic of scarce and difficult to imitate resources in the resource-based view and the adaptation requirements in the dynamic capabilities approach (Barney, 1991; Teece et al., 1997; Helfat & Peteraf, 2003). Labour markets are also affected. Noy and Zhang (2023) show that productivity is increasing, but at the same time quality control and interface competence are creating new requirements. Wamba et al. (2023) prove that knowledge work is being relieved and condensed. Coyle (2023) highlights the ambivalence between productivity gains and job losses. Political-economic analyses also make it clear that a lack of standards exacerbates information asymmetries within a global supply chain and shifts risks to weaker actors (OECD, 2021; Dwivedi et al., 2023).

Discussion of the findings in the light of theory

The results confirm the theoretical expectations. The resource-based view explains why data and models can lead to competitive advantages. The dynamic capabilities approach illustrates that reconfigurability is crucial for sustainable efficiency. Political economy approaches show that without regulation, distributional effects are unequal and risks are systematically shifted to weaker actors.

Empirical evidence underlines this logic.

The LaDe dataset provides large-scale benchmarks for operational efficiency and shows that forecasting and coordination gains are quantifiable. GAN-based risk simulations prove that vulnerabilities in supply networks become measurable and enable realistic stress scenarios, especially for pharmaceutical distribution. Surveys such as Li, Zhang and Chen (2024) make it clear that generative processes only generate performance gains if they are embedded via coordinative mechanisms between suppliers and buyers. In the pharmaceutical industry in particular, where regulatory fragmentation makes adaptation processes more difficult, it is clear that coordination and institutional safeguards are decisive levers.

This provides empirical support for the central diagnosis: Efficiency gains from Generative AIare real, but without technical reconfigurability and governance they will be transformed into structural fragility.

Scenario-based stress tests

The robustness of the findings is tested using scenario-based stress tests. This involves simulating external shocks that affect key dependencies in the supply chains. The aim is to assess the stability of the identified efficiency gains and vulnerability to structural risks.

First scenario: technological failure

A large-scale failure of cloud services or proprietary models means that central planning and control systems are not available in the short term. The LaDe dataset illustrates the extent to which operational KPIs such as on-time delivery or service times can be affected by the loss of digital control. Companies with tested fallbacks, redundant data pipelines and alternative providers keep recovery times low, while others suffer extended restarts and cascade effects.

Second scenario: Regulatory breaking point

Diverging data protection or digital regimes prevent the cross-border flow of data. In the pharmaceutical industry in particular, this has an impact on monitoring, tracking and quality assurance. Empirical reviews show that AI-supported forecasting and monitoring systems only remain effective if portability and compliance are ensured (Al-Hourani & Weraikat, 2025; WJBPHS, 2024). Companies with standardised interfaces and portability clauses adapt processes more quickly, while others lose efficiency due to regulatory fragmentation.

Third scenario: supplier shock

A sudden loss of a key supplier or specialised data provider puts the adaptability of the network to the test. In the automotive industry, this primarily affects just-in-time processes. In the pharmaceutical industry, it is dependencies on a few raw materials and specialised logistics paths. GAN-based simulations (Zhang et al., 2025) show that shocks in distribution networks can be modelled realistically and recovery indicators such as mean time to recover can be quantified. Companies with prepared switchover plans and contractually secured emergency access maintain efficiency gains, while others lose resilience.

Fourth scenario: Data distortion and modelling errors

It should be noted that incorrect or manipulated training data can lead to incorrect forecasts and decisions within global supply chains. Surveys such as those conducted by Li et al. (2024) show that coordination between suppliers and buyers is crucial in order to identify such errors and make adjustments. Companies with established feedback loops, monitoring processes and audits correct missteps more quickly. If this governance maturity is lacking, models become load amplifiers that systematically increase risks.

The stress tests clearly show that efficiency gains can only be achieved if technical, organisational and institutional restructuring options are available. If we do not align global supply chains accordingly, the associated short-term productivity gains will lead to structural fragility. Empirical evidence from data sets, simulations and sectoral studies supports this diagnosis. Comparing the four scenarios reveals that governance maturity and technical redundancy exert the highest stabilising effect across all stress conditions.

DISCUSSION

Comparison of findings with theory

The results from Chapter 5 confirm the central assumptions of the underlying theoretical approaches. The resource-based view shows that data, modelling skills and computing capacities act as scarce resources that are difficult to imitate. They enable efficiency gains if they are anchored in the organisation and used continuously (Barney, 1991). The dynamic capabilities approach expands this view. The reconfiguration and adaptation of global supply chains is the decisive factor in continuing to exploit competitive advantages even under shock conditions (Teece et al., 1997; Helfat & Peteraf, 2003). Research on resilience and viability also confirms that efficiency gains can become unstable without institutional and technical reconfigurability, especially in highly networked systems (Ivanov & Dolgui, 2020; Ivanov, 2023). The empirical validation underlines this logic. The LaDe dataset provides measurable benchmarks for operational efficiency. GAN-based simulations show that risks such as probability of failure or recovery time can be quantified. Evidence from the pharmaceutical industry illustrates that while forecasting and monitoring gains are real, regulatory fragmentation limits adaptability (Al-Hourani & Weraikat, 2025; WJBPHS, 2024). Surveys such as Li, Zhang and Chen (2024) confirm that performance gains only arise when coordinative mechanisms are institutionally anchored.

Efficiency versus systemic risk

The literature documents significant increases in productivity and efficiency. At the same time, the analyses show that these gains are linked to systemic risks. Platform concentration, proprietary interfaces and a lack of interoperability prolong restart times and increase cascade risks. Short-term performance gains can thus turn into structural fragility. The LaDe dataset visualises how sensitively on-time delivery and service times react to failures. GAN simulations confirm that risks in finance and distribution escalate measurably when redundancies are missing.

Demand, feedback and market structure

Generative AI smoothes forecasts and stabilises processes, but the data advantages of large players create a positive feedback loop. More utilisation leads to more data; better models are created and in turn increase market share. This loop reinforces concentration tendencies and further restricts the access of smaller players. The logics of scarce resources and dynamic capabilities are thus complemented by the dynamics of market concentration. Without binding standards for data portability and interoperability, these feedback loops solidify into structural risks (Barney, 1991; Teece et al., 1997; Richey et al., 2023). Empirical evidence from the pharmaceutical industry shows that regulatory fragmentation can exacerbate these risks, as adaptation paths remain restricted.

Governance as a productive factor

Governance is developing from an accompanying framework into a productive factor. Transparency about training data, auditability and institutionalised fallbacks determine whether efficiency gains persist or result in disruptions. Studies show that systems with tested switching plans, multi-supplier strategies and clear escalation processes are more resilient (Ivanov & Dolgui, 2020; Sheffi, 2023). Empirical validation supports this diagnosis: GAN simulations show that recovery times from shocks vary drastically depending on whether redundancy and governance are established.

Political and economic explosiveness

The findings highlight the political dimension of global supply chains. Control over data and models concentrates profits among a few players, while the risks are spread across suppliers, workers and society. Coyle (2023) emphasises that generative AI enables productivity gains, but at the same time can jeopardise jobs and stability in the system. Without regulation, a structural asymmetry emerges that jeopardises economic stability and social resilience. Political economy literature therefore calls for an active role for state institutions to dynamically ensure interoperability, data portability and competition (OECD, 2021; Dwivedi et al., 2023). This is particularly explosive for critical infrastructures such as the pharmaceutical industry, as security of supply and public health are directly affected.

Thesis

Generative AI only strengthens supply chains in the long term if efficiency gains are limited by institutional and technical reconfigurability. Governance thus becomes a mandatory requirement. Without open interfaces, data portability and tested switching plans, short-term speed turns into structural fragility. Power shifts in favour of a few players reinforce this tendency, while weaker companies and entire economies lose their ability to act. The theoretical approaches provide consistent explanations for this. Empirical evidence from data sets, simulations and sectoral case studies underpins the diagnosis: efficiency gains are real, but without governance and institutional safeguards they are transformed into systemic risks.

Implementation strategy

The findings make it clear that generative AI in global supply chains should not be viewed solely as a lever for efficiency. Without reconfigurability and governance, speed turns into structural fragility. Taking into account the three levels: economy, politics and regulation, and institutional cooperation, is fundamental to the development of a strategy.

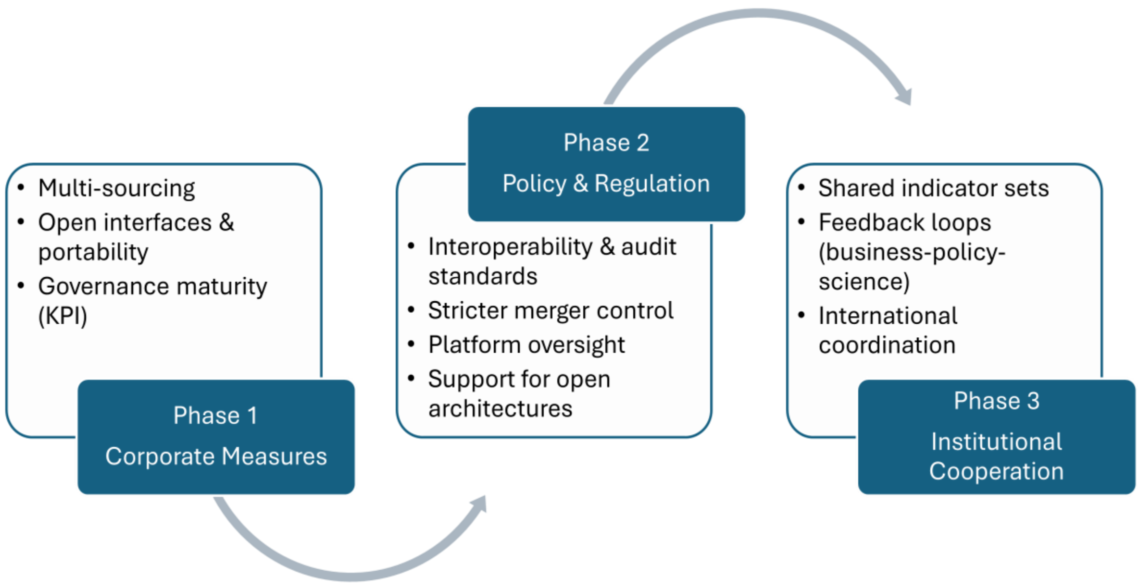

Figure 3: Implementation phases of a strategy for generative AIin global supply chains. Source: Own illustration based on OECD (2021), Dwivedi et al. (2023) and Ivanov (2023).

Companies

Organisations should systematically link efficiency programmes with resilience architectures. This includes multi-sourcing of models and infrastructures, the establishment of open interfaces and contractually secured portability clauses. In addition, companies must carry out regular stress tests to check the resilience of processes, data paths and models under realistic shock conditions. The use of empirical benchmarks such as LaDe makes it possible to continuously measure on-time delivery, service times and route lengths and recognise deviations at an early stage. GAN-based simulations help to identify financial risks and reduce recovery times. In the pharmaceutical industry, where cold chain security and regulatory compliance are essential, companies need to establish governance maturity as a performance indicator in its own right.

Policy and regulation

Regulators must actively limit digital dependencies and create institutional counterweights. Minimum standards for interoperability and auditability form the basis. In addition, stricter merger control is required in the digital sector in order to curb the formation of systemically relevant platform monopolies. Effective supervision of platforms that bundle central supply chain functions is necessary to prevent risks from being unilaterally passed on to downstream players. Empirical evidence from the pharmaceutical industry shows that regulatory fragmentation can quickly neutralise efficiency gains. Policymakers should therefore harmonise portability and compliance standards in order to minimise supply risks. At the same time, open model architectures should be promoted that are jointly supported and reduce dependence on proprietary solutions.

Common level

Institutionalised feedback loops are required between industry, science and politics. Indicator sets that record efficiency, vulnerability and distribution in equal measure create transparency and comparability. Data sets such as LaDe and simulation-based risk tests can serve as common reference points here. International coordination is essential, as divergent data protection and digital regimes promote fragmentation and weaken economies of scale in data access. Particularly in the pharmaceutical sector, which is considered a critical infrastructure, such coordination mechanisms must be strengthened in order to guarantee security of supply even in crisis situations.

Consequence

The implementation strategy shows that generative AI will only become a sustainable driver of global supply chains if technical, organisational and institutional measures are brought together. Only the combination of efficiency gains and reconfigurability will turn short-term productivity boosts into robust competitive advantages. Empirical evidence from operational benchmarks to simulation-based risk assessments and sectoral case studies proves that governance is not an accessory, but a mandatory condition for stability and value creation.

CONCLUSION AND OUTLOOK

The study draws a clear line. Generative AI increases efficiency in planning, procurement and logistics if data quality, process maturity and quality assurance match. At the same time, new vulnerabilities arise due to platform concentration, proprietary paths and governance gaps. The theoretical approaches offer consistent explanations for this. The resource-based view clarifies who can realise competitive advantages. The dynamic capabilities approach shows that these advantages can only be exploited sustainably if reconfigurability is guaranteed in the architecture. Political-economic analyses emphasise that without regulation, risks are distributed asymmetrically and social resilience is jeopardised.

Empirical evidence supports this diagnosis. The LaDe dataset proves that operational efficiency gains are measurable, but at the same time react sensitively to failures. GAN-based simulations show that credit and distribution risks can be modelled realistically and that recovery times are a critical factor. Studies from the pharmaceutical industry show that while AI improves forecasting and monitoring, regulatory breakpoints and raw material dependencies create new vulnerabilities. Surveys such as Li, Zhang and Chen (2024) show that performance gains can only be achieved if supplier and buyer coordination is institutionally secured.

This provides companies with a clear framework for action. Firstly, efficiency programmes must be metrically controlled and continuously fed back, for example via forecast errors, inventory turnover and service levels. Secondly, dependencies must be actively reduced through multi-sourcing, open interfaces, contractually secured data portability and tested fallbacks. Thirdly, reconfigurability must be institutionalised, for example through clear decision-making rights, incident processes and regular stress tests.

There are three key priorities for policymakers and regulators. Interoperability and auditability must be made mandatory. Data portability and competitive dynamics must be made enforceable in order to prevent lock-ins. Effective supervision of systemically relevant platforms is necessary so that risks are not unilaterally shifted to weaker players. Particular attention must be paid to the pharmaceutical industry as a critical infrastructure, as security of supply and public health are directly affected here.

The outlook points to an expanded research agenda. Robust before-and-after comparisons across industries and jurisdictions, standardised measures of model risk and governance maturity, and methods that more precisely capture attribution in complex change programmes are needed. In the future, technical and institutional reconfigurability should be modelled together to better manage cascading risks under realistic shock patterns. Empirical anchors ranging from

LaDe and GAN simulations to sectoral studies from the pharmaceutical industry form the basis for this. Interviews and analyses of key figures can expand this basis and validate the theoretically recorded indicators for efficiency and vulnerability even more precisely.

LIMITATIONS

The present study has several limitations that must be taken into account when interpreting the results. Firstly, the evidence base on generative AI in supply chains is young and heterogeneous. Many results come from early implementations that ran in parallel with other change programmes. This makes it difficult to accurately attribute effects. Leaps in productivity are documented, but their magnitude varies depending on the task, qualification profile and quality assurance. As a result, short-term gains may be overestimated and medium- to long-term side effects underestimated (Noy & Zhang, 2023; Wamba et al., 2023). Secondly, the qualitative multi-case study design allows analytical but not statistical generalisation. Transferability depends on market role, data access and institutional environment. Resilience remains path-dependent and embedded in complex systems (Ivanov & Dolgui, 2020; Ivanov, 2023).

Thirdly, although the integration of empirical evidence is a step forward, there are limits here too. The LaDe dataset provides reliable benchmarks, but remains sector-neutral and only indirectly reflects pharmaceutical characteristics. GAN-based simulations show realistic stress patterns, but are based on synthetic data and must be supplemented by real case studies. Survey data such as that from Li, Zhang and Chen (2024) illustrate coordination mechanisms, but are limited to a national context and cannot be easily transferred to other jurisdictions. Studies on the pharmaceutical industry (Al-Hourani & Weraikat, 2025; WJBPHS, 2024) provide valuable information, but are primarily review-based and not yet underpinned by broad quantitative evidence. Fourthly, there is a risk of selection and success bias. Some of the available evidence is based on provider reports that emphasise positive effects, while critical aspects remain underexposed. Triangulation and cross-checking reduce distortion, but cannot eliminate it entirely.

Fifthly, the stability of the results depends on external framework conditions. Diverging data protection and digital regimes make international comparability difficult. Models that work reliably in stable environments can fail under shock conditions. Without tested switching plans and redundancies, vulnerability increases so that efficiency gains are not sustainable (Sheffi, 2023).

Finally, the measurement of institutional effects remains challenging. Political and economic factors such as power shifts or distributional effects cannot be measured using quantitative indicators alone. They require qualitative sensitivity and institutional contextualisation (OECD, 2021; Dwivedi et al., 2023).

These limitations highlight the constraints of the current evidence base. They underscore the need for future research to focus more on robust measurement standards, before-and-after comparisons, and interdisciplinary methods in order to fully capture the dynamics of generative AI in supply chains. With regard to the pharmaceutical industry, given its critical infrastructure, in-depth empirical research is key to combining predictive and monitoring gains with institutional resilience.

Glossary of key terms

Data portability

The ability to transfer data between different providers without technical or legal barriers. It reduces dependencies and strengthens competition (OECD, 2021).

Dynamic capabilities

Corporate ability to continuously recognise, seize and reconfigure resources and processes in order to react flexibly to changes and shocks (Teece et al., 1997; Helfat & Peteraf, 2003).

GAN simulations
Generative Adversarial Networks that generate synthetic data. Used in supply chains to model credit and default risks and empirically test recovery times under shock conditions (Zhang et al., 2025).

Generative AI/ Generative AI
Artificial intelligence that independently generates texts, images or data structures and thereby influences decision-making and coordination processes in value chains (Noy & Zhang, 2023; Wamba et al., 2023).

Governance maturity
Degree of institutionalised control, transparency, auditability and clear roles that enable the safe and adaptive use of AIsystems (Dwivedi et al., 2023).

Interoperability
Technical and organisational ability of different systems, models and platforms to work together seamlessly (OECD, 2021)

LaDe dataset
Large-scale, publicly available dataset on last-mile logistics (over 10 million deliveries, multiple cities). Enables empirical measurement of efficiency indicators such as on-time delivery, service times and route planning (Wu et al., 2023)

Lock-in
Dependence on proprietary platforms, interfaces or models that make switching and reconfiguration difficult. This can increase dependencies and risks along supply chains (Sheffi, 2023).

Pharmaceutical review evidence
Systematic reviews documenting the use of AIin pharmaceutical supply chains. Focus on forecasting, monitoring, cold chain surveillance and regulatory breakpoints (Al-Hourani & Weraikat, 2025; WJBPHS, 2024).

Platform power
Concentration of data, algorithms and computing capacities among a small number of players, which generates economies of scale and structural bargaining power (Richey et al., 2023).

Reconfigurability
Ability to quickly adapt or switch processes, models and structures to ensure functionality even in the event of disruptions (Ivanov & Dolgui, 2020).

Resource-Based View (RBV)
Theoretical approach that derives competitive advantages from valuable, scarce, difficult to imitate and organisationally usable resources (Barney, 1991).

Resilience / Viability
Survival and adaptability of networked systems under shock conditions. Viability emphasises long-term sustainability over and above efficiency (Ivanov & Dolgui, 2020; Ivanov, 2023).

Stress tests (scenario-based)
Methodological approach in which external shocks (e.g. supplier failure, data distortion, regulatory breakpoints) are simulated to test the stability of efficiency gains and the vulnerability of networks.

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Appendix

Appendix A: LaDe dataset (benchmark efficiency)

Description: The LaDe dataset comprises 10.7 million parcel deliveries, 21,000 couriers in five cities over a six-month period. It enables the measurement of key efficiency indicators.

Indicator	Mean value	Dispersion	Comment
OTIF (On-Time-in-Full)	0,92	± 3 %	Adherence to delivery dates
Average distance	2.6 km	± 1.2 km	Per delivery
Service time	6.5 min.	± 2 min.	Per stop
ETA accuracy	0,89	± 4 %	Prediction quality

Source : Wu et al (2023). DOI : 10.48550/arXiv.2306.10675

Appendix B: Pharmaceutical review evidence

Systematic reviews (Al-Hourani & Weraikat, 2025; WJBPHS, 2024) show that AI/ML in pharmaceutical supply chains is primarily used for forecasting, monitoring and cold chain surveillance. Governance aspects are only considered in around 40% of the studies.

Field of application	Benefit	Governance gap
Forecasting	Improved demand forecasts	Little regulatory involvement
Monitoring	More robust quality tracking	Lack of auditability
Cold chain	Safer temperature control	High implementation costs

Appendix C: GAN simulations (credit and default risks)

Zhang et al. (2025) show that GANs are able to precisely model credit and default risks in supply chains. The models clearly outperform traditional methods.

Model	Accuracy	Recall	F1 score
GAN	0,96	1,00	0,97
Baseline (classic)	0,82	0,79	0,80

Appendix D: Survey evidence (Li et al. 2024)

A survey of 236 companies (Li et al., 2024) shows that the depth of use of Generative AIimproves performance. The effect is mediated by supplier and buyer coordination and reinforced by dynamic environments.

Variable	Relationship	Result
Depth of utilisation GenAI	→ Supplier coordination	Positive effect
Supplier coordination	→ Buyer coordination	Positive effect
Coordination (supplier/buyer)	→ Performance	Measurably increased

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