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Exploring the Interplay between International Trade and Industry 5.0: The Role of Collaboration

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Abstract

The milestones of transitions between industrial revolutions are increasingly nebulous, and thus their objectives and methods. In the search for a better understanding of the concept of the fifth industrial revolution and its impacts, it is suggested that the topic be analyzed from the perspective of International Trade, a perspective that remains unexplored in the literature. Industry 5.0 aims to reconcile the previous iteration with sustainability, bringing humans back into the system with their central role. In this sense, the present conceptual study analyzed aspects related to the benefits and challenges inherent to digital transformation, such as competitiveness, empowerment, cybersecurity, collaboration between man and machine, and digital divide. From this analysis, collaboration emerges as a central element, underlying every aspect of this revolution. As a social manifestation, trade presents itself as an element of fundamental union to society; on an international scale, International Trade appears to both shape and be shaped by the fifth industrial revolution, especially regarding the integration of the elements that make up the Cyber-Physical-System (CPS).

Keywords

Industrial Revolution, Industry 5.0, International Trade, Integration, Collaboration.

1. Introduction

Globalization has been intensified by digital transformation and the consequent increase in global competitiveness, driving companies to continuously improve efficiency and productivity in Industry 4.0. Such pursuit of growth has raised concerns regarding sustainability, social responsibility, and workforce well-being, provoking the emergence of the paradigm of Industry 5.0 that permits the company to get more sustainable competitive advantages via integration of all the elements in the supply chain under its principles (Bhat and Parvez, 2024; Dwivedi et al, 2023).

The industrial revolution is a socio-technological phenomenon that has enabled the emergence of different business models, which, in a feedback loop, influence values and social norms (Arman et al, 2025; Cantú et al, 2020; Shlapak

et al, 2023). In the international context, it is not up to the worker to resist change but to adapt to remain competitive in this new scenario; after all, innovation tends to overcome resistance.

It may be stated that the primary objective of Industry 5.0 is to ensure sustainable socio-economic development. And such a goal would be achieve moving from a machine-centric perspective. Although it still requires further exploration, collaboration between humans, machines, and systems emerges in the specialized literature as one of the elementary constituents of the fifth revolution, where the creativity of experts is leveraged alongside the efficiency and precision of intelligent systems (Bhat and Parvez, 2024; Demir et al, 2019; Dwivedi et al, 2023; Kampourakis et al, 2025; Maddikunta et al, 2022; Mourtzis et al, 2022; Ortiz and López, 2025).

As a social manifestation, trade presents itself as an element of fundamental union to society. International Trade is marked by collaboration and is essential for fostering the integration of supply chain members, companies, and nations, aligning divergent objectives. It acts as a strategic mechanism for sustaining peace, as mutual economic interests encourage nations to cooperate and maintain stable relations. By stimulating the integration of Cyber-Physical-Systems and Supply Chain 5.0 (Frederico, 2021), International Trade becomes the vehicle through which the core pillars of human-centric, sustainability, resilience, and social impacts are disseminated across the global value chains. The academic consolidation of the concepts of these rapidly shifting paradigms is still in its early stages. Even within the specialized domain of supply chain management, recent literature highlights a significant lack of a clear and holistic map regarding the current state of knowledge for both Industry 4.0 and 5.0 (Frederico, 2026). Such conceptual gap is even more pronounced when considering International Trade, where the intersection with Industry 5.0 remains largely unexplored. Therefore, investigating the sparse themes of Industry 5.0 from an International Trade perspective is paramount to gaining a deeper understanding of this socio-technological transformation.

This study is organized into eight sections. Following the introduction in Section 1, Section 2 outlines the identified gap and study's objectives. Section 3 details the methodology, describing the qualitative and systematic approach used to analyze the literature. Section 4 reviews the conceptual evolution toward Industry 5.0 and Supply Chain 5.0. Section 5 examines the relevance of technological transformation to International Trade dynamics. Section 6 discusses the critical challenges to adoption of disruptive technologies, while Section 7 presents a critical analysis on the role of collaboration supported by a comparative framework, arguing that the digital divide is an inorganic phenomenon resulting from the absence of cooperative synergy to reduce asymmetries. The section 8 concludes the paper summarizing the findings, suggesting directions for future research and presents theoretical and practical implications.

2. Research Gap and Objectives

Despite the growing body of research on Industry 5.0, its intersection with International Trade remains largely unexplored in the current literature. Although the distinctions between each Industrial Revolution are nebulous, the impact of the next revolution under the perspective of International Trade still has not been mapped.

This study aims to fill this gap by analyzing how the core pillars of the fifth industrial revolution – human centricity, resilience, and sustainability – interact with global trade processes, thereby presenting a novel approach and ample opportunity for potential contributions in this field. Specifically, this conceptual paper seeks to demonstrate that collaboration is the underlying driver that facilitates this transition and shapes the future of international supply chains.

3. Methodology

This research is characterized as a conceptual paper based on a qualitative analysis of the extant literature. The study design followed a multi-stage approach: (1) a systematic search for literature regarding the interplay between International Trade and Industry 4.0 and Industry 5.0; (2) the extraction of specific articles focusing on the transition to Industry 5.0 and the emergence of Supply Chain 5.0; and (3) a thematic synthesis of the gathered data.

Therefore, the present study derives from a broader systematic literature review on the relationship between International Trade and Industry 4.0 and its transition to the next iteration, from which articles specifically related to Industry 5.0 were taken for deeper analysis.

Following the constructs extracted from the literature reviewed, the analysis focused on four major thematic areas: Contextualization, emphasizing the phenomenon of the 5th Industrial Revolution; considerations about its practical consequences and precautions during technology adoption; the main challenges to digital transformation; and the role

of collaboration in the transition to Industry 5.0, where digital divide is used to evidence the practical importance of the current finding. This process allowed the creation of the comparative framework highlighting the role of collaboration in the interplay of International Trade and Industry 5.0, as presented in the last chapter.

4. Industrial Revolutions

The ongoing digital transformation has been the subject of thousands of surveys, especially since 2011, when the German government launched its strategy for industrial modernization, framing it as the Fourth Industrial Revolution, i.e., Industry 4.0 (Kagermann et al. 2013).

Since then, researchers have focused on mapping this industrialization phenomenon, examining its implications across areas such as technology adoption, socioeconomic and environmental impacts, and cybersecurity (Bajic et al., 2020; Mourtzis et al., 2022).

Similar to previous industrial revolutions, Industry 4.0 adds elements to production, such as digitization (conversion from analog to digital), the digitalization of processes, and the incorporation of cognitive features into machine automation through the integration of technologies, creating the so-called Cyber-Physical System (CPS), also called Smart CPS. Within this framework, factories become intelligent systems that connect to and use real-time information from the physical and virtual worlds to enhance operational flexibility while maintaining efficiency (Maddikunta et al, 2022; Mourtzis et al, 2022).

To conceptualize this phenomenon, researchers are often divided between the management perspective, focused on efficiency and productivity outcomes, and a technological perspective, based on the tools and applications used for its implementation (Bajic et al, 2020).

Among the various definitions proposed, the objective of Industry 4.0 to integrate physical and cyber environments of factories to achieve maximum efficiency and productivity is often highlighted. In this regard, interconnected device networks and related technologies are deployed to enable forecasting, control, maintenance, and process integration. In other words, its focus lies in collecting, preparing, tracking, preserving, and analyzing physical and digital information from numerous sources, with a priority on data processing (Bajic et al, 2020; Bhat and Parvez, 2024).
Its most recurring component technologies are: Big Data analysis, the Industrial Internet of things (IIoT), artificial intelligence (AI) with all its elements such as machine learning and deep learning, semantic network, blockchain, cybersecurity (authentication, integrity, control, audit, scalability etc.), 5G network, cloud computing (Cloud Computing), robotics (drones, autonomous vehicles etc.), additive manufacturing (3D and 4D), augmented and virtual realities, digital twin, wearable technologies (exoskeleton, glasses etc.) and cyber-physical systems (CPS) (Bajic et al, 2020; Bhat and Parvez, 2024; Maddikunta et al, 2022; Mourtzis et al, 2022).

Therefore, Industry 4.0 creates the smart factory by interconnecting machines and equipping them with cognitive technologies that enable process automation. Its focus resides in reducing costs and waste to achieve maximum efficiency, prioritizing productivity and mass production, hence the need to transform factories into CPSs. Moreover, the phenomenon of Industry 4.0 goes beyond factory boundaries, impacting supply chains' processes and their performance, by adopting Industry 4.0's technologies (Frederico et al. 2020). However, this focus does not ensure environmental protection and tends to isolate the human being, aspects that generate distrust and resistance to full adoption (Maddikunta et al, 2022; Mourtzis et al, 2022).

With the purpose to reach a paradigm shift from a full machine-centric to a more human-centric perspective, and by incorporating the principles of sustainability and societal aspects, the concept of Industry 5.0 has emerged. Also, in parallel, the vision of Society 5.0 has been proposed by the Japanese government as a human-centered society that reconciles economic growth with the resolution of social challenges (Keidanren, 2016). Additionally, by merging the concepts of Industry 5.0 and Society 5.0, Frederico (2021) introduced the concept of Supply Chain 5.0, which encompasses the principles involving transition issues, industry strategy, human-centric approach, sustainability and societal impacts and mass personalization. Villar, Paladini and Buckley (2023) reinforced the need for redesigned supply chains with the pillars of Industry 5.0 (i.e. Sustainability, resilience and human-centricity).Industry 5.0 also does not introduce entirely new technologies as such, nevertheless, as a more advanced phase, it is assumed to rely on even more sophisticated resources that will be part of the drivers of this revolution including extended reality technologies (3D, 4D, 5D), collaborative robots (cobots), 6G and beyond, Internet of Everything (IoE),

cognitive/edge/fog computing, enabling data processing at any point along the supply chain, and quantum computing which exponentially enhances existing processing capacity (Maddikunta et al, 2022; Mourtzis et al, 2022).

The 5th iteration seeks to build upon these technologies to reach the era of society 5.0, in which Industry 4.0 is reconciled with sustainable values in a broad sense, taking into consideration the long-term needs of both the planet and humanity, regardless of cultural context (Dwivedi et al, 2023).

It may also be understood as an agreement among supply chain members for the co-creation of a sustainable industrial model, grounded in consumer values that extend beyond mere productivity and efficiency, as well as in the resolution of social challenges (Mourtzis et al., 2022). Achieving this requires human-centered systems capable of enabling harmonious interaction between man and machine, where collaboration will make possible the customization and massive customization of products and services, placing creativity at the center of the production process (Frederico, 2021; Maddikunta et al, 2022; Mourtzis et al, 2022; Arman et al, 2025).
Therefore, Industry 5.0 seeks minimum cost and maximum precision in order to deliver mass customization and personalization, with robots playing a fundamental role in this process. It thus aspires to a symbiosis between humans and machines, leveraging the creativity of experts and the efficiency, intelligence, and precision of machines to deliver solutions that are better aligned with user expectations than in Industry 4.0 (Maddikunta et al, 2022; Mourtzis et al, 2022).
As an improved version of Industry 4.0, Maddikunta et al. (2022) highlight the features introduced by the fifth revolution:
- Intelligent additive manufacturing (3D) that enhances transparency, interoperability, automation, and practical understanding. It also saves energy, reduces resource consumption, and shortens delivery time.
- Predictive maintenance, supported by the IoT, provides transparency and aims to endow systems with self-awareness capabilities.
- Hyper-customization is a strategy that integrates artificial intelligence, machine learning, cognitive systems, and computer vision with real-time data. The first step to its adoption is the transition to agile manufacturing.
- CPCS aims to add cognitive methods to the CPS to enhance performance, where learning and knowledge are the primary components in decision-making in the CPS.

5. The Meaning of Technological Transformation

It is relevant to examine how the objectives of this Fifth Industrial Revolution relate to those of companies.
Organizational survival depends on profitability, which requires competitiveness and is closely linked to a company's capacity for rapid threat identification and agile, efficient response. Technologies align with these objectives by equipping operations with competitive capabilities such as responsiveness, resilience, efficiency, increased productivity, and access to information (Arman et al, 2025; Mourtzis et al, 2022; Rekabi and Sazvar, 2025).

Responsiveness refers to an operational capability to adjust quickly and appropriately to fluctuations, and it can be achieved through the deployment of technologies such as Big Data, IoT, Cloud Computing, and RFID. These technologies include cost optimization, data management, tracking, demand forecasting, resource allocation, and inventory control. All operating in an interdependent relationship (Arman et al, 2025; Rekabi and Sazvar, 2025).

Business Intelligence plays a crucial role in identifying patterns and trends to support informed decision-making on market opportunities, fraud detection, and security improvement, thereby enhancing responsiveness across the supply chain (Ortiz and López, 2025).

Sustainable productivity growth is a central challenge of the new revolution, which is expected to be achieved through human-machine symbiosis, which requires adequate regulation (Bhat and Parvez, 2024; Demir et al, 2019).

Security remains a relatively underexplored topic in the literature, possibly due to its technical complexity; however, there is broad agreement among several authors that cybersecurity can contribute to responsiveness and resilience (Arman et al, 2025; Ghobakhloo et al, 2024; Kampourakis et al, 2025).

Regardless of the targeted capability, it is important to distinguish between essential or structural technologies, supporting technologies, and auxiliary technologies (Bhat and Parvez, 2024) and to adopt only those necessary to

avoid excessive system complexity (Bajic et al, 2021). In this regard, the aim is to create a CPS to integrate people, technologies, and processes available to organize and control the operating system before adopting new technologies. However, the mere adoption of technologies does not imply the acquisition of the aforementioned capabilities; the literature indicates that specific conditions and challenges must be addressed to implement 5.0 technologies successfully.

6. Challenges to Adoption

The number of scientific publications that explore the relations between International Trade and Industry 5.0 remains limited; however, it is already possible to state that there is a relationship of dependence between digitalization and trade facilitation. In this context, additional barriers to development include the lack of standardization and data sharing, as well as the absence of appropriate legislation for e-commerce platforms, data protection, and privacy (Dwivedi et al, 2023; Shlapak et al, 2023).

Among the main challenges, Bajic et al. (2021) reveal that approximately 80% fall into 5 categories: technological (25%), data (15%), and financial, security, and human resources (12.5% each). It is important to highlight the challenges linked to implementation costs, the need for high data processing, data security and sensitivity, processing power, energy consumption, and interoperability (Bajic et al, 2021; Bhat and Parvez, 2024; Jena and Patel, 2022).
Consequently, a significant barrier to the rapid adoption of industrial revolutions lies in the substantial investment required for advanced technologies, in addition to the difficulty of obtaining skilled labor (Bhat and Parvez, 2024; Jena and Patel, 2022). The latter, in particular, also appears to be a key enabler of the adoption of cutting-edge technologies (Delke et al, 2023).
Without aiming to exhaust the subject, some high-impact challenges affecting International Trade companies will be presented, namely cybersecurity, sustainability, interoperability, and workforce training.

6.1 Cybersecurity

Data production has exceeded all limits imagined at the beginning of the century (Figure 1), largely influenced by the expansion of e-commerce. This context helps explain the position of researchers such as Bajic et al. (2021), who state that Big Data analysis is the main bottleneck and the foundational element for the implementation of Industry 4.0 technologies.

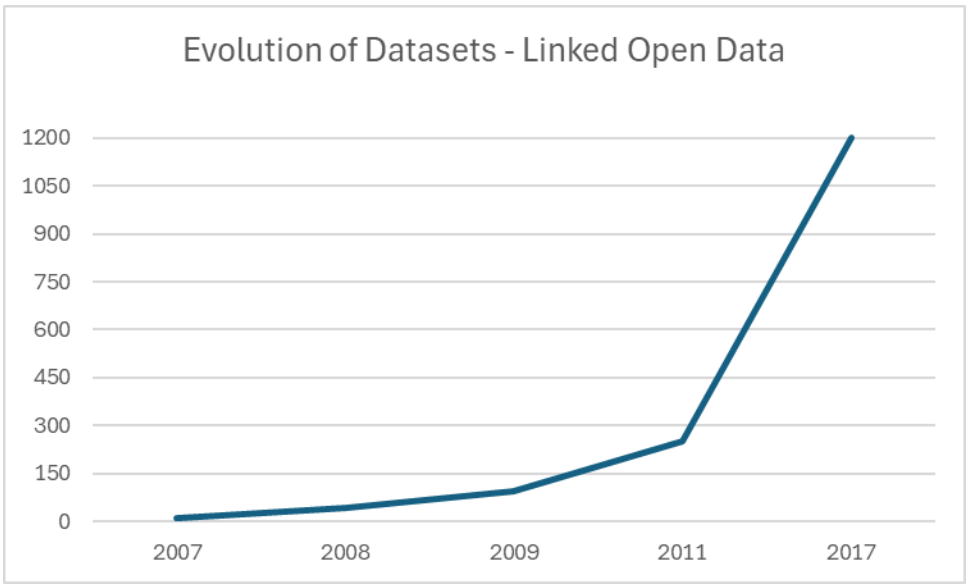

Figure 1. Estimated Growth of Data

Cybersecurity is a challenge beyond professional training. The cost of data breaches has reached around USD 4 million in 2021, and cyber-attacks grew by 431% between 2021 and 2025 (Bhat and Parvez, 2024; Kampourakis et al, 2025).

Although some authors have attempted more detailed analyses of cyberattacks (Kampourakis et al, 2025), limited attention has been given to the associated trade-offs. Security measures can restrict innovation to preserve system exposure; for instance, in the name of privacy, we tend to reduce levels of customization (Bajic et al, 2021).

At the same time, Ivanov and Altufeva (2024) argue that innovation enables the achievement of technological sovereignty and security, aligning with the broader notion of global cybersecurity. A similar idea is found in the concept of local technological autonomy, explored by Ortiz and López (2025), which aims to ensure sustainable growth and active participation in the global economy.

In this sense, digital security can be seen as a component of sovereignty and collaborative governance, ensuring trust among the stakeholders of International Trade.

6.2 Sustainability

International Trade acts not only as a user of technologies but also as a promoter of sustainability, through initiatives such as paperless trade, green logistics, certificate of origin, and traceability. The drawback is the need to equip companies with data processing capabilities and to reduce energy consumption, which has led to increased investment in telecommunication infrastructure and research for alternative energy sources.

The definitions presented in the literature converge toward human-centricity, systemic resilience, and sustainability; therefore, Industry 5.0 must be responsive, resilient, and respect the limits of the planet while stimulating talent, diversity, and autonomy. It should be guided by humans, grounded in the principles of creative reuse, and characterized by efficiency driven by intellectual capacity and creativity, through the integration of workflows with intelligent systems (Maddikunta et al, 2022; Mourtzis et al, 2022).

Industry 5.0 will be a symmetrical innovation and the next generation of global governance; an incremental advance of Industry 4.0, which has been associated with asymmetrical innovation and resulting inequalities. In the era of the socially intelligent factory, stakeholders should focus on human factors across all stages, from development to implementation of solutions, using social networks to facilitate communication between man and machine, enabling autonomous personalized manufacturing (Maddikunta et al, 2022).

As systems, companies must recognize that the behavior of each element affects the whole, that elements are interdependent, and that certain properties are lost when they are separated from the system (Melnyk et al, 2021). This systemic perspective is not a philosophical choice; it is a technological imposition that requires interaction between the parties, especially in the international context.

6.3 Interoperability

The materialization of Industry 5.0 requires human-oriented actions, effective sustainable development, and the execution of a virtuous cycle across physical-digital-physical spheres (Mourtzis et al., 2022). To realize this cycle, a functional infrastructure is required to enable fluid communication among systems, devices, and humans.

Interoperability is a long-standing issue, but it has become more evident with the technological evolution of recent decades and refers to the interdependence of technologies, or the capacity of different systems and technologies to communicate and operate jointly, thereby making the virtual world useful (Arman et al, 2025).

Integration has gained momentum through several attempts to combine technologies. A cyber-physical system (CPS) is the interface that provides real-time data between physical and virtual phenomena. Thus, the IoT is a key technology that enables cloud computing (CC) to read physical environments, generating data that is analyzed through Big Data Analytics and Artificial Intelligence to transform them into information. With the evolution of algorithms that replicate cognitive functions (Cyber-Physical-Cognitive Systems), systems have become more powerful, capable of learning through observation and assisting in decision-making, fostering deeper human-machine collaboration within a Human-Cyber-Physical System (Maddikunta et al, 2022).

From this dialogue in literature, it is possible to state that the human being is the vector that will lead society toward the desired technological advancement, from training machines to supervising their applications throughout the entire supply chain.

6.4 Training

In terms of workforce training, it is crucial to understand the context in which individuals operate and how their skills will be deployed. In this respect, Melnyk et al. (2021) argue that individuals are being forced to simultaneously live through 3 revolutions. Driven by the digitalization of production processes, the increasing efficiency of digital models, and the growing opportunities to bring students closer to the processes, they advocate for the use of technologies such as Digital Twin and augmented reality in the training process.

As previously discussed, in the eagerness to automate processes and systems, humans have been increasingly removed from the scene to make way for machines, perceived as more efficient and cost-effective, thereby expanding corporate profit margins. The fourth wave of industrialization resulted in a substantial increase in the deployment of robots in factories (Figure 2).

Resource and operational efficiency depend on knowledge capabilities, technological readiness of operations and information, effective change management, and technology governance (Ghobakhloo et al, 2024). In the context of Industry 5.0, training must create a synergistic union between human cognitive abilities and CPS, while also supporting individuals to unlock creative potential. Co-evolution/co-adaptation between humans and CPS is necessary, particularly as lower cognitive tasks become increasingly automated (Melnyk et al, 2021).

A case study conducted on dry ports revealed that workforce training reduced total cost by 19% and increased container handling by 25%. Another consequence was decreasing average working time and reducing worker fatigue (Rekabi and Sazvar, 2025).

Key competencies identified in the literature include cognitive skills, which are highly demanded in International Trade, such as adaptability, problem-solving, critical thinking, and creativity, as well as interpersonal skills such as intergenerational collaboration, group work, and people management. Additional competencies include negotiation skills and multifunctional knowledge of processes. Several authors emphasize the need to develop digital skills to create value and mitigate risks arising from malicious actors (Delke et al, 2023; Kacapor et al, 2020; Kampourakis et al, 2025; Melnyk et al, 2021).

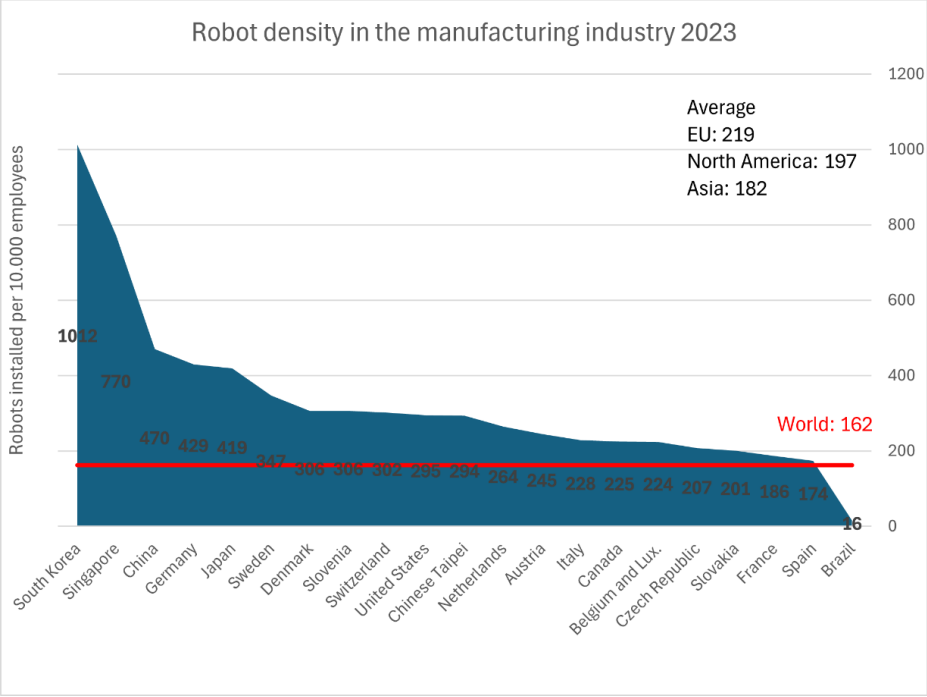

Figure 2. Robot density in the manufacturing industry 2023

Source: The authors based on International Federation of Robotics

It is also necessary to highlight the importance of the development of managerial capabilities and corporate maturity, to understand the need for the implementation of this Revolution and its interdependence with previous industrial paradigms, thereby facilitating digital transformation and avoiding limitations caused by insufficient technical understanding (Dwivedi et al, 2023; Maddikunta et al, 2022; Melnyk et al, 2021).

Co-creation will also become essential, building partnerships that go beyond mere corporate alliances by combining multiple strategies to solve social problems and create outcomes aligned with the consumers' values (Mourtzis et al, 2022). This evolution is expected to increase the complexity of global value chains.

Maddikunta et al. (2022) foresee the creation of the Lead Robotics Officer, a specialized professional (coboter) in human-machine interaction. This transition is likely to face challenges, including concerns about job loss and personal preference regarding collaboration with specific types of robots. Given that many workers may lack the cognitive skills needed for rapid occupational transitions, the use of robots to complement human labor may serve as a mitigation strategy, even though it entails greater investment (Demir et al, 2019).

Widespread acceptance will depend on secure regulatory frameworks, certifications, and oversight bodies, as well as a clear definition of the roles and responsibilities assigned to robots and their capabilities. This is particularly important because robots with learning capability may exhibit unpredictable behavior, and employees may differ in their interactions with them, especially in higher positions, which creates compliance challenges (Demir et al, 2019).

Shlapak et al. (2023) further highlight that accelerating the adoption of advanced technologies by society requires improvements in the regulatory environment, the development of IT infrastructure, and active government involvement.

Additional challenges include the expected reduction in social interaction and intensified competition, which tends to complicate management and organizational behavior (Demir et al, 2019).

It is important to note that the positive relationship with technologies is fundamental for sustainability; however, its success depends on its broader societal impacts, including issues related to responsibility, algorithmic errors, social control, etc. (Mourtzis et al, 2022). Just as sustainability generates costs, but companies invest in it as a differential, there will be companies investing in being a "human-centered" organization, despite the costs (Demir et al, 2019).

7. Collaboration

Regardless of a company's strategic planning and individual capabilities, it is widely acknowledged that every business depends on the ecosystem in which it operates, and this is particularly critical in the context of multinationals. From a macro perspective, Ghobakhloo et al. (2024) believe that among the main reasons governments are encouraging this digital transformation agenda are the potential socioeconomic positive impacts of symmetrical or democratized innovation.

Society 5.0 incorporates Industry 5.0 and represents a distinct social organization, where the control of information sources (collection, processing, transmission, preservation, and analysis of information) is the main source of power and productivity. In this perspective, Industry 5.0 corresponds to an advanced human-centered production model, in which technologies are developed to create social value through creativity supported by the fusion of physical and cyber spaces and supported by increasingly autonomous artificial intelligence systems (Bhat and Parvez 2024; Mourtzis et al, 2022).

Industry 5.0 will be an era in which society lives in harmony with technologies and the planet. This superintelligent society will have high quality of life, or the freedom to seek it, and would ensure the sustainability of civilization (Maddikunta et al, 2022; Mourtzis et al, 2022). In this sense, supply chains in the context of Industry 5.0 (i.e. Supply Chain 5.0) will play a crucial role to the development of a more sustainable and intelligent society (Frederico, 2021) and collaboration is a key element to foster initiatives among supply chain's members.

Although only marginally addressed in much of the literature (Arman et al, 2025, Bajic et al, 2021; Kampourakis et al, 2025) collaboration emerges as a central role in this revolution in light of such ambitious objectives. The adoption of any technology requires integration, while sustainability itself is the result of harmony between all components.

While machines contribute with productivity and precision, and humans contribute with creativity and customization, the defining feature of the Fifth Industrial Revolution is the element of collaborative effort between humans and robots (Bhat and Parvez, 2024).

The researchers agree that the integrated development of Industry 5.0 technologies, combined with collaboration between governments, firms, and educational institutions, will be crucial to foster an ecosystem that of innovation and competitiveness (Arman et al, 2025; Ortiz and López, 2025). For instance, Dwivedi et al. (2023) highlight the need for future research on international governmental collaboration; a dimension that deserves to be highlighted, as collaboration dynamics differ significantly between public and private actors.

Trade itself is an element that contributes to sustaining peace, as mutual economic interests encourage nations to cooperate and maintain good relations. In this regard, International Trade assumes strategic importance as one of the mechanisms to achieve the Fifth Industrial Revolution by fostering collaboration (Table 1).

Table 1. Comparative Framework: International Trade 5.0 and Collaboration

Principles 5.0	Impact on International Trade	Role of Collaboration
Human Centricity	Humans as the vector of technological advancement and ethical supervision.	Integration of cognitive capabilities with the precision of intelligent systems (HCPS)
Resilience	Protection of the supply chain against disruptions that can generate global crises.	Collaborative integration among stakeholders (countries, organizations and consumers).
Sustainability	Holistic view of the ecosystem, ensuring business sustainability.	Co-creation of innovative partnership models for supporting global governance.

Source: The authors

Collaboration permeates all dimensions of this revolution, opening space even for new business models such as innovation sourcing, which directly affects International Trade (Delke et al, 2023).

This type of business model is based on the idea of combining efforts to generate bigger and better results; however, it would be imprudent to base it on trust or solely on technologies. At this point, it can be argued that digital transformation must be accompanied by human skills, as indicated by the reviewed literature (Delke et al, 2023; Kacapor et al, 2020; Ghobakhloo et al, 2024).

Strengthening interactions among people, machines, processes, and systems enhances trust among stakeholders. Ultimately, responsive supply chains depend on collaboration and information sharing (Arman et al, 2025).

The central role of collaboration identified in this study aligns with the knowledge map proposed by Frederico (2026), which positions elements such as knowledge management and technology adoption as essential supporters for more developed and contemporary supply chains.

7.1 Digital Divide

Collaboration plays a significant role in shaping development processes. Increased access to technological devices such as smartphones has enabled the emergence of new technology-driven business models, thereby leading to digitalization, which has given rise to new ways of living and interacting in the globalized society (e-commerce, transportation, food applications, electronic contracts). This digital transformation has occurred in all spheres and was intensified during the COVID-19 pandemic, when people were forced to adapt to the digital environment quickly (Cantú et al, 2020; Shlapak et al, 2023).

Despite the increase in the number of connected devices, there is a significant difference between regions in terms of the use of new technologies. The so-called digital divide concept refers to imbalances in population connectivity, their technological skills, and regulatory maturity, as well as aspects related to social, political, and economic context (Ghobakhloo et al, 2024; Mourtzis et al, 2022; Shlapak et al, 2023).

To assess the gap in achieving the conditions for implementing Industry 5.0, global connectivity indicators provide useful insight. According to data from the United Nations Agency for Digital Technologies (Bogdan-Martin et al. 2022), from the 2.7 billion people who were offline in 2022, there were still 2.2 billion people disconnected in 2025 (Zavazava et al, 2025), which represents approximately 1/4 of the global population, predominantly in less "dynamic" and "peripheral" countries (Ghobakhloo et al, 2024).

Although the diffusion of new technologies has always been unequal, declining production costs, intensified globalization, and the facilitation of global trade could have accelerated the reduction of this gap by lowering barriers to wider adoption.
However, investment in infrastructure and the transfer of advanced technology usually occur when foreign industries expand their operations abroad. Therefore, it is uncommon to have an interest in a trade-off that enables competitive advances. This suggests that this phenomenon may not be an entirely organic economic event, that would be driven by countries' strategic choices regarding whether to adopt a certain technology or not.

In this context, the term digital divide can refer specifically to an inorganic phenomenon, which is an intentional, opportunistic, and antagonistic behavior aimed at preserving competitive advantage, rather than merely technological inequality.

This perspective is echoed in the work of Ivanov and Altufeva (2024), who examine how sanctions constrain targeted countries by limiting their ability to benefit from globalization and labor specialization.

Moreover, the predominant focus on the positive aspects of the Fourth Industrial Revolution has, in some cases, contributed to the marginalization of its negative consequences, such as digital divide, as highlighted by Bajic et al. (2020).

Such disparities create infrastructural and technological asymmetries in International Trade, directly impacting national economic development (Kacapor et al, 2020; Shlapak et al, 2023). Consequently, Industry 5.0 aims to move beyond extractive logics toward a broader and more equitable distribution of prosperity, which calls for a reassessment of economic priorities (Mourtzis et al, 2022).

This may explain why recent research has increasingly focused on sustainability-related dimensions of industrial revolutions, thereby proving a more holistic perspective on development.

8. Final Considerations

This study achieved its objective of analyzing the interplay between International Trade and Industry 5.0, contributing to fill a gap by identifying the role of trade as a driver of digital transformation. The qualitative and conceptual review of the selected literature enabled the identification of key conclusions regarding the phenomenon of the fifth Industrial Revolution, along with the formulation of inferences concerning the role of International Trade in its effective implementation through collaboration.

The research demonstrated that collaboration is an underlying driver that enables the transition from a machine-centric to a human-centric industrial paradigm. The results, consolidated in a comparative framework, evidence that while technology offers competitive capabilities, its successful implementation depends on overcoming barriers such as the digital divide – which this study identifies as a consequence of insufficient collaboration – and the need for specialized workforce training. Ultimately, these findings contribute to trade theory by proposing collaboration as a central manifestation that shapes global supply chains in the era of Industry 5.0.

The current industrial revolution has deepened the negative social consequences of industrialization, which puts business sustainability at risk. Thus, the Fifth Industrial Revolution can only be considered fully adopted through

reconciliation with sustainable values, which also highlights the societal role in shaping guidelines (Dwivedi et al, 2023).

As the researchers point out, these concepts remain dynamic and subject to ongoing evolution (Delke et al, 2023; Dwivedi et al, 2023). Nonetheless, given that the core pillars of Industry 5.0 are sustainability, resilience, and human-centricity, new technologies must respect privacy rights, autonomy, and human dignity (Rekabi and Sazvar, 2025). Only under these conditions can Industry 5.0 continue to be defined as a key enabler for achieving the Sustainable Development Goals (SDGs), especially in emerging countries (Arman et al, 2025; Mourtzis et al, 2022).

8.1 Contributions and Implications

In terms of theoretical contributions, the present research expands the Industry 5.0 discourse by integrating it with International Trade theory – which allows the evolution toward more contemporary supply chains to be not only resilient and sustainable but fundamentally equitable –, and proposes collaboration not merely as a tool, but as a central social and technological manifestation that shapes the CPS on a global scale.

Practical contribution is offered by the study as it provides insights for policymakers and managers. By identifying collaboration as the underlying driver, the study demonstrates that the digital divide – often an inorganic result of competitive antagonism – can be approached as an opportunity for global governance. The study highlights that successful adoption of disruptive technologies depends on overcoming the digital divide and investing in workforce training focused on cognitive and interpersonal skills – such as critical thinking and intergenerational collaboration – which are essential for the human-machine symbiosis of Industry 5.0.

The framework proposed in this study offers a dual strategic path for both developed and emerging economies. For developed nations, it facilitates a shift from the purely machine-centric efficiency of the previous revolution toward a "supersmart society" (Mourtzis et al, 2022) that leverages human creativity alongside intelligent systems to create long-term social value. Simultaneously, for emerging and populous economies, the framework acts as a catalyst for "symmetrical innovation" (Maddikunta et al, 2022), allowing these nations to reposition their vast workforce as primary stakeholders rather than mere operational costs.

For methodological purposes, the study sought to delimit its scope in accordance with its objective. It is therefore argued that this objective has been achieved by identifying the potential contribution of a relatively underexplored construct in the reviewed literature, International Trade, to digital transformation. The analyses conducted suggest the existence of underexplored research pathways, particularly concerning the role of collaboration in digital transformation and the use of International Trade as a tool to promote collaboration.

While this study provides a foundational conceptual framework, it is limited by its reliance on existing literature up to 2025 and the dynamic, rapidly evolving nature of these industrial paradigms.

Future research should move toward empirical validation of the proposed role of collaboration. Specifically, there is a significant opportunity to investigate international governmental collaboration and the role of emerging technologies in reducing the digital divide between countries.

To support future research, we highlight major thematic areas that received significant attention between 2015 and 2022, including Economy, Application, AI and Condition (Mourtzis et al, 2022). Furthermore, we recommend that researchers interested in the topic adopt more critical technical approaches, particularly in addressing the challenges faced since the beginning of the Fourth Industrial Revolution and in examining how collaboration can turn sustainability discourse into concrete results.

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