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ORIGINAL ARTICLE

Emerging positions of German firms in the industrial internet of things: A global technological ecosystem perspective

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Abstract

The industrial internet of things (IIoT) has created entirely new inter-firm competitive and collaborative dynamics that focus on the supply of digital infrastructures, services and platforms for industrial users. These dynamics typically involve machinery builders, information technology suppliers and traditional technology buyers from various asset-intensive sectors. Given the global character of IIoT technology, transnationally relevant inter-firm arrangements have emerged for which we still lack a conceptually grounded understanding. This study addresses this research gap from the German perspective by combining the concepts of global value chains and complex technical systems. Empirically, we develop a multiple case study of established German firms that have provided IIoT technologies in the domain of 'smart manufacturing.' We investigate the firms' evolving positions within the multi-layered IIoT stack and explore their technological dependency on global cloud-infrastructure suppliers. Second, we put the case study into the context of the recent German industrial-policy initiatives related to the discourse of 'digital sovereignty', which attempt to improve the positions of domestic actors vis-à-vis the multi-national tech companies. Conceptually, this study offers the framework of global technological ecosystems as a

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new perspective on the transnational platform economy, which highlights the enabling character of global-scale digital infrastructures and acknowledges active involvement of non-firm actors in ecosystem governance.

KEYWORDS

digital industrial policy, digital sovereignty, German industry, global technological ecosystems, global value chains, online platforms, the industrial internet of things (IIoT)

INTRODUCTION

Since the early 2010s, the concept of the industrial internet of things (IIoT) has given rise to new kinds of cross-sectoral competitive and collaborative dynamics in a number of asset-intensive industries such as electricity, manufacturing or transportation (Willner, 2018). These new dynamics centre on the supply of digital infrastructures, services, and platforms for the industry and take an increasingly transnational character.

Initially, the idea of IIoT was pushed by some well-established industrial-machinery firms that attempted to shift their business models from hardware production to digital services based on industrial data. Around 2013, General Electric (GE) launched a digital platform called 'Predix', which enabled remote monitoring and control of industrial equipment (Evans & Annunziata, 2012). Later, a number of highly capable digital companies have entered the emerging IIoT market. The most prominent examples of this are the two leading 'big tech' firms from the US, Amazon and Microsoft, which are currently becoming the dominant suppliers of cloud infrastructures and analytics for the industry (Cho et al., 2018; Hübner, 2017). Furthermore, many large industrial-technology users, for instance, manufacturing companies, have started developing IIoT platforms of their own—often relying on cloud technologies from the global tech giants.

In this article, we investigate these cross-sectoral competitive and collaborative dynamics in the emerging market for IIoT platforms from the perspective of global political economy. Empirically, we focus on the positions of German firms in the domain of 'smart manufacturing' (Kusiak, 2018) and explore the firms' technological interdependencies with foreign multi-national cloud-technology providers. For at least two reasons, Germany represents a highly relevant context in which to investigate this issue. *First*, Germany has been a leading producer of industrial machineries, upon which IIoT solutions rely. The machine-building sector is even cited as a key example of the 'German industrial model' characterized by high-quality production, a skilled workforce or high export reliance (Herrigel, 2015). In addition, IIoT technologies should generate new opportunities for value creation and productivity growths in the manufacturing sector—which is of strategic importance for the German national economy. However, and *second*, concerns have recently been raised by industry experts that the emergence of IIoT can make the German manufacturing and manufacturing technology sectors critically dependent on foreign providers of cloud technology (Müller, 2020; Roland Berger, 2015). These concerns correspond with the broader observation discussed by Farrell and Newman (2019), whereby multi-national cloud industry firms—and in particular, the US-American ones—are becoming global technological 'hubs' that enable the provision of data-based services in multiple domains of the digital economy. But at the same time, the issue of foreign technology dependence has already been addressed by various German and European Union (EU) industrial-policy initiatives related to the discourse of 'digital sovereignty.' These initiatives attempt to improve the position of domestic technology actors (both users and providers) vis-à-vis the multi-national tech companies (Pohle & Thiel, 2020). In Germany, the 'digital sovereignty' discourse has focused especially on establishing new institutional frameworks and on developing new technological capabilities in the industrial domain of the digital economy (Lechowski, 2021; Schieferdecker & March, 2020).

By studying the case of IIoT platforms from the German perspective, our article links to recent sociological debates on the global restructuring of industries related to digitalization (Brun et al., 2019; Humphrey, 2018; Sturgeon, 2021). Drawing on Kenney and Zysman (2016), we define the ‘platform economy’ as a broad spectrum of economic activities enabled by cloud-based digital infrastructures and services. In conceptual terms, our analysis combines the global value-chains framework (GVC; Ponte et al., 2019) with the complex-technical-systems perspective (CTS; Baldwin, 2015) to illuminate the emerging global-scale divisions of labour within the multi-layered technological ecosystems of the digital (Chalaby & Plunkett, 2020; Clark & Sudharsan, 2020; Kenney & Zysman, 2016; Sturgeon, 2021). While, empirically, our study focuses on inter-firm dynamics, we put the company strategies that we analyse in the broader context of the EU’s ‘digital sovereignty’ discourse. In this way, we extend the current debate on how the emerging ‘digital industrial policies’ (Foster & Azmeh, 2019) are re-shaping international technological competition to the case of the European political economy.

Given our empirical and conceptual goals, this article asks the following three questions:

1. How can the global-scale supply of digital infrastructures, services and IIoT platforms in the ‘smart manufacturing’ domain be conceptualized in terms of inter-firm arrangements and the related government interventions?
2. What strategies have German firms pursued to succeed as IIoT technology providers and how have they organized their relations with the established foreign cloud-technology suppliers?
3. How might the recent government interventions related to the discourse of ‘digital sovereignty’ influence the competitive positions of the domestic IIoT technology firms?

Methodologically, our study relies on 17 expert interviews collected between 2019 and 2021, and on a rich set of archival data describing firm strategies and government interventions in the emerging IIoT market. Our argument is organized as follows. In the next section, we introduce our analytical framework and conceptualize IIoT as a global-scale technological ecosystem structured by both firm and non-firm actors. Building on this, the third section presents the empirical case study of the evolving IIoT ecosystem positions of established German technology firms. In the last empirical part, we contextualize the observed pattern of vertical specialization between the domestic IIoT firms and the multi-national cloud-technology suppliers in relation to selected government interventions. We conclude the analysis by discussing the challenges encountered by the German firms and government-led initiatives in the IIoT market, and by pointing to the broader analytical potential of the *global technological ecosystem* (GTE) concept as a new perspective on the transnational inter-firm dynamics in the platform economy.

CONCEPTUALIZING IIOT AS A GLOBAL TECHNOLOGICAL ECOSYSTEM

The key idea behind the ‘smart manufacturing’ paradigm is to digitally interconnect diverse industrial devices and organizational entities in order to improve the efficiency and flexibility of production processes (Kusiak, 2018). The novel analytical insights derived from the collected industrial data and the opportunity to control the inter-connected processes in ‘real time’ should create significant competitive advantages at the level of individual firms, value chains and entire national economies (Belton et al., 2019; Kusiak, 2018). From a technological perspective, the key elements of the ‘smart manufacturing’ paradigm are IIoT platforms—the so-called ‘operating systems’ of IIoT (Sinsel, 2019) that enable the digital integration of diverse industrial devices and organizational entities. Manufacturing firms can either acquire this kind of platforms and platform components from external commercial providers or, alternatively, they can build them on their own for internal use.

Both the IIoT platforms and the entire ‘smart manufacturing’ paradigm represent relatively new phenomena and our knowledge about their characteristics and impacts remains limited. Existing research from the perspective of transnational industrial organization has mostly focused on the implications of IIoT for supply-chain integration and geographical arrangements of production networks. From this standpoint, one of the key hypotheses discussed in the

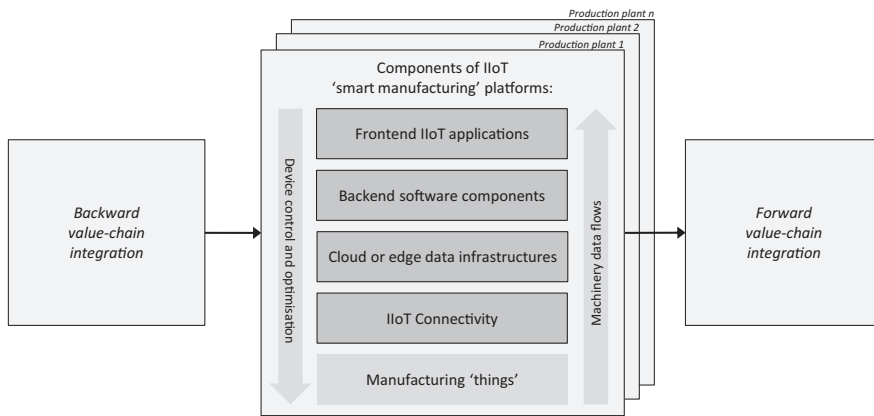


FIGURE 1 The architecture of a 'smart manufacturing' IIoT platform. *Source:* own elaboration

literature is that the adoption of IIoT in manufacturing sectors may entail near- and re-shoring processes to high-wage locations (Kinkel, 2020). But at the same time, the research has almost entirely neglected the transnational inter-firm arrangements that develop on the technology-supply side of IIoT—that is, the globalized competitive and collaborative dynamics related to the provision of the digital infrastructures, services and platforms, on which the 'smart manufacturing' networks rely. This is the dimension that we explore in our analysis.

The technological infrastructure of IIoT

In technological terms, a 'smart manufacturing' IIoT platform is a complex information system that collects and analyses data from industrial devices or organizational entities and provides various related digital services over the internet (Haucap et al., 2021; Sinsel, 2019). Typical digital services for industrial users include device monitoring applications, which examine the performance of industrial hardware based on sensor data; or predictive maintenance services that estimate future conditions and possible failures of devices or entire production systems. In addition to the applications focused on the physical production processes, the scope of 'smart manufacturing' solutions includes also various down- and up-stream elements of the production chain such as product design, supply-chain management or marketing and sales (VDMA & Roland Berger, 2018). In this article, however, we will specifically focus on IIoT solutions in the direct manufacturing sphere to explore the inter-firm dynamics within this probably most technologically complex segment of the industrial platform economy.

From a system-architectural perspective, the key element of the 'smart manufacturing' platforms—and the key novelty compared to traditional factory automation solutions—are various cloud-based computing resources enabling an efficient collection, organization and analysis of large-scale industrial data within and across individual production plants. As we show in Figure 1, the architecture of industrial platforms can be described as a set of components within a multi-layered technology stack, whose higher level functions depend on the inputs from the lower-level layers. We can distinguish the following system layers within this architecture:

- The layer of manufacturing 'things', that is, the physical machineries equipped with sensors, microchips or on-device software, which produce the industrial data and which can be remotely controlled by the platform-based applications.
- The layer of connectivity technologies, which are used to interconnect the industrial hardware and various remote computing resources.

- The layer of data infrastructures, which stores and processes the collected industrial data—either remotely (i.e., in the cloud) or on the edge (i.e., in data centres located in close geographical proximity to the machineries).
- The layer of application-enabling backend software, which supports the frontend platform functionalities through background services such as analytics or machine learning.
- And finally, the layer of the frontend software applications themselves which delivers specific IIoT services to the end-user (e.g., device monitoring or predictive maintenance).

Beyond these stylized system layers, IIoT platforms contain a variety of smaller technological components. In particular, due to the on-going shift toward ‘microservice’ architectures (Singleton, 2016), the software functionalities have become much more granular and modular. Instead of building monolithic, single-purpose applications, technology firms tend to provide smaller and reusable software services, which deliver generic inputs to a number of different frontend applications (e.g., data processing or machine learning services; see GE Digital, 2016).

Unpacking the global-scale inter-firm dynamics in IIoT

Regarding the inter-firm dynamics within the ‘smart manufacturing’ ecosystem, our analysis builds on the general observation in the expert literature that a distinct pattern of cross-sectoral vertical specialization between, on the one hand, large software- and cloud-industry firms and, on the other hand, more traditional machinery producers is developing in this domain of the platform economy (Broos & Dripke, 2018; Soldatos et al., 2019). While the entrants from the IT industry tend to provide the more generic digital services, the traditional machinery builders are specializing in the more domain-specific ‘smart manufacturing’ applications. The main hypothesis guiding our empirical analysis from the German perspective is that this cross-sectoral vertical specialization pattern will have also a *geo-economic dimension*. By this, we understand that the leading US cloud-technology firms will dominate the layer of the infrastructural IIoT services, while German firms will focus on the more manufacturing-specific digital components. But at the same time, we assume that the divisions of labour within the IIoT stack may actually be more fluid and more granular than the stylized vertical specialization argument suggests. Our exploratory empirical data indicate, for instance, that the leading US cloud-industry firms have already started to extend their IIoT market scope beyond the generic data-storage services. One example of this is Amazon Web Services (AWS)—broadly perceived as the globally dominant provider of cloud infrastructures for business users (Forrester, 2020)—which has recently launched a number of digital services more directly embedded into the physical machinery layer of IIoT (e.g., AWS SiteWise, a partly on-premise application enabling a smooth integration of machinery data into the AWS cloud).

To unpack the transnational dimension of these competitive and collaborative dynamics in the IIoT market, our analysis adopts the GVC perspective (Gereffi, 1994; Gereffi et al., 2005).¹ In particular, we apply the concepts of GVC governance and up-grading. From the perspective of *governance*, the GVC literature assumes that organizationally fragmented production processes are embedded in various firm-to-firm institutional arrangements, which regulate the divisions of labour between interdependent producers (Gereffi, 1994; Gereffi, et al., 2005; Ponte et al., 2019). The key concept used in early GVC research to study this phenomenon was ‘lead firm’, understood as a particularly powerful business actor shaping the overall structure of value-chain relations (Humphrey & Schmitz, 2002). More recently, the notion of multipolar governance (Ponte & Sturgeon, 2014) has been introduced to extend the analysis to broader political-economic contexts and to include such factors as the regulatory influence of public authorities (Ponte et al., 2019). Regarding the question of *up-grading* (or down-grading; see: Gereffi, 2019; Humphrey & Schmitz, 2002), the GVC analysis investigates how the integration into different value-chain arrangements creates specific economic opportunities for firms and regions. Focusing on the case of organizationally complex technology sectors (i.e., sectors structurally similar to the IIoT ecosystem analysed in this article), the GVC research suggests that an important up-grading path for less advanced firms is created by the modularization of sectoral product architectures. More specifically, the literature shows that emerging producers may be able to develop internationally competitive prod-

ucts of their own by building on various key components acquired from leading global suppliers (Brandt & Thun, 2011; Haakonsson & Kirkegaard, 2016; Lechowski, 2019). But at the same time, existing research suggests that the 'modularized' GVC arrangements entail also important economic risks for the emerging producers—such as the risk of being trapped into various relatively low value-added down-stream segments of the sectoral value chain (Sturgeon & Kawakami, 2011).

However, while the GVC perspective provides useful analytical tools to study inter-firm dynamics within transnational production systems, it is still conceptually challenging to apply this framework to the case of the platform economy (Humphrey, 2019; Sturgeon, 2021). The key underlying problem is the linear understanding of actor interdependency, which relies on the imaginary of a sequential chain of direct firm-to-firm supply transactions in manufacturing sectors (Humphrey, 2019). Two recent contributions to the GVC literature that have attempted to adjust this perspective to the characteristics of the platform economy are the studies by Brun et al. (2019) and Sturgeon (2021), who both highlight the complexity of inter-firm relations within the multi-layered technological infrastructures of the digital. Expanding on these novel contributions, we will argue that a more conceptually grounded understanding of the technology-supply side of the platform economy is provided by linking the notions of GVC governance and up-grading with the analytical perspective of CTSs (Baldwin, 2015). Drawing on management and innovation research (Baldwin, 2015; Peine, 2008), we define a complex technical system as a set of discrete but inter-related components (or sub-systems) that belong to a common technological architecture and deliver specific functions to the user. This perspective bears some similarities with the concepts of large technical systems (Mayntz & Hughes, 1988) and complex product systems (Davies & Brady, 2000), which were used to analyse firm strategies in various capital-intensive infrastructure industries (e.g., utilities or telecommunication). In our approach, we will rely specifically on Baldwin's (2015) notion of CTS, which has been relevant for the research on vertically dis-integrated 'digital' technology sectors (Baldwin & Clark, 2000; Jacobides et al., 2006; Jia & Kenney, 2016; Langlois, 2003; Pon et al., 2014). We adopt three main ideas from this body of literature.

- First, instead of applying the linear concept of a transactional supply chain, we propose to understand interdependencies between different component producers as relations embedded in the architecture of a given CTS—that is, as relations embedded in the structure of established technological dependencies between discrete system components. In this regard, the CTS perspective is broadly consistent with the concept of a technological (or: innovation) 'ecosystem' discussed in business studies (see Adner & Kapoor, 2010).
- Second, and more specifically, we predicate our approach on the idea that the inter-firm collaborative and competitive dynamics are structured around the control of key system-internal technologies. The main heuristic construct that was used to explicate this idea by Baldwin (2015) is the notion of a 'bottleneck' component. This concept refers to a system-internal technology, which is controlled by a given firm and which can be perceived as a particularly valuable one based on two conditions: (1) the component solves an important technical problem and improves the system's overall performance; (2) the component is difficult for other firms to imitate, because its production requires some rare firm-specific capabilities (Baldwin, 2015; Ballon, 2009).
- Third, and finally, we integrate into our analysis the idea that inter-firm power positions and dependencies do not simply mirror the technical characteristics of system architectures or components. Rather, firms are conceived as strategic actors who actively shape the parameters and 'design rules' (see Baldwin & Clark, 2000) of technologies and, in this way, structure their relations with other ecosystem actors. Two important management strategies that have been discussed in this context in the CTS literature are: (1) component 'modularization', referring to the practice of opening and standardizing interfaces to enable component interoperability (Baldwin, 2015); and (2) the firms' decisions regarding their overall 'scopes of control' (Baldwin, 2015) within a given CTS, which determine the selection and the combination of components that the firms want to produce.

Explicated in this way, the non-linear notion of ecosystem interdependency derived from the CTS research provides a novel standpoint from which to study the transnational competitive and collaborative dynamics on the

technology-supply side of the platform economy. We propose to call the analytical approach that emerges from the combination of this notion with the key assumptions of the GVC theory a global technological ecosystems (GTEs) perspective.

Focusing on the case of the 'smart manufacturing' IIoT platforms investigated in this article, we may use the GTE framework to develop more concrete guiding concepts to inform our empirical study. First, and most basically, the following analysis will investigate how technology firms position themselves within the multi-layered IIoT stack in terms of their *component specialization*—and, in particular, in terms of their possible control over any 'bottleneck' technologies (i.e., the ecosystem components related to some 'rare' productive capabilities). Second, we will examine how IIoT firms strategically shape their relations with other ecosystem actors by means of both component design and the decisions regarding their overall component specialization. In this regard, we will rely especially on Baldwin's (2015) notion of *small and large spans of control* and link this idea to the management-studies perspective on digital platforms, which highlights the question of different control arrangements over the platform-enabling technological infrastructures (Constantinides et al., 2018; de Reuver et al., 2016). Starting from the largest possible span of control, we define an *end-to-end IIoT platform* as a strategy whereby an individual company provides all the required IIoT components (as described in Figure 1) on its own. One historical example of this approach was the case of GE, whose ambitions extended from hardware production to the provision of cloud infrastructures (Darrow, 2015; Gryta & Mann, 2020; Winig, 2016). Yet, as we indicated above, in the IIoT 'smart manufacturing' ecosystem, we are currently observing the emergence of cross-sectoral divisions of labour with relatively smaller firm-specific spans of control—the pattern that we propose to call a *platform-on-platform* arrangement. And finally, third, in reference to the discourse of multi-polarity in the GVC literature, our analysis will explore how the technological ecosystem of IIoT is structured not only by firms but also by various socio-political actors. One important example of *external regulatory involvement* into 'smart' technological ecosystems that has been discussed in the literature is interoperability standards (Ho & O'Sullivan, 2019). In terms of the underlying institutional procedures, these kinds of standards are usually set through a mixture of market-based, associational, and government-driven mechanisms (Wiegmann et al., 2017).

RESEARCH DESIGN AND METHODS

Empirically, the present study explores *the emerging positions of German technology firms in the IIoT 'smart manufacturing' ecosystem* and attempts to understand how these positions may be influenced by *government interventions related to the discourse of 'digital sovereignty'*. Regarding the first aspect, we investigate IIoT platform strategies of various established German producers, who have been active in the domain of 'smart manufacturing'. We develop qualitative historical case studies of selected companies to re-construct the strategies they have pursued and to describe the outcomes they have achieved in depth. More specifically, we analyse the firms' positioning strategies in terms of: (i) the 'smart manufacturing' products and services they have been developing; (ii) the firms' related technological capabilities and (iii) their 'spans of control' within the IIoT platform ecosystem. In doing so, our particular focus is on how the German IIoT entrants have managed their ecosystem relations with the key foreign cloud-infrastructure providers.

In terms of sectoral case selection, our analysis focuses on the following three kinds of German companies²:

- Machinery and plant engineering (MPE) firms, whose key strategic resources within the IIoT ecosystem are their capabilities as producers of traditional industrial hardware (e.g., robots, machine tools or factory automation systems) and the related digital technologies (e.g., control systems or device-specific software);
- Enterprise IT (EIT) producers, which may rely on their capabilities in the production of business and industrial management applications (ERP, MES)³ or the related backend software (e.g., databases).
- And, on the technology-user side of the IIoT market, large car manufacturing companies, which are of strategic importance for the German economy and which may develop relatively strong positions within the IIoT ecosystem drawing on such resources as: their control over the actual production processes and industrial data; their

TABLE 1 Data collection strategies

Data collection strategy	Collected data
1. Expert interviews	17 qualitative interviews with the following different types of actors: <ul style="list-style-type: none"> • industry experts: machinery and plant engineering industry (4 interviews), IT industry (1), global consultancies (1), automotive sector (1); • German and international associations (1 interview each): Fraunhofer Society, Industrial Internet Consortium, International Data Space Association, MT Connect Association, OneM2M Association, OPC Foundation, VDMA⁴, VDW⁴; • German public agencies (1 interview each): BMWi⁴, Plattform Industrie 4.0
2. Database of archival sources	Systematic collection of online materials on the IIoT platform strategies of German and multi-national firms and the relevant government ecosystem interventions (1429 archival sources): <ul style="list-style-type: none"> • firm publications; • press releases; • articles from trade journals and mainstream media outlets; • online materials published by German public agencies.

market power in the industrial-equipment sector; their strong in-house expertise in manufacturing technology (Krzywdzinski, 2021).

Building on these three general categories of key German IIoT entrants, we used insights from our interview data (see below) to identify specific firms on which our in-depth case studies have focused. In sum, the following 12 companies were selected to represent the variety of German ‘smart manufacturing’ technology providers: (1) seven major companies from the MPE industry—including the two large German multi-technology conglomerates (Bosch and Siemens) and five smaller firms representing three different manufacturing-equipment sectors (industrial robots, machine tools and automation solutions); (2) two established domestic companies from the enterprise-software industry (SAP and Software AG); (3) the three main German car manufacturers (BMW, Daimler and Volkswagen).

Regarding the second dimension of our analysis, we have first conducted exploratory empirical research on the relevant German and EU-level government interventions related to the policy discourse of ‘digital sovereignty’. In doing so, our main focus was the possible impact of the policy interventions on the IIoT ecosystem relations between multi-national cloud-service suppliers and the domestic firms specializing in the more domain-specific solutions. Overall, we have found out that a large variety of relevant government activity can be identified—ranging from legally binding EU-level regulations (e.g., within the proposed Data Governance Act) to basic research and development projects and state support for specific (pre)competitive industrial-cloud technologies. While it lies beyond the scope of the present article to discuss the full range of these policy interventions, we have decided to focus on one particular type of government involvement to explore the political-economic dynamics that structure the emerging industrial platform economy in the EU. More specifically, we will analyse the possible impact of government-supported but market-based technological solutions, by means of which German public agencies have intervened into the IIoT ecosystem. We will discuss three examples of such non-legislative intervention: (i) interoperability standards; (ii) inter-firm data-sharing frameworks and (iii) the much-discussed case of the Gaia-X project.

In terms of data collection and analysis, our study integrates two strategies (see Table 1). First, we rely on interview data. Between January 2019 and October 2021, we conducted 17 industry-expert interviews (14 online interviews and 3 offline interviews in Berlin, Munich and Frankfurt am Main), which lasted from 1 to 2 hours. All interviews

were recorded, transcribed, and then analysed (deductively and inductively) with a thematic focus on: (i) the technological structure of the IIoT 'smart manufacturing' ecosystem; (ii) the related IIoT platform strategies of the German and multi-national technology firms and (iii) the ecosystem involvement of German public agencies. *Second*, our analysis builds on a large set of online materials describing the relevant firm and government activity (see Table 1).⁵ To gather a large and possibly diverse set of materials, we relied on two research assistants for the data collection—which also increases the objectivity of our dataset. In total, 1429 online sources were collected for the present study. When analysing the data, we used bibliography management software to sort the empirical material into a number of categories describing different aspects of the firm and government IIoT strategies. We then applied these categories to re-construct the historical competitive and collaborative dynamics in the emerging 'smart manufacturing' ecosystem. In addition, during the entire process of data collection and analysis, we were triangulating the insights from the archival data by integrating them into our interview guidelines and discussing them with our interview partners.

In the following section, we present the results of the empirical analysis, which, for reasons of space, will be condensed to high-level summaries complemented by a selection of more in-depth case-specific insights.

POSITIONS OF GERMAN TECHNOLOGY FIRMS IN THE GLOBAL IIOT ECOSYSTEM

Multi-technology conglomerates

We first focus on the strategies of the two multi-technology conglomerates, Bosch and Siemens. Due to their rather exceptional organizational scale and market power, we will discuss them separately from the other, relatively smaller manufacturing-technology producers (see the next sub-section).

In the mid-2010s, both firms launched very ambitious IIoT platform strategies. The *first* one, Bosch, wanted to become a globally leading provider of digital services for different technology sectors, including connected vehicles, smart homes and industrial manufacturing. To achieve this goal, the company tried to capitalize on its existing capabilities in the production of hardware, sensors or electronics in these different technological domains. Regarding the firm's position within the IIoT stack, Bosch initially attempted both to develop its own IIoT software and to operate its own cloud infrastructures. Yet, these ambitious plans proved very difficult to achieve. Around 2017, the company decided to drop the idea of building an end-to-end IIoT platform and started moving its digital services (including 'smart manufacturing' applications) to the cloud infrastructures provided by multi-national firms such as Amazon or Microsoft. The *second* company, Siemens, followed a different path—but also came to increasingly rely on the multi-national cloud suppliers. Siemens' IIoT strategy revolves around the platform brand MindSphere, which was launched around 2016 and is conceived as a commercial IIoT service for clients from the manufacturing sector and beyond. The platform offers a broad range of functionalities—from machine connectivity to frontend IIoT applications. The main difference in comparison to Bosch is that the platform strategy of Siemens did not include the idea of hosting industrial data on own cloud infrastructures. Instead, the company initially relied on infrastructure services provided by the key German enterprise-software firm, SAP. Later, Siemens started developing closer ties with the two dominant multi-national cloud suppliers, Amazon and Microsoft. In the following paragraph, we will take a closer look at how the company has positioned itself within the multi-layered IIoT stack in the process.

First, in the connectivity layer, Siemens benefits from its pre-existing technological capabilities in industrial networks and controllers. As an established provider of these technologies in Europe, the company holds an important advantage within the IIoT ecosystem—this point has been stressed by many of our interview partners. Clients who already own Siemens' factory-automation systems are likely to select MindSphere as their platform solution. Moreover, adding to the positive effect of the installed base of legacy technologies, Siemens MindSphere integrates also various new connectivity solutions (including open standards) that allow the users to connect diverse industrial

devices to the platform. *Second*, regarding the infrastructure layer, MindSphere relies exclusively on the technologies of established external suppliers. More specifically, the company managers stressed that the infrastructure services provided by the dominant multi-national firms bring with them the advantage of geographically well-developed data-centre networks (Kuppinger, 2018)—which is a critical consideration if MindSphere is to become a truly global-scale service. But at the same time, the partnerships with the ‘tech giants’ also imply significant risks for Siemens. For instance, when MindSphere is implemented on AWS or Microsoft Azure, it uses a large (and increasing) number of back-end services provided by the multi-national partners. This reduces the company’s value capture within the IIoT ecosystem and, in the long run, may also strengthen the position of the involved multi-national cloud-industry partners as independent IIoT technology providers. Finally, *third*, at the layer of the frontend services, Siemens has been quite successful in developing the portfolio of applications attached to MindSphere—which is an important factor determining the market attractiveness of IIoT platforms. Most of the applications were introduced either by Siemens itself or by companies that are organizationally linked to it. In addition, the company has taken various steps to stimulate third-party development. For instance, in 2018, Siemens acquired the American software producer Mendix, which provides user-friendly ‘low-code programming’ tools for application developers.

Manufacturing-technology specialists

Another important group of German IIoT entrants are the somewhat smaller firms specializing in the production of diverse manufacturing technologies, including industrial robots, machine tools or automation solutions. Since around 2015, a number of such companies have attempted to launch their own IIoT platforms. Some of them, however, have already withdrawn from the market, while in other cases, commercial success remains uncertain.

The challenges related to operating own IIoT platforms can be illustrated by the case of two medium-sized firms from our sample—an industrial-robots company (RoboTech) and a producer of metal-cutting machine tools (ToolTech).⁶ Both firms had well-established positions in their respective product markets and both of them attempted to launch IIoT platforms for external clients characterized by: (i) large spans of control within the IIoT stack (including own data centres); (ii) open interfaces allowing the integration of third-party devices at the physical machinery layer and (iii) broad sets of frontend IIoT applications. However, both of the companies failed to achieve their ambitious goals. The IIoT platform by RoboTech was, in fact, never launched as a commercial product, and the platform by ToolTech was abandoned after around 4 years of operation. Comparing the experiences of these two firms to the platform strategies of the multi-tech conglomerates discussed above, we may identify the following three factors that contributed to these failures. First, both companies lacked technological and organizational capabilities to gather a ‘critical mass’ of IIoT applications attached to the platforms. In addition, within their IIoT platform strategies, the two firms could not rely on any system-relevant IIoT technologies (such as connectivity solutions). And finally, both firms failed to develop strategic partnerships and well-thought-out divisions of labour with external technology suppliers (e.g., with the established cloud-infrastructure providers).

However, in our sample, we identified also other IIoT strategies by the smaller manufacturing-technology firms, which may represent viable alternatives to the model of a single-firm IIoT platform with a broad span of control. *First*, two of the case-study companies decided not to launch commercial IIoT platforms of their own but rather focused on up-grading their established products by developing various product-specific applications that could run on platforms or infrastructures operated by larger IIoT firms. *Second*, there is the noteworthy case of the Adamos IIoT platform, which illustrates how relatively small technology producers can join forces to try to overcome the disadvantages of scale and develop some platform-relevant capabilities. Adamos was launched in 2017 by four mostly domestic machine-building specialists (DMG Mori, Dürr, Zeiss, ASM PT) and a well-known German enterprise-software firm, Software AG⁷. Later, two other established machine-tool builders (Karl Mayer, Engel Austria) and the global consultancy PwC joined the initiative. In terms of its ecosystem scope, the Adamos platform wants to deliver a broad range of IIoT functionalities—from device connectivity and edge services to diverse frontend applications. But importantly,

many of these inputs are provided by specialized external partners. At the frontend application layer, the platform offers an app store with products supplied by both the platform owners and various third-party complementors. Regarding backend software, the key components are provided by the sole IT specialist within the joint venture, Software AG. In terms of data hosting, the Adamos platform does not rely on its own cloud infrastructures, but rather on the services of multi-national tech firms—of which the Microsoft Azure cloud was mentioned in our data most explicitly.

Enterprise IT firms

Beyond industrial-technology and cloud-infrastructure firms, the IIoT ecosystem has attracted various entrants from the enterprise software sector (Cho et al., 2018). In the German case, the most relevant ones have been Software AG and SAP—the country's two largest EIT companies.

The *first* one, Software AG, has already featured in this study as the technology partner of the Adamos IIoT platform (see the previous sub-section). The main contribution of this firm to the Adamos joint venture has been to provide a bundle of backend IIoT components supporting such platform functionalities as device connectivity or data management. But importantly, Software AG has also been selling the same set of technologies under the brand name 'Cumulocity IoT' to other customers and in other vertical IIoT markets. In addition, within the 'smart manufacturing' domain, the company provided data-management modules for the MindSphere platform and was a technology partner of Bosch. What all these different examples indicate is that Software AG does not intend to position itself as an independent platform operator but rather as a specialist supplier of the backend IIoT software components. In this way, the company avoids entering into direct competition with the dominant cloud-industry multi-nationals (such as Amazon or Microsoft). But at the same time, this ecosystem position may become much less secure if the 'big tech' firms—with their much greater innovation capabilities—decide to diversify towards the more domain-specific IIoT functionalities.

The *second* key German EIT firm active in the 'smart manufacturing' domain, SAP, is one of the leading global producers of ERP software. In the early 2010s, responding to the growing demand for online services, the company started massively up-grading its cloud computing capabilities and established its own data-centre infrastructures. Around 2016, SAP decided to enter the IIoT market and, in doing so, followed a two-pronged strategy. On the one hand, the company provided cloud-infrastructure services to various commercial IIoT platforms—the most prominent example of this being its involvement with Siemens MindSphere. On the other hand, SAP decided to launch its own industrial platform called Leonardo. This platform was conceived as an end-to-end IIoT service and provided a broad portfolio of applications in a number of different domains, including 'smart manufacturing'. However, neither of these two strategies was successful. *First*, as the provider of cloud-infrastructure services, SAP has been steadily losing ground to multi-national competitors such as AWS or Microsoft. One important reason for this—as we indicated also above discussing the Siemens MindSphere case—was that the global cloud suppliers were able to offer data-centre networks with larger geographical footprints. In addition, the scale of SAP's cloud-infrastructure business may have been too small to achieve comparable profitability levels (Ried, 2020). And *second*, regarding the Leonardo platform (which was abandoned in 2020), the company's limited success in the manufacturing domain was related to the fact that, as a producer of mainly enterprise software, SAP may have lacked relevant technological capabilities in the digitalization of physical production processes.

But at the same time, despite the failure of its two earlier IIoT platform strategies, SAP has recently managed to outline a new approach—focusing, this time, on the provision of higher layer IIoT functionalities. Within this new strategy, SAP is developing a technological partnership with Microsoft and plans to use both the cloud infrastructures and some back-end services of the Azure platform. Regarding its own inputs, the company plans to provide various frontend applications in the domains of manufacturing and supply-chain management.

Car manufacturers

The fourth and final group of German firms included in our study are the country's three largest car manufacturers—BMW, Daimler, and VW—who are trying to position themselves not only as users, but also as developers and providers of IIoT platforms. In doing so, however, these firms have relied heavily on technological partnerships with the key US-American cloud-industry companies (Liu, 2019).

The *first* of the three carmakers, BMW, launched its 'smart manufacturing' initiative in 2019—building on a close collaboration with Microsoft. The project, known as Open Manufacturing Platform (OMP), is conceived as a manufacturer-independent digital ecosystem open to firms from the automotive sector and beyond. In technological terms, OMP uses Microsoft Azure at the cloud infrastructure layer and provides its own data model and a reference architecture as the back-end software resources, which the ecosystem members may use to develop their own firm-specific frontend solutions. The *second* carmaker, Daimler is following a somewhat different strategy. The company is also using Microsoft's cloud infrastructure, but, in contrast to BMW, it has not announced any plans to open its platform ecosystem to external complementors or users. Interestingly, around 2018, Daimler had already decided to re-locate its entire supplier-management system (based on SAP software) to Microsoft Azure—which indicates a risk of significant technological dependency on one foreign tech supplier. And finally, *third*, there is the case of VW, which, since 2019, has been building an IIoT platform together with AWS. Relying on diverse cloud-based 'microservices' provided by the tech giant, VW wants to develop a range of own frontend IIoT applications. The platform will have two relatively independent elements. First, it will gather and analyse data from the carmaker's over 120 world-wide factories based on AWS cloud. In addition, a cross-firm data ecosystem should help the company manage its relations with over 1500 suppliers. Let us discuss this case in more detail to explore how the carmaker has managed the technological partnership with AWS.

Based on our interview data, two aspects of VW's complex platform project are important to understand the logic of the collaboration with the cloud supplier. *First*, there is the question of the very decision to enter into the technological partnership with AWS. Given its large organizational scale, VW could, theoretically, have built the needed cloud infrastructures on its own. Our respondents, however, argued that this kind of project would have been more expensive and much slower to implement than the reliance on AWS technology. In addition, own cloud infrastructures could also hardly have matched the AWS services in terms of security and geographical availability. Another argument to develop the partnership with Amazon was related to the structure of VW's overall cloud-supplier base. A few months before the IIoT platform project was made public, the company announced a plan to develop an autonomous-vehicle ecosystem based on technologies provided by Microsoft. Thus, the later decision to build the IIoT platform with AWS (and not Microsoft) was meant to offset a possible overreliance on one foreign tech supplier. The *second* key question is the issue of data governance within the 'smart manufacturing' project. As a precondition for any of the two envisaged platform functionalities coming into operation, the cloud-based analytics provided by AWS will have to gain access to sensitive data describing VW's production and logistics processes (Kroker, 2020). This creates serious risks for the carmaker, including the possibility of intellectual property leakages. Therefore, to ascertain VW's sole control over its production data, the 'big tech' supplier had agreed to integrate various contractual and technical data-governance measures into the platform project. One example of this is the full encryption of the carmaker data stored in the AWS cloud.

Government ecosystem involvement

The above case studies indicate some important similarities between the platform strategies of the established German technology firms. Despite various sector- and firm-specific differences, these companies have ended up positioning themselves on the relatively higher layers of the IIoT ecosystem—while relying on the cloud services provided

by the foreign 'big tech' players at the more infrastructural technology layers. Notwithstanding the possible benefits of inter-firm specialization, this emerging division of labour creates some significant risks for the German companies. For instance, it may lead to a decrease of the firms' value capture within the IIoT ecosystem, or entail a loss of control over industrial data processed by the platform-based applications. However, diverse industrial-policy initiatives have recently been launched in the EU and Germany that attempt to strengthen the positions of the domestic IIoT actors vis-à-vis the established cloud infrastructure providers. In the following, we will explore one specific category of government intervention: the state support for technological solutions and standards, which may reshape the architectural interdependencies within the IIoT 'smart manufacturing' ecosystem. Focusing on Germany, we have identified three relevant cases of this kind of government involvement.

First, there are the voluntary technological standards. One early example is the support provided by German government agencies and industry associations for the technological standardization processes related to the 'Industrie 4.0' initiative. These include: the RAMI 4.0⁸ architectural framework, which introduced a technological model for the digital integration of the different IIoT layers and manufacturing value-chain segments; or the OPC UA communication standard, which facilitates interoperability between diverse physical machineries and other digital ecosystem components. Beyond their purely technical role, establishing such voluntary standards may help European industry actors prevent the IIoT ecosystem from 'locking in' to proprietary technologies (David & Greenstein, 1990) provided by the established multi-national cloud-infrastructure providers. *Second*, the German government (together with national industry associations) has supported the development of non-commercial organizational frameworks for inter-firm data sharing that may become an alternative data governance model to the one based on proprietary cloud infrastructures supplied by the 'big tech' companies. For example, the project called International Data Spaces (IDS) combined different infrastructure services available on the market through a common vendor-independent interface in order to allow industrial cloud-technology users to maintain control over their data (Gelhaar & Otto, 2020). And finally, *third*, there is the Gaia-X project—on which we will focus in more detail.

Gaia-X was initiated by the German Ministry for Economic Affairs in 2019 (BMW, 2019); later in the same year, the French Ministry of Economy became the second coordinating partner in the project. In 2020, the governments handed over the initiative to 22 private firms—11 from each country. In technological terms, Gaia-X can be described as an additional software layer within the IIoT stack, which is positioned below the frontend application layer and which gives the end-users various instruments to manage the underlying backend or cloud-infrastructure services. In the long run, this software layer should be available in a number of sector-specific variants—including dedicated frameworks for such different domains as manufacturing, energy or healthcare. In terms of the project's impact on inter-firm relations, the domain-specific Gaia-X solutions will not try to compete with the commercial cloud services available on the market. Rather, similar to the idea proposed earlier by the IDS initiative, Gaia-X wants to mediate the access to the existing services through its own software interface, a set of organizational rules and a marketplace for third-party data stored in the cloud.

However, as beneficial as Gaia-X may eventually become for the domestic IIoT actors, its success remains uncertain. One of the key open questions is the impact of the inclusion into the project of the three main US cloud-technology companies (AWS, Microsoft and Google), which occurred in 2020. The decision to include these firms seems problematic in particular given the project's initial goal of strengthening the EU's 'digital sovereignty' vis-à-vis the multi-national tech firms. Second, the extent to which European industrial-cloud users will actually select this government-sponsored technological framework for their IIoT platform strategies is also unclear. The overreliance of the domestic firms on foreign cloud infrastructures may raise concerns related to national security (Farrell & Newman, 2019) and may create risks of technological dependency for the companies themselves. But at the same time, given the various economic benefits of inter-firm specialization, many European companies may nevertheless keep developing technological partnerships with the established multi-national cloud providers. And finally, third, Gaia-X initiative remains dependent on the availability of government funding—which, especially in the context of the recent geopolitical disruptions and the related economic pressures in the EU and Germany, can no longer be taken for granted.⁹

SUMMARY AND CONCLUSIONS

Adding to the recent GVC literature on the emerging global-scale divisions of labour in technologically complex sectors of the platform economy (Brun et al., 2019; Sturgeon, 2021), this article has explored the transnational competitive and collaborative dynamics in the 'smart manufacturing' IIoT ecosystem from the perspective of German industry. Our study makes two main contributions to the literature.

First, we advance the conceptual framework for the analysis of inter-firm relations within the globalized platform economy by introducing the perspective of GTEs. This new approach combines the notions of GVC governance and up-grading with a non-linear conceptualization of inter-firm dependencies as relations between different component producers contributing to a common technical system. Instead of analysing linear supply-chain transactions, this approach focuses on the complex technological architectures of the digital in order to investigate how different ecosystem actors compete for the control over key platform technologies and, in doing so, strategically shape their technological interdependencies with other ecosystem actors. In contrast to various more established perspectives on the inter-firm dynamics in the platform economy, the proposed framework does not treat online platforms as monolithic entities, which insert themselves into traditional value-chain arrangements, but rather sees the platforms as global-scale technical systems dependent on inputs from a diverse set of technological actors. In addition to the inter-firm dynamics, the proposed perspective draws on the notion of multi-polarity discussed in the GVC literature to highlight the role of external political-economic processes in ecosystem governance. This includes the possible impact of technology-specific regulatory or institutional frameworks (e.g., technological standards) by means of which government or industry actors may try to create—or destroy—system-internal technological 'bottlenecks'. In terms of its broader relevance for the research on the globalized platform governance, the GTE perspective can be applied to study competitive and collaborative dynamics in various sectors of the platform economy, in which diverse technological components and capabilities are needed and a heterogeneous set of technology suppliers can be expected.

Our second main contribution to the literature is an improved understanding of the inter-firm and political-economic dynamics in the global-scale IIoT 'smart manufacturing' ecosystem from the German perspective. While these dynamics are still relatively new phenomena and their characteristics may further evolve over the coming years, our study offered three sets of empirical observations on the emerging vertical specialization pattern between German and US-American IIoT platform firms (see Figure 2). *First*, the four presented sectoral case studies have provided a multitude of firm-specific evidence of the US technology giants becoming key cloud-infrastructure suppliers for German IIoT platforms. More specifically, our analysis suggests the following three key factors explaining the success of the US firms vis-à-vis German competitors: (i) these firms' already accumulated base of data-centre infrastructures, (ii) their scale advantage over the local cloud suppliers and (iii) their global operational reach—corresponding with the globalized market strategies of many German IIoT platform firms. In addition, seen from the perspective of the German technology providers, in some of the analysed cases, we have observed processes of functional down-grading (Blažek, 2015) in relation to the US-American cloud-technology suppliers. This refers to those firms that either abandoned their initial end-to-end IIoT platform business models or reduced their ecosystem scopes based on the technological partnerships with the 'big tech' firms.

Second, regarding the sectoral specificities of the analysed platform strategies, our case studies revealed how the German IIoT entrants have used different pre-existing technological or organizational capabilities to position themselves within the technological ecosystem of 'smart manufacturing'—and what kinds of challenges they have faced in the process. In the case of the multi-technology conglomerates (Bosch, Siemens), we note that the firms have a relatively strong ecosystem position grounded in their large organizational scale and their established competences in the production of industrial hardware, software and connectivity. For the relatively smaller industrial-technology firms, who lacked a comparable organizational scale and strong capabilities in system-relevant components (e.g., connectivity), the situation was more difficult. One interesting exception was, however, the case of the joint-venture IIoT platform project (Adamos), which indicated that medium-sized machine-building companies can cluster together

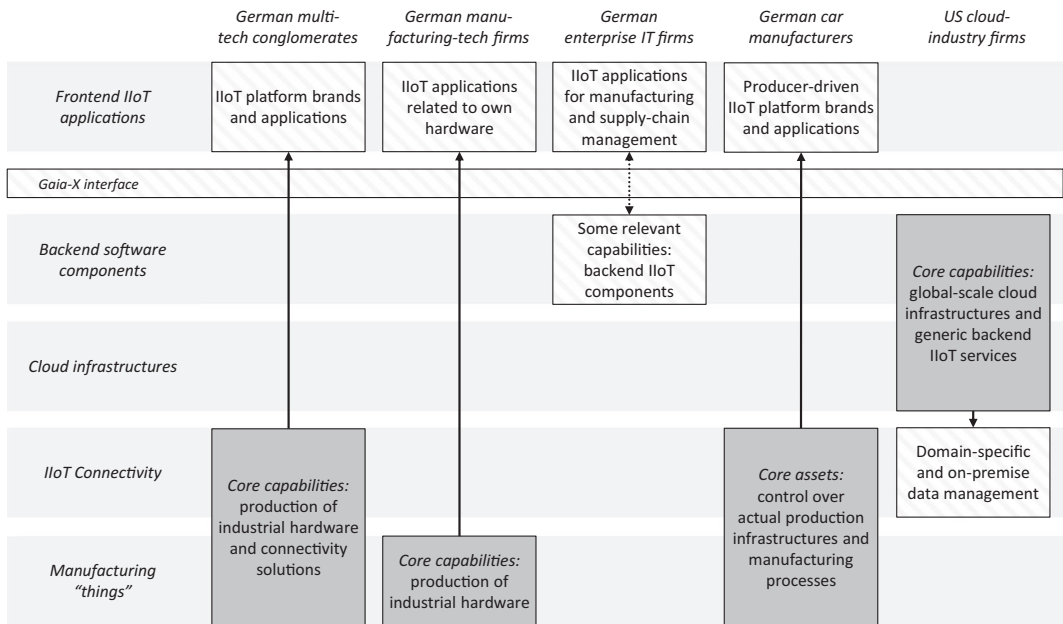


FIGURE 2 Stylized positions of the case-study firms in the ‘smart manufacturing’ IIoT ecosystem. Full dark grey = established actor positions; patterned light grey = key emerging actor positions. Source: own elaboration

to develop various resources necessary for platform-oriented innovation. Furthermore, the German EIT producers also exhibited quite precarious trajectories. These firms faced growing competitive pressures from the multi-national cloud-technology suppliers and, at the same time, lacked relevant domain-specific capabilities in the digitalization of manufacturing processes. Finally, the three dominant German carmakers have managed to launch their own IIoT platform projects based on close collaborations with the US-American cloud-industry firms. Our in-depth analysis of the VW case revealed that the carmaker has taken a number of steps to reduce the risk of technological dependency on the foreign tech partner and to maintain sole control over the production data.

While the presented company case studies refine our understanding of the competitive and collaborative dynamics between the different ‘smart manufacturing’ technology providers, our *third* empirical contribution in this study is the reconstruction of the characteristics and possible impacts of the recent IIoT ecosystem interventions by German government actors. The three cases of government-supported initiatives that we described focused on developing technological solutions or standards, which (if successful) could loosen the ‘bottleneck’ of cloud infrastructure services within the multi-layered IIoT architecture. Our main example was the high-profile Gaia-X project, which introduced to the market a vendor-independent software interface allowing cloud-technology users and providers of higher-layer IIoT applications to manage the more infrastructural ecosystem components (such as data storage or back-end software services). However, as we have observed, the Gaia-X initiative has faced significant challenges related to the issues of market adoption, the involvement of ‘big tech’ companies in the project or the further availability of government funding. Considering this, our study brings into question the extent to which such direct ecosystem interventions by EU governments will be able to reshape the competitive and collaborative dynamics between the domestic and foreign IIoT firms. At the same time, future research should investigate more closely how policymakers in the EU may try to apply various alternative—but also complementary—instruments (e.g., legally binding regulations) in order to pursue the goals of the ‘digital sovereignty’ discourse in the industrial platform economy.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Research data are not shared due to privacy and ethical restrictions related to the need to protect anonymity of our respondents and/or of the firms we studied.

ENDNOTES

- ¹We acknowledge that the GTE concept could also benefit from applying the cognate global production networks (GPN) approach. However, GPN's strong spatial-geographical focus (Yeung 2008) makes this approach less relevant for our framework.
- ²This purposive case selection implies that the study does not include some other German IIoT players – such as start-ups, telecom firms, or IT consultancies, which still seem to play a minor role as “smart manufacturing” technology providers.
- ³ERP stands for enterprise resource planning applications and MES for manufacturing execution systems.
- ⁴Abbreviations in Table 1: VDMA: German Mechanical Engineering Industry Association; VDW: German Machine Tool Builders' Association; BMWi: German Ministry of Economic Affairs.
- ⁵Since our archival data collection focused on the European market, the study does not cover the firms' strategies in other regions, where we may expect already different inter-firm arrangements.
- ⁶We anonymise these two firms (our respondents) in order to protect their identities – which is important in particular because their IIoT platform strategies failed.
- ⁷The IIoT strategy of this firm is discussed below.
- ⁸'RAMI 4.0' stands for: Reference Architectural Model Industrie 4.0.
- ⁹For instance, following the outbreak of the Ukraine war in February 2022, the new German government decided to cut the funding for the development of some new domain-specific Gaia-X use cases.

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