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The Influence of the US-China Trade War on Industry 4.0 Adoption in the EU: a Case Study on Dutch Machinery Manufacturing Companies

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Abstract

The growing adoption of Industry 4.0 technologies is changing global manufacturing. However, increasing geopolitical tensions, caused by the US-China trade war introduces complexity for navigating Industry 4.0 adoption. This geopolitical uncertainty is especially present in international operating companies such as in the machinery manufacturing sector. This qualitative study investigates how the US-China trade war influences the adoption of Industry 4.0 among EU-based machinery manufacturing companies, by focusing on the Netherlands. Interviews were held with respondents at five machinery manufacturers in the Netherlands. The interview data is enriched by including the national policy on Industry 4.0 adoption. The Gioia methodology is used for data coding and analysis to identify key drivers, barriers and other influences. The findings show that geopolitical uncertainty is a catalyst for Industry 4.0 adoption. Companies see Industry 4.0 technologies as a means to differentiate and improve competitiveness. Company characteristics such as firm size remain influential. The effect of policy framework through national policy such as WBSO is mostly effective, but regulatory conditions and compliance requirements pose implementation challenges which weigh on international competitiveness. The adoption of Industry 4.0 in machinery manufacturing companies in the EU is shaped by geopolitical dynamics. Firms are leveraging Industry 4.0 technologies to respond to global uncertainty, which makes it not merely a modernization trend, but a way to strategically position for the future.

Keywords: Industry 4.0 adoption, digitalization, US-China trade war, geopolitical uncertainty, machinery manufacturing, policy frameworks.

1. Introduction

1.1 Background

Industrial revolutions marked how production evolved from manual labor to industrial processes. These processes were first powered by steam, then electricity, and later through electronics and computers. This progress has led to Industry 4.0 (Pilevari, 2020). Industry 4.0 was introduced in 2013 by the German government, focused on the concept of smart factories and cyber-physical systems (CPS) which integrated advanced technologies such as automation, cloud computing and Internet of Things (IoT). The core concept of "Industry 4.0" is integration. Integration from the physical basis system and software system, integration with branches, economic sectors, and other industries. Industry 4.0 is interpreted as a new level of organization and control over the entire value chain of the lifecycle of products (Li, 2018). Five industrial revolutions can be identified in total, however current exploration of industry 5.0 in still in its initial stage, research findings are scarce and not systematic (Leng et al., 2022).

In response to Germany's high tech "Industry 4.0", China announced the "Made-in-China 2025" plan in May 2015. This plan defines China's intention to launch an industrial transformation from labor intensive production to knowledge intensive manufacturing at a fast speed. MIC2025 focuses on improving the quality of product produced in China, creating China's own brand, building solid manufacturing capability by developing cutting-edge advanced technologies, researching new materials, and producing key parts and components of major products (Li, 2018). MIC2025 has the target to improve several competitive capabilities, such as innovation, quality and costs, while Industry 4.0 takes a dual strategy to integrate information and communication technologies with the traditional high-tech strategies and to create and serve new leading markets for Cyber Physical System (CPS) technologies and products (Wang et al., 2020).

There are similarities in targets, but improving multiple capabilities simultaneously was a major difference between MIC2025 and Industry 4.0. There is another major difference. The average industrialization level in Germany is Industry 3.0 and some firms may be even higher. However, the average industry level in China is between Industry 1.8 to Industry 2.1 (Wang et al., 2020).

1.2 Context

Chinese technology companies have presented new possibilities with their level of innovation and advanced the global economy (Ciuriak, 2019). However, the United States has started a trade war against China due to the differences in political values and geopolitical pursuits (Sun, 2019). Another concern and reason for the technological war is that China's trade practices, such as trade imbalances and technology transfers, will enable it to become even more dominant in the US market, which undermines American competitiveness (Ciuriak, 2019). In preparation for launching the trade war the US released a report that criticized China's industrial policies as aggressive and distorting, with the most notable being the MIC 2025 project (Ju et al., 2024).

The technology war between the USA and China has started in April 2018 (Goulard, 2020). By late 2019, the US had already imposed tariffs on $350 billion of Chinese imports, and China had imposed tariffs on $100 billion of US exports (Fajgelbaum & Khandelwal, 2022). The EU, The third major economic region along China and the USA, shares concerns along with the USA about China. The gains for the EU from the technological war are limited in the short-

term. For the long-term there is uncertainty about the EU's benefits as this is to some extent dependent on how the US-China tensions unfold (Goulard, 2020).

1.3 Research gap

The world believed that with the arrival of industry 4.0, within a few years production would become faster and cheaper, with boosted revenues and increased market agility. Companies have started to adopt Industry 4.0, which results in a change of business model elements such as key resources, value proposition, key partners and customer relationships (Müller, 2019). However, the deployment of Industry 4.0 is far from being achieved and embraced by both SMEs and large companies (Martinetti et al., 2024). They face burdens when it comes to supply chain integration for example, there needs to be a willingness to exchange far-reaching information with partners and the technological interface for trouble-free communication is missing (Preindl et al., 2020). The implementation of Industry 4.0 is also multifaceted and affects more than individual companies. It is also about the connection between companies' value chains and value creation networks (Veile et al., 2021). Industry 4.0 reshapes supply chains, which this also lead to changes in supply chain design, such as closer collaboration, leading to a more consolidated supplier base (Veile et al., 2024). The methods for implementing Industry 4.0 strategies also differ, where some companies rely on classical phased based strategies and long-term visions, others do not have a long-term plan at all (Preindl et al., 2020). Obradović et al. (2021) indicated that Industry 4.0 represents an important future research stream to support open innovation in the manufacturing industry.

While existing research has mainly focused on factors within the company influencing Industry 4.0 adoption, the impact of macroeconomic forces remains underexplored. More specifically, it is unclear how geopolitical uncertainties shape the adoption and implementation of Industry 4.0. The imposed tariffs have influenced the collaboration between the US, China, and Europe, through for example a decrease of China's direct investment in the US and Europe. The gains for the EU from this technological war are limited in the short-term and their future is somewhat dependent on how these tensions unravel (Goulard, 2020). This ongoing geopolitical uncertainty, caused by the US-China trade war, has added another layer of complexity in understanding Industry 4.0 adoption dynamics. By addressing this gap, the literature on drivers and barriers for Industry 4.0 adoption will be enriched with the dynamics of operating in an uncertain global environment. This can help firms and policymakers develop strategies and policies that are resilient to geopolitical risks.

1.4 Problem statement

Industry 4.0 has the potential to make production faster and cheaper, boost revenues, increase market agility, and stimulate collaboration and innovation in supply chains. However, the practical implementation of Industry 4.0 is far from being achieved. Companies face challenges in the implementation. These challenges could be related to collaboration, technology and possibly geopolitical tensions.

It is currently unclear how the geopolitical uncertainties caused by the US-China trade war influences the adoption of Industry 4.0, and how this relates to the inherent challenges in implementing Industry 4.0. Understanding the influence of these dynamics is essential for a better understanding of the drivers and barriers for the adoption of Industry 4.0.

1.5 Research objective

The study focusses on the adoption of Industry 4.0 among machinery manufacturing companies in the EU. The choice for machinery manufacturing companies is made because they have the ability to enable their customers to automate and become more advanced (Wan et al., 2020), which allows this study to detect upcoming trends in technologies before they are used widely used by manufacturing companies. The choice for the EU is made because there is uncertainty about the EU's future benefits from the US-China tensions (Goulard, 2020). The research objective of this study is therefore summarized in the following research question:

"How does the US-China trade war influence the adoption of Industry 4.0 among EU-based machinery manufacturing companies?"

1.6 Significance of the study

This study explores how the adoption of Industry 4.0 is influenced by global uncertainty, within the context of machinery manufacturing companies in the EU. The findings of this study are valuable to practice. This research aims to provide actionable insights for the management of machinery manufacturing companies in the EU for implementing Industry 4.0 technologies. The insights from this study could also help to give guidance in tailoring EU and national policy ambitions based on the drivers and barriers for implementing modern technologies during times of geopolitical tension.

This study contributes to the literature on Industry 4.0 by focusing on adoption in machinery manufacturing companies in the EU. It also contributes valuable knowledge to policymakers and businesses in the EU to tailor their strategies and policies to support innovation. This paper is positioned to inform future research on industrial revolution cycles by linking geopolitical uncertainty to the implementation of Industry 4.0. It creates a path for exploring how macroeconomic forces influence the adoption of technologies, summarized in a conceptual model to clearly illustrate this relationship. This conceptual model could be used as the basis for analyzing similar phenomena in other sectors or countries.

1.7 Structure of the thesis

To answer how the US-China trade war influences the adoption of Industry 4.0 among EU-based machinery manufacturing companies, a multiple case study was conducted in the Netherlands by conducting interviews in five selected companies, enriched with data on the national policy. This thesis introduction (chapter 1) is followed by five chapters:

- The second chapter is 'Theory'. This chapter explores the theoretical and conceptual background of this study. It examines key themes, such as the impact of industry 4.0 and the emerging US-China trade war, which is followed by the research propositions.
- The third chapter is 'Methodology'. In this chapter the research design and approach are explained. It starts with an overview of methodology, followed by a description of the research object, data collection and data analysis.
- The fourth chapter is 'Findings'. This chapter presents the results of the analysis of the interviews and national policies, summarized in a data structure. This data structure is used to form a conceptual model which shows the effect of geopolitical uncertainty on Industry 4.0 adoption in the EU.

- The last chapter ‘Discussion and Conclusion’ (Fifth chapter) interprets these findings and connects them to the existing theory on Industry 4.0 adoption. Theoretical and practical implications will be given, as well as the limitations of this study. The chapter concludes with a summary of the key insights and the answer to the research question.

2. Theory

2.1 The evolution of industrial revolutions

The industrialization revolution started when processes were mechanized instead of being done manually. This accelerated development and growth. Steam and mechanization led to the beginning of Industry 1.0. Steam led to the development and improved productivity by replacing muscular power in the spinning industry, followed by different industries. The second industrial revolution (Industry 2.0) was sparked by electricity. Also, division of labor is a prominent feature that increased profits. In this period, mass production and assembly lines are created and principals such as agile were introduced. The third industrial revolution (Industry 3.0) was created by electronics and computers which led to the development of manufacturing automation, reducing challenges in various tasks and introducing the concept of mass production. This revolution is followed by Industry 4.0. The use of information and communication technology is a distinctive feature compared to previous revolutions. The theme of Industry 4.0 is "smart manufacturing for the future" (Pilevari, 2020). In the future, Industry 5.0 aims to combine human subjectivity and intelligence with industry 4.0 technologies and reflects the value of care for humans, evolving toward a symbiotic ecosystem (Leng et al., 2022)

The trigger for the emergence of industry 4.0 are general social, economic, political and technological changes (Scherrer, 2022). Those are in particular: Short development period, innovation periods needed to be shortened and is an essential success factor for many enterprises; Individualization on demand: the market has become more of a buyers-market, leading to increased individualization of products; Flexibility: Due to the new framework requirements, higher flexibility in product development and production is needed; Decentralization: to cope with the specified decisions, faster decision-making is necessary, reducing organizational hierarchies; Resource efficiency: Increasing shortage and prices of resources as well as social change in the ecological aspects in an industrial context (Lasi et al., 2014).

2.2 The impact of Industry 4.0

Industry 4.0 was introduced in 2013 by the German government, focused on the concept of smart factories and cyber-physical systems (CPS) (Li, 2018). Industry 4.0 arrived with initial promises and expectation of improvements compared to before. Creating smarter, more efficient workplaces and increasing process quality would facilitate faster production. Seamless interconnections within factories, sectors and cross-sectors, using data for extracting insights and patterns helps to achieve cost reduction and boost revenues. It has also created potential for a more sustainable industry (Martinetti et al., 2024). The core concept of "Industry 4.0" is integration. Integration from the physical basis system and software system, integration with branches, economic sectors, and other industries. Industry 4.0 is interpreted as a new level of organization and control over the entire value chain of the lifecycle of products (Li, 2018).

Industry 4.0 changes the nature and form of manufacturing processes and trades in goods and services. Goods and services are becoming increasingly complex and more costly. Developed countries will enjoy the best competitive chance, given their capital and state of technology. First-movers will benefit the most. There will be substantial change of world trade. The growth of services will accelerate as services that required face-to-face contract will be simplified though advanced digital infrastructure, such as Internet of things, smart devices and blockchain (Rymarczyk, 2021).

Industry 4.0 is benefiting the manufacturing sector in three different ways, horizontal integration, vertical integration and end-to-end integration. Horizontal integration is the integration of various IT systems used in different stages of manufacturing and internal business planning such as logistics, production and marketing. Vertical integration is the integration at the different hierarchical levels (such as at actuator and sensor level or production management level) to deliver an end-to-end solution. End-to-end digital integration means the integration throughout the engineering process across a product's entire value chain, across different companies (Liao et al., 2017).

Industry 4.0 can be seen as a convergence of several emerging concepts and new technologies, such as big data, cloud computing, machine learning (ML), robotics and Artificial Intelligence (AI) that have the potential to significantly increase production productivity. However, researchers have indicated that implementation of industry 4.0 is complex and many companies across different countries are facing implementation issues due to different barriers (Raj et al., 2020).

2.3 Industry 4.0 implementation

Frank et al. (2019) makes the distinction between front-end technologies and base technologies to understand the adoption patterns of industry 4.0 technologies in manufacturing firms. The first technology layer is called "front-end technologies" because the four "smart" dimensions are concerned with the operational and market needs. The four dimensions of front-end technologies are: smart manufacturing, smart products, smart supply chain and smart working. In the literature there are many definitions for these dimensions. In this paper the following definitions will be used: smart manufacturing is a fully integrated, collaborative manufacturing system that responds in real-time to changing customer demands, internal conditions and changes in the supply network (Kusiak, 2018); Smart products are products that get smart via built-in intelligence through awareness and connectivity (Raff et al., 2020); Smart supply chain is the new interconnected business system which extends isolated, local, and single-company applications to supply chain wide systematic smart implementations (Wu et al., 2016); Smart working means that the human role in production systems will be performed with smart approaches and grounded in information and communication technologies (ICTs). Each of these dimensions presents a specific subset of technologies (Frank et al., 2019).

The second technology layer is called 'base technologies' because they provide connectivity and intelligence for front-end technologies. Base technologies comprise four elements: Internet of Things (IoT), cloud services, big data and analytics (Frank et al., 2019). Internet of Things is defined as a dynamic global network infrastructure with self-configuring capabilities based on standards and interoperable communication protocols; physical and virtual 'things' in an IoT have identities and attributes and are capable of using intelligent interfaces and being integrated as an information network (Rose et al., 2015) Cloud services have the capacity to store date in an internet service provider which can be easily retrieved through remote access (Frank et al., 2019). Big data is a term for massive data sets having large complex structure with difficulties of storing, analyzing and visualizing for further processes or results (Sagiroglu & Sinanc, 2013). Industry 4.0 is currently mainly related to a systematic adoption of front-end technologies in which smart manufacturing plays a significant role. The implementation of base technologies is challenging, since big data and analytics are still low implemented (Frank et al., 2019). There are two type of industry 4.0 implementation challenges. managerial industry 4.0 implementation challenges and technological Industry 4.0 implementation challenges. Managerial challenges refer to managerial issues in implementing Industry 4.0. For example, a lack of financial resources or security issues. Technological implementation challenges refer to

specific technological issues in the implementation of industry 4.0. For example, related to device incompatibility or data analysis (Bajic et al., 2020).

It is acknowledged that the adoption of industry 4.0 technologies is not supported by itself. There are at least three complementary socio-technical dimensions to consider the digitization process towards industry 4.0 implementation: organization of work, new technologies comes with the need to rethink how the organization will operate; human factors, new technologies require new skills and competences from the workforce; and external environment: adoption of new technologies is dependent of the maturity of the environment where they are implemented (Dalenogare et al., 2018). The most prominent barrier to Industry 4.0 implementation in both developed and developing economies is the lack of a digital strategy, alongside resource scarcity. Industry 4.0 relies on a consistent flow of data across organizations, which poses a challenge for SMEs because they have resource constraints. Medium-sized firms reject cloud computing, largely due to cautious attitude from senior management. Additionally, reservations at top management level make it potentially difficult to develop a digital strategy and implement Industry 4.0 technologies. The most important influencing factor specifically in a developed economy is the low maturity level of the desired technology, companies are cautious in the implementation of early stage, poorly tested technologies, because it could create chaos in an interconnected system of technologies (Raj et al., 2020).

The literature focuses primarily on internal drivers and barriers to Industry 4.0 implementation. There have been a few studies on external drivers of Industry 4.0 adoption, but they are not related to geopolitical uncertainty, which is still largely underexplored in the literature on Industry 4.0 adoption. This limits the understanding of opportunities and risks firms and policymakers encounter when positioning their Industry 4.0 strategy. Geopolitical uncertainty is related to the effect of the industrial strategy. This is why current EU initiatives to support Industry 4.0 adoption will be discussed in section 2.4.

2.4 EU policy on Industry 4.0 adoption

Technological infrastructure is needed to promote the adoption of Industry 4.0 in developed countries, with physical systems, management models, business models as well as industry 4.0 scenarios, supported by policies to make the implementation easier (Oztemel & Gursev, 2020; Raj et al., 2020). The strength of the negative relation between investment and the cost of capital decreases when uncertainty in economic policy is high. Policy uncertainty distorts the negative link between investment and cost of capital, leading to firms not investing as much in response to cheaper capital (Drobetz et al., 2018). Also, different contextual factors such as the type of firm, industry and country influence managerial perceptions of uncertainty. Larger and older firms for example tend to have more resources that help reduce the risk and adapt in an uncertain environment (Sharma et al., 2020).

In 2016, the European commission together with EU member states sought to establish a governance framework to stimulate initiatives like industry 4.0. The “Digital Single Market” was an EU initiative launched with the goal to conduct the EU countries towards adoption of digitalization of practices in their industries. The five pillars for this initiative were: Digital Innovation Hubs (DIHs), Coordination of the Digitizing, workforce qualifications, Digital Industrial Platforms and Public-private partnerships, and Investment in high-impact technologies and Digital Public Services (Teixeira & Tavares-Lehmann, 2022). European Digital Innovation Hubs (EDIHs) for example, are one-stop shops which support companies and the public sector in responding to digital challenges with the goal to become more competitive (European Commission, n.d.). Individual EU countries also have initiatives to stimulate the digitalization of the economy. Among these are some more focused on Industry

4.0 (Germany) and some are more narrowly focused on the implementation of ICTs (Teixeira & Tavares-Lehmann, 2022).

2.5 The rise of China

China is recognized as one of the world's fastest-growing economies, its real annual GDP growth averages nearly 10%. China's exports contributed significantly to its economic development, as the share of its exports relative to GDP increased from 4.55% in 1978 to 19.51% in 2018. Its manufacturing industry has developed significantly, accounting for 38.4% of the GDP, on average, from 2001 to 2018 (Charoenrat & Amornkitvikai, 2024). China has become a strong international player when it comes to sourcing globally and assembling at one place before shipping to the final destination. The Chinese government has been actively promoting processing trade since 1980 to stimulate exports by offering tax and tariff benefits for firms importing raw materials to manufacture goods exclusively for re-export (Dai et al., 2016).

In response to Germany's high tech "Industry 4.0", China Announced the "Made-in-China 2025" plan in May 2015. MIC2025 is a ten-year, state-led industrial policy designed to transform China into an advanced global manufacturing leader (Li, 2018). It seeks to leverage the power of the Chinese state to promote innovation, advance technological self-sufficiency to create comparative advantage on a global scale (Glaser, 2022). The plan signals China's intention to launch an industrial transformation from labor intensive to knowledge intensive manufacturing at a fast speed (Li, 2018). The Chinese government supports future technologies by providing financial support and creates incentives through for instance beneficial regulations to quickly turn ideas from niche industries into products suitable for mass consumption. However, dependency on foreign core components is still a major bottleneck for China's tech ambitions. They have already experienced difficulties when cut off from access to chips or other high-tech components from abroad (Zenglein & Holzmann, 2019).

Made in China 2025 (MIC2025) is only the first step of a three-step plan, with the aim of making China the world manufacturing power. The goal of step one, which should be achieved by 2025 is for China to become a major manufacturing power, the goal for step two is for China to become a global manufacturing power (2035), and the last step is for China to be a leading manufacturing superpower by 2049. 2049 is set as an end goal since China celebrates her 100-year anniversary of the People's Republic of China (Agarwala & Chaudhary, 2021; Li, 2018; Zenglein & Holzmann, 2019).

In preparation for launching the trade war the Trump administration released a report that openly criticized China's industrial policies as aggressive and distorting, with the most notable being the MIC 2025 project (Ju et al., 2024).

2.6 The US-China trade war

The United States has waged a trade war against China due to the differences in political values and geopolitical pursuits (Sun, 2019). The other concern and reason for the technological war is that China's trade practices, such as trade imbalances and technology transfers, will enable it to become even more dominant in the U.S. market which undermines American competitiveness (Ciuriak, 2019). This technology war between the USA and China has started in April 2018 (Goulard, 2020).

These are the major moments in the US-China trade war (Council on Foreign Relations, 2024):

- 2018-2019: Trump imposed tariffs on Chinese goods, leading to several rounds of retaliation until US tariffs covered nearly all Chinese imports. By late 2019, the US had

already imposed tariffs on $350 billion of Chinese imports, and China had imposed tariffs on $100 billion of Us exports (Fajgelbaum & Khandelwal, 2022).

- 2020: Washington and Beijing reach a “Phase One” trade agreement. It contained agreements on intellectual property protection, technology transfer, trade in food and agricultural property protection, market access in China for financial services, exchange rates and transparency and trade sanctions if one side did not live up to the agreement (Bown, 2021).
- 2022: Joe Biden institutes export controls on computer chips to restrict China’s advanced manufacturing sector.
- 2024: A bill is passed via Congress, and signed by Biden, required the sale of Chinese-owned TikTok to a non-Chinese buyer.
- 2025: At the time of writing this study, new tariffs are in place. The Trump administration increased the tariff on imports from China multiple times and in response China retaliated with counter tariffs.

The escalation of the trade war reduces GDP in China by 1.41% and in the US by 1.35%. When taken into account global value chains, the negative impacts are more widespread across countries, and because of it the world GDP is reduced by $450 billion (Itakura, 2020). However, this study does not account for the measures after 2019. The US-China trade war also created net export opportunities rather than shifting trade across destinations. This means that countries outside the US and China gained new market access to fill the gaps caused by the reduced trade due to the imposed tariffs. Many bystander countries grew their exports of taxed products into the rest of the world (excluding the US and China) (Fajgelbaum et al., 2024).

2.7 EU’s stance towards the US-China trade war

The size of the US and Chinese economy make up for 40% of global GDP, so the stakes for the US-China trade war are high. The US is Europe’s most important trade and investment partner, as well as a critical strategic ally. Chinese policies that the US attacks are equally unpopular in Europe, such as theft of intellectual property and trade secrets, as well as security concerns. The competitiveness of American and Chinese firms is suffering the most in the trade and Europe could benefit from this (Plummer, 2019).

The EU feels squeezed by the strategic competition between the US and China and is in need to determine its position in the global set-up. The EU has supported multilateralism with the US at all costs, which is increasingly fruitless since ‘America First’ policies do not align with this vision. The EU could increase its reliance on the US, but this would also mean that the EU needs to align with policies against China. The EU could also strengthen its collaboration with China but this is also hard because there is currently a very restricted access to the Chinese market (Garcia Herrero, 2019). The big threat to the EU is not the direct impact of the US-China trade war, but the uncertainty that comes with it. This weighs on confidence in the future (Goulard, 2020; Plummer, 2019).

2.8 Research propositions

The theory forms the theoretical foundation to answer the research question. This section formulates four research propositions based on the literature that structures the exploration how geopolitical tensions, in particular the US-China trade war influences the adoption of Industry 4.0 among EU-based machinery manufacturing companies. These propositions are created, based on the theory to reflect the dynamics of Industry 4.0 adoption and will be answered in Chapter four.

1. EU-based machinery manufacturers with higher levels of technological maturity, greater firm size, and clear strategic priorities are currently in a more advanced stage of Industry 4.0 adoption.

This proposition is based on the idea that the adoption of Industry 4.0 differs depending on the characteristics of the firm. Frank et al. (2019) makes the distinction between front-end and base-end technologies in Industry 4.0 and illustrates that firms that are more technologically advanced are better able to integrate technologies like smart manufacturing and smart supply chain into their operations. Raj et al. (2020) illustrates that smaller firms experience more difficulties in Industry 4.0 adoption due to resource constraints. Additionally, Dalenogare et al. (2018) indicates the need for a strategy in the adoption of Industry 4.0, when it comes to for example the organization of work and the technological skills of the workforce.

2. The adoption of Industry 4.0 among EU-based machinery manufacturers is driven by the need for a competitive edge, cost efficiency and supply chain resilience, but is hindered by high investment costs and the lack in ability to analyze data.

The second proposition focuses on the adoption dynamics of Industry 4.0 for the machinery manufacturing industry. Industry 4.0 presents significant potential to create smarter and more efficient workplaces resulting in several benefits such as the ability to produce faster. (Martinetti et al., 2024). Industry 4,.0 also enables to create an interconnected business system and smart supply chain (Frank et al., 2019; Wu et al., 2016). However, the theory also illustrated that there are also barriers in the implementation. In particular, a lack of financial resources and the ability to analyze data (Bajic et al., 2020).

3. Changes in Industry 4.0 approach in response to the US-China trade war are likely to slow down the adoption of Industry 4.0 technologies among EU-based machinery manufacturers, especially in smaller firms.

The third proposition focuses on the role of geopolitical instability in shaping a company's approach to Industry 4.0 adoption. The literature highlights the shock that the US-China brought in dependency of China on foreign suppliers (Zenglein & Holzmann, 2019). The threat to the EU is not the direct impact of the trade war, but the uncertainty that comes from it (Goulard, 2020; Plummer, 2019). Policy uncertainty distorts the negative link between investment and cost of capital (Drobetz et al., 2018). However, larger and older firms tend to have more resources to adapt to an uncertain environment (Sharma et al., 2020).

4. The role of the policy environment is critical in shaping Industry 4.0 adoption, because supportive EU and national initiatives encourage adoption among EU-based machinery manufacturing companies.

The fourth research proposition highlights the effect of policy on Industry 4.0 adoption. Various countries have formulated strategies and policies to incentivize Industry 4.0 technologies and support investment (Teixeira & Tavares-Lehmann, 2022). Moreover, the policies are implemented to make the implementation easier (Oztemel & Gursev, 2020). The EU has created a governance framework through EU-wide initiatives, like the Digital Single Market to facilitate Industry 4.0 adoption. Individual EU countries also have initiatives to stimulate the digitalization of the economy. (Teixeira & Tavares-Lehmann, 2022).

3. Methodology

3.1 Overview of methodology

This study employs a qualitative multiple case study approach in analyzing machinery manufacturing companies in the Netherlands to explore how the US-China trade war influences the adoption of Industry 4.0 among EU-based machinery manufacturing companies. The intent of qualitative research is that open-ended emerging data is collected with the aim of developing themes from the data (Creswell & Creswell, 2017).

Semi-structured interviews are held with managers and decision-makers at five machinery manufacturing companies in the Netherlands. A total of 12 interviews will be held to identify the current stage of Industry 4.0 adoption, responses to the US-China trade war, plans for future implementation of Industry 4.0 technologies, what the drivers and barriers are for these implementations and how policies facilitate or restrict the adoption of Industry 4.0. This study uses a cross-case analysis approach to analyze the responses (Yin, 1981). To ensure rigor and in-depth analysis, the Gioia methodology is used for data analysis. The Gioia methodology employs systematic coding and data analysis to develop grounded theory that can meet standards of rigor associated with trustworthy research (Magnani & Gioia, 2023). Additionally, data on the Dutch policy on Industry 4.0 technologies is collected to contextualize the responses and be able to better infer to the EU.

3.2 Research sample

The research sample of this study are five manufacturing companies in the Netherlands and is secondly the policy in the Netherlands for implementing Industry 4.0 technologies. Machinery manufacturing companies in the Netherlands have been selected, since the Netherlands is a founding member of the European Union (European Union, n.d.). The Netherlands also has a national strategy for digital transformation. It launched the concept of "Smart Industry" in 2014 (Teixeira & Tavares-Lehmann, 2022). The objective of this initiative was to strengthen the Dutch manufacturing position and increase productivity in the industry (European Commission, 2017). The addition of policy makes it possible to discover adjustments made in policy in response to the US-China trade war and creates a more complete view of the influences the US-China trade war has on the adoption of Industry 4.0.

The selected companies represent a cross-section of the Dutch machinery manufacturing industry, and contains machinery manufacturers that vary in size, industry and technological advancements. An important selection criterion for the selected companies is that they operate internationally. This is important for determining the influence of the US-China war on Industry 4.0 adoption. By selecting companies from various industries that operate internationally and produce different machines, this study captures a broad spectrum of the Dutch machinery manufacturing industry.

To preserve confidentiality, the companies included are only referred to in general terms. One company focuses on the manufacturing of Industrial machinery for steel processing supported by software and service solutions to deliver all-in solutions. Another specializes in the automation of processes related to logistics and packaging, A third company develops equipment and systems in the agricultural sector, with an emphasis on mechanization and automation. The fourth company provides custom manufacturing solutions tailored to client-specific requirements, through the application of advanced technologies. The fifth company

supplies technical solutions used in infrastructure and other sectors, to improve the performance of their customers. Combined with the additional data on the national policies in the Netherlands, this study aims to provide a complete overview of the Industry 4.0 adoption, including the effects of the policy framework.

3.3 Data collection

This study employs a combination of semi-structured interviews and policy document collection to gather data on the influence of the US-China trade war on Industry 4.0 adoption among EU-based machinery companies. This study specifically focusses on data regarding machinery manufacturing companies based in the Netherlands. A total of 12 semi-structured interviews are conducted with managers and decision-makers who are involved in the adoption of Industry 4.0 technologies or technology implementation strategies within the five selected machinery manufacturing companies. The interviews are conducted semi-structurally. This means that the questions are pre-planned prior to the interview, but the respondent has the chance to elaborate and explain particular issue through the use of open-ended questions which improves the depth and richness of the responses (Alsaawi, 2014). A pilot study was conducted at the first company by conducting four interviews, instead of two. The goal of the pilot study was to test if the respondent was able to answer the questions and retrieve how quickly data saturation was achieved. The last two interviews brought little additional insight into Industry 4.0 adoption of the company which is why two interviews were held with the other four companies. The interviews were transcribed and translated using various transcription software applications to be confident of the accuracy of the translation. The interview questions were designed with the aim to answer the research propositions, formulated in section 2.8, which led to the following interview topics:

- Current stage of Industry 4.0 adoption
- Drivers and barriers to Industry 4.0 adoption
- Organizational responses to the US-China trade war
- Policies facilitating or restricting Industry 4.0 adoption

Secondary documents are collected to contextualize the answers from the respondents regarding policy and understand them within the national and international frameworks. Only publicly available literature will be used to enhance the transparency and replicability of this study. The following literature will be included in this study:

- Literature on the Smart Industry initiative and national Industry 4.0 adoption policy.
- National industrial policies facilitating or restricting technological adoption.
- National policy adjustments in response to global trade challenges.

The choice for using interviews as well as document collection is made to translate the findings from the interview towards the national policy and determine how the policies facilitate and restrict Industry 4.0 adoption in the Netherlands. The combination of data collection methods allows for in-depth contextualized data collection and rich data analysis. To support a structured and ethical data collection, an interview invitation has been developed, which was sent prior to the interviews to all the respondents explaining the topic of this research (Appendix A), also a consent form for the interviews is developed to make clear what the purpose was of the interview and how the interview data will be used (Appendix B). In addition, an interview guide was created to structure the interviews (Appendix C).

3.4 Data analysis

This study uses the Gioia methodology and thematic analysis to analyze the interviews with the managers and decision-makers from five machinery manufacturing companies to identify shared and divergent strategies and responses to Industry 4.0 adoption and the influence of the US-China war. Additionally, the data will be enriched with document analysis on the Dutch policy on Industry 4.0 technologies to be able to contextualize the findings in the Netherlands to the EU. Document analysis is a procedure for reviewing and evaluating documents systematically by selecting, appraising and synthesizing data in documents, to derive meaning, gain understanding and develop empirical knowledge (Bowen, 2009).

The Gioia methodology starts with 1st order analysis, which tries to adhere to information from the informant, with little attempt to distill categories. This leads to a lot of 1st order codes. The second step is to seek similarities and differences within the many 1st order codes. The third step is to determine to what extent the emerging concepts suggest themes that help describe and explain the phenomena. To structure this transition from 1st order codes to 2nd order themes thematic analysis is used. This is a method for identifying, analyzing and reporting patterns within qualitative data (Braun & Clarke, 2006). It describes ideas within the data, which are formed into themes (Guest et al., 2011). Thematic analysis is executed in six phases, as described by Braun and Clarke (2006): familiarizing with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes and producing the report. Once a set of themes is in hand, it is investigated whether it is possible to distill the 2nd-order themes into aggregate dimensions (Gioia et al., 2013).

After doing the interviews, they were transcribed and translated to English. This enabled all 1st order codes and quotes to be compared and used in this study. Next, the codes were grouped and coded per company. Because of the exploratory nature of this study and since the goal is to compare companies, the choice was made to not include repetitive codes within a company's respondents. For instance, in the situation below where two respondents of the same company both mentioned automation as their current focus: *"Automation and robotization is important for us, where we can distinguish ourselves"*, and *"That means that we adjust our positioning. By differentiating ourselves over the software layer and the automation layer."* In this case the code "Focus on automation" is only assigned once.

An example of the coding process and the transition from first order categories is given below. The respondents indicated that the regulatory requirements were a significant factor that shaped their adoption approach to Industry 4.0 technologies. They were described as being time-consuming. As one participant described: *"This is quite an enormous, I would say effort, actually, that we need to put in that we can fully comply to the regulations. And we see those regulations popping up all over Europe, especially year to year. And this increases complexity on the process level…"* This section was given the code "Compliance with regulations in EU is time-consuming", which reflects the broader dimension of "Restrictive regulatory conditions". It indicates that regulations effects the development of Industry 4.0 solutions, which will be further explained in the next chapter where the outcomes related to the research propositions are explained (chapter 4.3).

When a full set of 1st-order concepts, 2nd-order themes and aggregate dimensions were developed, the next step was to build a data structure. The data structure is a sensible visual aid, and it also provides a graphic representation of how was progressed from raw data to themes

and aggregate dimensions in conducting the analysis, which is a key component of demonstrating rigor in qualitative research. It also allows to think about the data theoretically, not just methodologically (Gioia et al., 2013). The data structure is used to answer the research propositions and give more context, while using the research propositions (chapter 2.8) as a guideline. The explanation of the data structure incorporates policies about Industry 4.0 technology adoption, to form a more comprehensive view of the Netherlands in the context of the EU. The outcome of this analysis are refined researched propositions and a conceptual model that illustrates how the US-China trade war influences the adoption of Industry 4.0 among EU-based machinery manufacturing companies, by taking the Netherlands as a case study.

4. Findings

4.1 Introduction to findings

The Findings chapter starts with the interpretation of the interviews to answer the research propositions which have been analyzed to find patterns and themes to better understand the industry 4.0 adoption machinery companies in the Netherlands. The findings related to policy, research proposition four, will be supported by literature on the Dutch policy on Industry 4.0 adoption. Following this analysis a conceptual model is constructed to analyze Industry 4.0 adoption in other sectors and EU countries.

4.2 Application of the Gioia methodology

The interviews are coded using the Gioia method. The first step is 1st order analysis, which led to an abundance of codes. After the initial 1st order analysis, the number of codes was 347, but after deleting codes that were not related to this study or appeared twice within a company, there were 261 codes left. The next analysis was to merge and include codes that appeared more than once across machinery manufacturers. All these codes have been included in the data structure (Figure 1). The codes were grouped based on their context and topic, which led to second order themes. The second order themes were grouped, which led to four aggregate dimensions.

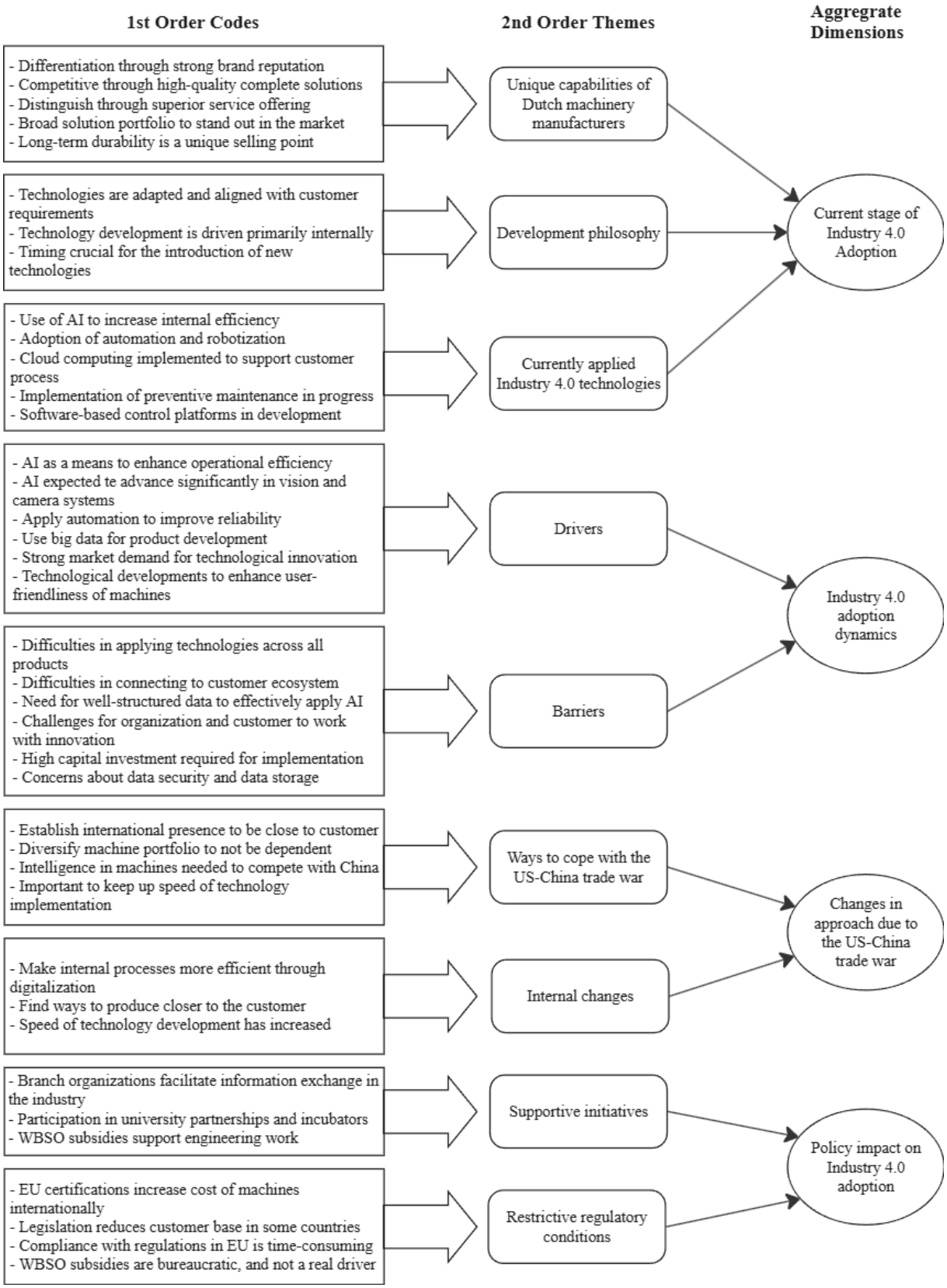

Figure 1 Data structure on Industry 4.0 adoption

4.3 Outcomes related to the research propositions

The aggregate dimensions in the data structure (Figure 1) are related to the research propositions, which were listed in Chapter 2.8. These research propositions are designed to explore trends and dynamics when it comes to Industry 4.0 adoption. They are the framework for examining patterns and relationships in the data to structurally answer the research question. The first research proposition is the following:

4.3.1 Research proposition 1

1. EU-based machinery manufacturers with higher levels of technological maturity, greater firm size, and clear strategic priorities are currently in a more advanced stage of Industry 4.0 adoption.

When looking at EU-based machinery manufacturing it became evident that they differentiate through brand reputation. Multiple companies indicated that customers choose them because they have been a player in the market for a long time and understand the industry. The companies indicated that they could offer complete solutions to their customers, which makes them stand out. As one respondent indicated: *"Our main focus is to complete the proposition next to the machine."* They also offer a broad solution portfolio which enables them to tailor the solution to the needs of the customer. The solutions these machinery manufacturers offer are also described as durable compared to competitors. The completeness of the solution is not solely related to the machines they produce, but also to the service network they have in place.

This is the basis for machinery manufacturers to build a development philosophy. It is important for them that their technologies are adapted and aligned with customer requirements. Although technological development is driven primarily internally. It is very important to time the introduction of new technologies, so the market is ready for innovation. Several technologies have already been implemented, such as AI to increase internal efficiency, automation and robotization in internal processes and machines, cloud computing to support the customer in their process, preventive maintenance to be able to better service the customers' machines and lastly software-based control platforms are implemented to work smarter and improve the ease of use for the machine operator. The interviews indicated that these technologies have a certain maturity, which is why they can be applied in the company. However, the priority that is given to the implementation of these technologies varies.

The machinery manufacturing companies differentiate themselves in various ways, reflecting the strategic priorities in their development philosophy when it comes to Industry 4.0 adoption. Some firms indicate that their technological maturity is way higher than the US and Chinese competitors in the industry. Moreover, all companies included are working on the implementation of Industry 4.0 to improve or extend their current operations. Their technological basis helps them in this implementation. The direct relationship between the current stage of Industry 4.0 adoption and company size isn't explicitly mentioned in the data structure but it became clear that the trend is an increase in scale in the industry. *"The scale increases, the customers are getting bigger. More and more need bigger machines, reliable machines, and also the software."*

This is deemed necessary for the adoption of Industry 4.0 for various reasons, such as the ability to finance development*: "You have to have a certain size to be able to finance software development"*. To conclude, most machinery manufacturers are still early in the adoption of

Industry 4.0 technologies, but technological maturity, firm size and strategic priorities sets these companies up for Industry 4.0 adoption. Moving on to the second research proposition, which is:

4.3.2 Research proposition 2

2. The adoption of Industry 4.0 among EU-based machinery manufacturers is driven by the need for a competitive edge, cost efficiency and supply chain resilience, but is hindered by high investment costs and the lack in ability to analyze data.

The machinery manufacturers pointed to various drivers for Industry 4.0 adoption. They see AI as a means to increase operational efficiency and also expect that it will significantly enhance vision and camera systems. A driver for applying automation is to improve reliability in outcome. Where it was mentioned multiple times that a machine is more reliable than a production worker, *"If you have someone. Who didn't sleep all night because he is stressed…then he just makes a less good product"*. The driver for Big Data was to be able to improve the machines using production data. Another reason for Industry 4.0 technology adoption is that there is strong market demand for innovations. The last driver that was mentioned is that technological developments can be used to enhance the user-friendliness of the machines.

There are also various barriers to the adoption of Industry 4.0. The first barrier is that many machine manufacturers find difficulties in applying the technologies across their product range and to the customers' ecosystem. The customer can also have competitor machines and would like to have all data in a central warehouse, which is often a challenge. There is also the need for well-structured data to effectively apply technologies such as AI. When using data, the firms are also concerned about data security and data storage. Technological advancements also mean that there will be internal changes, and changes at the customer, so they should learn how to work with the innovation. Through the interviews it also became clear that Industry 4.0 adoption requires high capital investment, which is also a barrier to Industry 4.0.

Overall, machinery manufacturers recognize the added value in Industry 4.0 adoption. This is driven by customer demand and also by several needs on product and internal process level. This makes that the technology is a driver for a competitive edge, reliability and cost efficiency. The link to supply chain resilience was not clear from the data. High investment costs and the lack of ability to analyze data are seen as prominent barriers. The lack in ability to analyze data is multifaceted and has several causes, such as unstructured data and data security. Another often-mentioned barrier was the ability to integrate in the customer's ecosystem. The third research proposition that will be explained is:

4.3.3 Research proposition 3

3. Changes in Industry 4.0 approach in response to the US-China trade war are likely to slow down the adoption of Industry 4.0 technologies among EU-based machinery manufacturers, especially in smaller firms.

The interviews showed various organizational responses to the US-China trade war. The first thing to note is that some machinery manufacturing companies experienced the consequences more than others. Respondents at multiple companies mentioned that it was because of the uniqueness of their product on a technological level, which relates to the Industry 4.0 approach.

Moving on to the ways to cope with the US-trade war it became clear that more companies are establishing an international presence close to the customer. They are also increasingly diversifying their machine portfolio to not be dependent on their product range and associated customers. The trend is also to integrate more intelligence in machines to compete with China and to keep up with the latest technology on all levels of the organization.

This translates to several internal changes. Amidst the US-China war the trend is to make internal processes more efficient through digitalization, which is stimulated by customers waiting to invest in new machines. The companies are looking at ways to produce more for the customers and are in constant negotiations with the customer to come to a solution to the tariffs, *"Machines were in order. They are ready now. We are in consultation with the customer, to ask are you ready to pay that 10% tariff?"* Machinery manufacturers are also investing in the speed of technological development.

Machinery manufacturers in the Netherlands have responded to the US-China trade war by changing their strategy, whereby companies with little attention to Industry 4.0 change their strategy the most. In contrast to the research proposition, the data shows an increase in investment instead of slowdown amidst geopolitical uncertainty. These changes are mostly based on the uncertainty about the future, and not for example on the sustainability of the supply chain. One respondent of a company mentioned that their company is diversifying the supply chain, *"I think we now have 9 suppliers all over the world. The goal is to bring them to 20 within 1 or 2 years.",* but no trend was found. The last research proposition is:

4.3.4 Research proposition 4

4. The role of the policy environment is critical in shaping Industry 4.0 adoption, because supportive EU and national initiatives encourage adoption among EU-based machinery manufacturing companies.

Dutch machinery manufacturers make use of various supportive initiatives. They maintain good contact with competitors through branch organization and exchange information. They also participate in university partnerships and incubators; one achieves more through these collaborations than the other. All companies included in the research make use of WBSO subsidies to support their engineering work to create new innovations, *"WBSO. That is the agency where we get engineering time, to work on that technology"*.

There are restrictive regulatory conditions that worsen the environment for Dutch machinery manufacturers. While WBSO subsidies are used to support engineering work, they are bureaucratic and are not a real driver for engineering. Also, legislation such as quotas restricts the customer base in some countries. When it comes to EU regulations, the interviews showed that compliance with these regulations is time-consuming, and EU certifications increase the cost of machines internationally. This strengthens the position of the machinery manufacturers in the EU but worsens their positions internationally, *"There are very different laws in Europe that by definition make our machine more expensive than our competitors from China"*.

The interview findings are enriched with policy document analysis to determine how the national policies facilitate Industry 4.0 adoption in the Netherlands. The Dutch government supports companies that develop innovative products by giving them tax benefits and innovation credit. There are also multiple EU grants for innovation so business can bring their products and services to the market more quickly. The government, private sectors, universities

and research centers are working together to make sectors even stronger and encourage innovation in the following ways: National icons competition, Innovation expo, 'Volg Innovatie' database, National science Agenda, Innovation Attaché Network, and Smart Industry (Government of the Netherlands, n.d.-a).

For example, as mentioned in the Methodology, the Netherlands has a national strategy for digital transformation. It launched the concept of "Smart Industry" (SI) in 2014. (Teixeira & Tavares-Lehmann, 2022). The objective of this initiative was to strengthen the Dutch manufacturing position and increase productivity in the industry by capitalizing on existing knowledge, accelerating ICT in companies and strengthen ICT conditions when it comes to knowledge and skills. (European Commission, 2017). As part of the Digital Europe program a network of Digital innovation hubs (EDIH's) is being formed that covers all regions of the European union to digitalize the regional economy, targeted at small and medium-sized companies. Entrepreneurs get access to testing facilities, knowledge facilities and financing possibilities (Smart Industry, n.d.).

To provide entrepreneurs with an incentive to research the Dutch government has implemented WBSO. If a business carries out research, they may be able to make use of the R&D tax credit WBSO. It offers support for development projects, where new products, production processes or software is being developed and for technical-scientific research, which is explanatory research or of technical nature (Netherlands Enterprise Agency, 2025).

De Nederlandsche Bank indicated that the Netherlands is sensitive to fragmentation of the globalized economy and warned policymakers that this should be weighed when trying to achieve strategic autonomy (De Nederlandsche Bank, 2023). Despite this warning, due to security risks the Dutch government has imposed export restrictions on advanced semiconductor manufacturing equipment to outside the EU (Government of the Netherlands, n.d.-b).

Considering the Dutch policy environment, which is sensitive to changes in globalization, it can be concluded that machinery manufacturers are making use of some of the policy. The Dutch government has various supportive initiatives of which WBSO is most used by machinery manufacturers. However, the current regulatory conditions in the Netherlands are also restrictive since they are bureaucratic and increase the cost and time to build machines. On the other hand, EU legislations and certifications are mostly restrictive and weaken the position of machinery manufacturers in the Netherlands outside the EU. Overall, machinery manufacturers see the current policy framework as somewhat beneficial but are also in constant search for ways to adapt to the policies.

4.4 Refined research propositions

The research propositions, analyzed using interview and policy data, have led to refined research propositions that capture the insights from the data.

1. EU-based machinery manufacturers with higher levels of technological maturity, greater firm size, and clear strategic priorities are better positioned for Industry 4.0 adoption. However, most remain in the early stages of Industry 4.0 adoption.

2. The adoption of Industry 4.0 among EU-based machinery manufacturers is driven by the need for a competitive edge, reliability, cost efficiency, and customer demand, but is hindered by high investment costs, integration challenges and difficulties in data handling.

3. Changes in Industry 4.0 approach in response to the US-China trade war have accelerated investment in the adoption of Industry 4.0 technologies among EU-based machinery manufacturers, particularly for companies that had previously given little attention to Industry 4.0.

4. The role of the policy environment is mixed in shaping Industry 4.0 adoption, as supportive EU and national initiatives encourage adoption among EU-based machinery manufacturing companies, while regulatory conditions and compliance requirements are restrictive and hinder global competitiveness.

4.5 Conceptual model on Industry 4.0 adoption

The conceptual model (figure 2) captures the insights from the Gioia methodology and illustrates the relationships between the aggregate dimensions and second order themes. The arrows and effects in the model do not imply statistical causality, moderation or mediation and are based on the collected data. It serves as a basis for machinery manufacturing companies and policy makers in the Netherlands and EU to navigate challenges related to Industry 4.0 adoption.

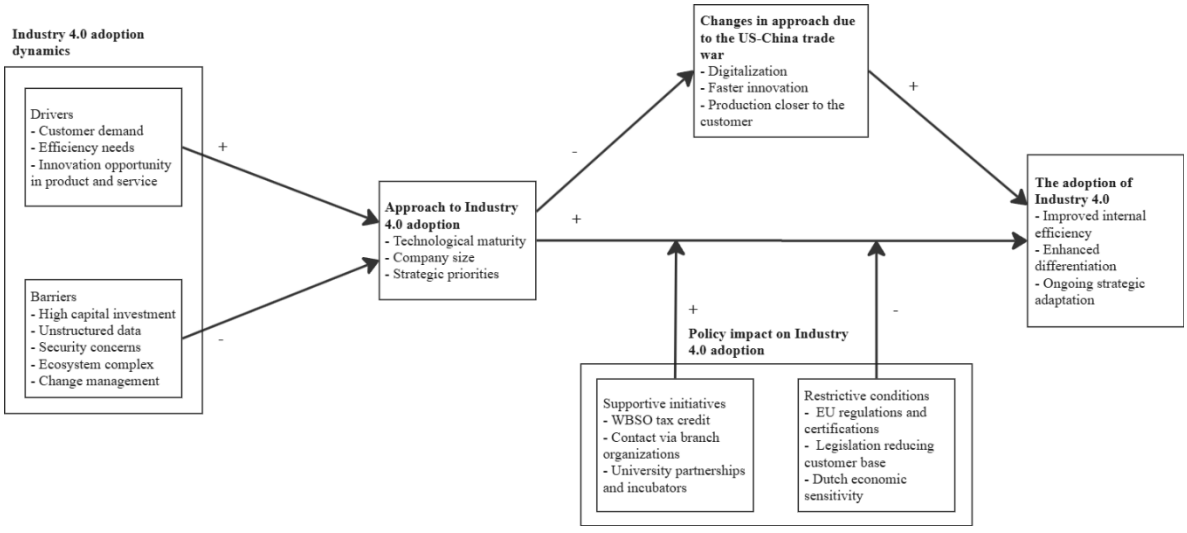

Figure 2 Conceptual model on Industry 4.0 adoption

The drivers of Industry 4.0 among Dutch machinery manufacturers (customer demand, efficiency needs, innovation opportunity in product and service and market competitiveness) positively influence the approach that companies have towards Industry 4.0. However, there are also barriers (high capital investment, unstructured data, security concerns, complex ecosystems and change management) that negatively influence the approach that companies take towards Industry 4.0. The Industry 4.0 approach of the machinery manufacturer is also determined by various company characteristics (technological maturity, company size and strategic priorities). The industry 4.0 approach the machinery manufacturers have contributes positively to their adoption of Industry 4.0.

In this study it became clear that this approach is shaped by responses to the US-China trade war, where there is less impact if there is an existing Industry 4.0 strategy, because the responses (Digitalization, faster innovation and production closer to the customer) are related to the existing Industry 4.0 approach. Moreover, policies are influencing the relationship between the Industry 4.0 approach and the adoption of Industry 4.0 through enabling and constraining factors. Supportive initiatives (WBSO tax credit, contact via branch organizations, university partnerships and incubators) positively contribute to the adoption of Industry 4.0 technologies, whereas restrictive conditions (EU regulations and certifications, legislation reducing customer base and Dutch economic sensitivity) hinder the adoption of Industry 4.0.

The conceptual model contains the findings derived from the interview data and the Dutch policy on Industry 4.0 adoption. It provides the foundations for interpretation, which will be discussed in the “Discussion and conclusion” (Chapter 5).

5. Discussion and conclusion

This chapter interprets the findings from the data. It connects them to the literature on Industry 4.0 adoption, geopolitical uncertainty and doing business internationally, in the context of the US-China trade war. This chapter interprets the findings and compares them to previous studies. Based on this, the chapter provides theoretical and practical implications. This is followed by the limitations and ends with the conclusion of this study.

5.1 Interpretation of results

The conceptual model (Figure 2) shows that there are various drivers and barriers for companies to implement an approach to Industry 4.0 adoption. The approach itself is also determined by the characteristics of the company, technological maturity, firm size, and strategic priorities. The US-China trade war makes companies revisit their Industry 4.0 strategy and sparked the willingness to adopt more Industry 4.0 technologies. This makes it a key external driver in the adoption of Industry 4.0. Industry 4.0 technologies are seen as tools through which a company can strategically adapt amidst this uncertain time. Mainly by offering differentiation in products and improved internal efficiency. The degree by which they can do this depends on the industry that the machine manufacturing company operates in. While existing literature focuses mostly on internal drivers, the role of geopolitical uncertainty as motivating factor to invest in Industry 4.0 technologies is understudied. It changes current adoption models. Moreover another understudied factor, is the effect of policies. The effect of supportive policies, such as WBSO tax credit and university partnerships, enhance the ability to adopt new technologies to a certain extent. However, the regulatory conditions, such as regulatory conditions set by the EU limit the effect or slow down the implementation of Industry 4.0.

5.2 Comparison with previous studies

There are various managerial and technological implementation challenges that companies encounter when implementing Industry 4.0 technologies (Bajic et al., 2020). This is the case for both base technologies and frond-end technologies. Frank et al. (2019) already mentioned that the current adoption of technologies is mostly related to front-end technologies, because big data and data analytics still poses a challenge. This study found that the base technologies (data-related challenges in particular) are barriers to making optimal use of the front-end technologies. The drivers and barriers that this study found are consistent with prior research and emphasize the complexity of Industry 4.0 adoption. Like Raj et al. (2020), This research confirms that resource constraints are a barrier to Industry 4.0 adoption. Machinery manufacturing companies in the Netherlands need to be selective in choosing which technology they give priority because of the high investment costs. This study also shows that a lack of a digital strategy or as mentioned in this study as “approach to Industry 4.0 adoption” is also a barrier to Industry 4.0 adoption.

This study is different than other studies that include adoption models because it includes the external environment, specifically the US-China trade war as a factor that shapes the companies’ approach. Sharma et al. (2020) argued that different contextual factors influence the managerial perceptions of uncertainty, whereby larger and older firms are better equipped in an uncertain environment. This is also supported by this study. The trend is an increase in scale, an increase in scale comes with the ability to invest in Industry 4.0 technologies and the ability

to diversify production for example. Smaller firms are restricted in their ability to diversify because of factors like resource constraints (Raj et al., 2020).

Additionally, this study extends the work of Drobetz et al. (2018), who showed that policy uncertainty weakens the negative relationship between investment and cost of capital, leading in firms not investing as much in response to cheaper capital. In the context of the US-China trade war this is different. Geopolitical uncertainty creates focus on Industry 4.0 initiatives and accelerates the adoption. It emphasizes the effect of macroeconomic pressures on Industry 4.0 adoption. Furthermore, the effect of policy has shown to have both a positive and a negative side for the machinery manufacturing companies in the Netherlands. While Oztemel and Gursev (2020) and Raj et al. (2020), mentioned the positive effects of policy. This study extends their work by factoring in also the negative effects of policy.

5.3 Theoretical implications

This research contributes to the literature on Industry 4.0 by introducing the effect of an external variable, geopolitical uncertainty. It positions this variable as a key external driver for Industry 4.0 adoption, which has been underexplored. Traditional models focus merely on the firm's characteristics, internal capabilities and overall organizational readiness in the market (Dalenogare et al., 2018; Frank et al., 2019; Raj et al., 2020). The research finds that geopolitical uncertainty, caused by the US-China trade war, is a driver in shaping a company's Industry 4.0 adoption, next to the characteristics of the firm. Moreover, this study demonstrates that this uncertainty accelerates rather than delays investment, in contrast to the findings of Drobetz et al. (2018). The trend in the machinery manufacturing industry is an increase in scale to be able to invest in Industry 4.0. Machinery manufacturers perceive Industry 4.0 technologies as a means to differentiate and improve on several fronts amidst uncertainty. This makes Industry 4.0 not merely a modernization trend, but also a strategic response to international geopolitical uncertainty, for instance caused by the US-China war. This external factor acts as a accelerator for innovation. This study also explored the effect of policy as influencing factor of Industry 4.0 adoption. While national initiatives like WBSO and university partnerships are enablers of Industry 4.0 adoption, restrictive conditions, such as EU regulations and compliance can slow down implementation and reduce competitiveness internationally. The results of this study extends existing adoption frameworks by adding geopolitical uncertainty, a macro-level factor, to the existing firm-level perspective on Industry 4.0 adoption, illustrated in a conceptual model.

5.4 Practical implications

On a practical level the findings emphasize the importance of flexibility in the strategic plans of machinery manufacturers. The firms are reacting to the geopolitical uncertainty by increasing their attention to Industry 4.0 so they can stand out in several ways amidst the global uncertainty. For managers, this means that industry 4.0 technologies can act as a way to establish long-term sustained advantage for the company. Based on these insights managers should implement flexible strategies that are resilient to geopolitical developments. Moreover, investing in base technologies (Frank et al., 2019), such as data structures is essential for optimally leveraging advanced technologies. Managers should approach digitalization not as a way to modernize but as a means to differentiate and be competitive.

From a policy perspective, the results highlight that the current policy is not always supportive for the implementation of Industry 4.0 technologies. Many of the Dutch initiatives are directed at SMEs, but there is also the need for more support at bigger companies. The current EU

initiatives are either not used or are not having an impact on Dutch machinery manufacturing companies. This study emphasizes the need for changes in the current policy framework. A thorough evaluation of the national and EU legislation is needed, alongside improved access to funding, which will help improve the technological level of machinery manufacturers in the EU and allows them to compete internationally.

5.5 Limitations of this study

Several limitations of this study should be acknowledged. Because of the limited time frame of this master thesis the study is limited to five machinery manufacturers in the Netherlands who are internationally active, which may restrict the generalizability of this study to the broader machinery manufacturing industry and the EU. Secondly, the geopolitical context of the US-China trade war is rapidly evolving, and this study gives a snapshot in time. Future developments of the US-China trade war may change the approach that companies take to the adoption of Industry 4.0. These limitations create avenues for future research. Although the Gioia methodology using interviews and policy documents is a structured way to conduct analysis. There are other methodologies that could be incorporated in future studies, such as focus groups or longitudinal studies, to achieve more triangulation and gain an even more comprehensive understanding of the topic. Secondly, future research should expand the scope of this study to a wider range of machinery manufacturing companies or industries in the EU to validate the conceptual model and the findings. This could be achieved through quantitative research. Lastly, further research could also investigate the effect of other geopolitical events, such as the EU Green Deal, that might affect Industry 4.0 adoption.

5.6 Conclusion

This qualitative study is conducted to answer the following research question: *"How does the US-China trade war influence the adoption of Industry 4.0 among EU-based machinery manufacturing companies?"*

The data confirms proposition 1 (firms with higher levels of technological maturity, greater firm size and clear strategic priorities are better positioned to adopt Industry 4.0), although most companies remain in the early stages of Industry 4.0 adoption. The findings partially support proposition 2 (Industry 4.0 adoption is driven by the need for a competitive edge, high investment costs is a barrier), while the need for supply chain resilience was not found, instead other drivers were efficiency and customer demand. The data showed that also integration challenges and difficulties in data handling (broader than ability to analyze data) are adoption barriers. In contrast to proposition 3 (US-China trade war slowed down Industry 4.0 adoption), the collected data suggests that the US-China trade war has accelerated investment in Industry 4.0, particularly for companies that had previously given little attention to Industry 4.0. Proposition 4 is partially supported (supportive policies encourage Industry 4.0 adoption), because the findings also showed that policy has negative effects. Supportive EU and national initiatives encourage adoption, while regulatory conditions and compliance requirements are restrictive and hinder global competitiveness.

Overall, this study illustrates that geopolitical uncertainty is not a restricting factor to Industry 4.0 adoption, instead it motivates companies to make strategic decisions to innovate using Industry 4.0 technologies. The machinery manufacturers in the EU do not see Industry 4.0 as a trend, but as a conscious choice to position themself in an increasingly unpredictable world.

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Appendices

Appendix A: Introductory mail to respondents

Mail subject: Industry 4.0 adoption in Dutch machinery manufacturing companies

Dear [Name],

I hope this email finds you well. My name is Arnaud Lensink, and I am conducting a study for my master thesis Business Administration at the University of Twente. This study explores how the US-China war influences the adoption of Industry 4.0 technologies among EU-based machinery manufacturing companies, with a specific focus on the Netherlands as a case study.

The study aims to address the following research question:

"How does the US-China trade war, influence the adoption of Industry 4.0 among EU-based machinery manufacturing companies?"

About Industry 4.0
Industry 4.0 was first introduced in 2013 by the German government and represents a transformative approach to manufacturing. Industry 4.0 aims to create smart, interconnected factories by integrating advanced technologies such as big data, Artificial Intelligence (AI), robotics, and the Internet of Things (IoT) with physical systems. These technologies enhance productivity, reduce costs, and have the ability to foster sustainability while reshaping global manufacturing.

This study explores how Dutch machinery manufacturers are navigating Industry 4.0 adoption under geopolitical shifts such as the US-China trade war. The trade war has introduced complexities in global supply chains and market access, mostly through implementing tariffs. This may hinder or drive companies to implement advanced technologies to remain competitive.

To create a comprehensive understanding this interview will be about the following topics:

1. Current stage of Industry 4.0 adoption
2. Drivers and barriers to Industry 4.0 adoption
3. Organizational responses to the US-China trade war
4. Future plans for adopting Industry 4.0 technologies
5. Policies facilitating or restricting Industry 4.0 adoption

I look forward to hearing your and your company's perspectives. Your insights greatly contribute to understanding this emerging topic. If you have any questions prior to our interview, please let me know.

Kind regards,

Arnaud Lensink
Student Master Business Administration (M-BA)
University of Twente

Mail: xxxxxxxx
Telephone: +31 6 xxxxxxxx

Appendix B: Interview consent form

Study title: The influence of the US-China trade war on Industry 4.0 adoption in the EU: A case study on Dutch machinery manufacturing companies

Dear participant,

Thank you for your willingness to take part in this study! The study is part of a master thesis at the University of Twente. It aims to explore how the US-China trade war influences the adoption of Industry 4.0 technologies within machinery manufacturing companies in the EU, using the Netherlands as a case study.

If you agree to participate, you will take part in a semi-structured interview that will take approximately 45 minutes. The interview will focus on Industry 4.0 adoption, organizational responses to trade tensions, drivers and barriers for implementing advanced technologies, and policies related to this implementation. Your input will be valuable to identify trends on how global trade tensions influence Industry 4.0 innovation in EU machinery manufacturing companies.

Your participation in this study is completely voluntary, and you can withdraw at any time, without giving a reason. If you choose to withdraw, the data collected from your participation will not be used in the study, unless the participant specifically states otherwise. There is no known risk associated with participating in this study. The information you provide in the interview will be treated confidentially and processed anonymously. This means that none of your answers will be disclosed in a way that could personally identify you or your company. The collected data will only be accessible for the researcher and is used solely for answering the research question. The recordings will be securely stored and deleted after completion of this study.

If you have any questions or would like some additional information before or during the interview, please let the researcher know. Should you have any questions after your participation in this study, please contact the researcher. The researcher will answer your questions to the best of his ability.

Researcher's contact information:
Name: Arnaud Lensink
Mail: xxxxxxxx
Telephone: +31 6 xxxxxxxx

Researcher

	Date	Signature
Arnaud Lensink	_____	_____

Participant

	Date	Signature
[Name]	_____	_____

Appendix C: Interview guide

Introduction

Consent request
Do I have your permission to record, transcribe and analyze this interview? Have you read and agreed to the informed consent sheet? Please note that all data will be treated confidentially, and the recordings will be deleted upon completion of the research. You are free to decline from answering any question or to stop the interview at any time.

Start recording

Purpose of this interview
The interview is part of my master's study Business Administration at the University of Twente. For my study, I am currently working on the Master thesis. The study aims to explore how the US-China influences the adoption of Industry 4.0 technologies among machinery manufacturing companies in the EU, using the Netherlands as a case study. Your participation will help to uncover insights into the drivers and barriers of Industry 4.0 adoption and the relation with the current global trade tensions.

Questions

Background

1. Can you tell me more about yourself and your role in the organization?
    - What is your role in the company?
    - How long have you been in this role?
    - Can you describe the company's main operations and target market?

Topic A: Current stage of Industry 4.0 adoption

2. How would you describe the current stage of Industry 4.0 adoption within your organization?
3. What technologies or processes have been adopted and are you currently adopting that relate to Industry 4.0? (Li, 2018; Martinetti et al., 2024)
4. What is the motivation of your organization to implement these technologies? (Martinetti et al., 2024)

Topic B: Organizational responses to the US-China trade war

5. How has the US-China trade war affected your company's operations or strategy? (Supply chain, automation, reshoring)
6. Has the trade war influenced your organization's decision to adopt new technologies? (Frank et al., 2019; Müller, 2019; Preindl et al., 2020)
7. In what ways do you see global trade tensions shaping your long-term strategic goals, in particular technological advancements?

Topic C: Future plans for adopting Industry 4.0 technologies

8. What are your organization's plans for further adoption of Industry 4.0 technologies?
9. How do you see Industry 4.0 technologies contributing to your organization's competitiveness in global markets? (Raj et al., 2020)
10. What external factors do you believe will influence your future adoption plans?

Topic D: Drivers and barriers to Industry 4.0 adoption

11. What do you see as the main internal and external drivers for adopting Industry 4.0 technologies in your organization? (Li, 2018; Martinetti et al., 2024)
12. What are the key barriers or challenges your organization has encountered in implementing Industry 4.0? (Raj et al., 2020)

Topic E: Policies facilitating or restricting Industry 4.0 adoption

13. How does EU or government policy facilitate or restrict your adoption of Industry 4.0 technologies? (Teixeira & Tavares-Lehmann, 2022)

Conclusion

14. In your opinion, what is the most significant influence of the US-China trade war on Industry 4.0 adoption in your organization?
15. What role do you see your organization playing in advancing Industry 4.0 adoption within the broader machinery manufacturing sector?

Stop recording

Thank the participant for taking part, and there will be the possibility to give feedback on the interview.