Robotising, but how? Evidence from the automotive sector in South Africa

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Abstract

Purpose. This paper focuses on understanding firm-level determinants of industrial robots' adoption and how these determinants result in heterogenous processes of robotisation across firms within the same sector. The paper presents results from in-depth case studies of final assemblers in the South African automotive sector.

Methodology. The research has been conducted through multiple case studies with a focus on final assemblers. During the case studies, as well as before and after it, data coming from in-depth semi-structured interviews were triangulated with secondary data available from the international database on industrial robots' adoption and documents provided by firms and institutions.

Findings. This paper identifies three firm-level determinants of robotisation – i.e., modularity of the production process, flexibility in the use of technology and stability in product design. The results also showed that firms' robotisation depend on each of these determinants as well as their interdependence. We introduce a framework to study interdependence between these technology-organisational choices, which reveals heterogenous patterns of technology deployment and related managerial implications.

Originality/value. This research introduces a new framework on factors driving industrial robotisation – a key digital production technology – and offers empirical evidence of the heterogenous deployment of this technology. We identify two main manufacturing approaches to robotisation in the automotive sector: one in which the firm designs a robotized process around a certain product design – i.e., the *German/American way*, and one in which the firm designs its product based on certain robotized processes – i.e., the *Japanese way*. These findings are valuable for both industry, operational research, and the scientific community as they reveal heterogeneity on the 'how' of robotisation, and implications for manufacturing technology management.

1. Introduction

Despite the increasing focus on digitalisation and the so-called Fourth Industrial Revolution, the relationship between digital production technologies and firm-level organisational models remains largely unexplored. The high degree of novelty of Industry 4.0 technologies and their interconnectedness, such as the Industrial Internet of Things, can generate technological improvements within the firm and along supply chains (Kagermann et al., 2013; Li, 2018). Industry 4.0 innovations have led to deep changes in production processes, and the tendency towards full automation has been one of the most important characteristics. Although robotisation dates back to the 1960s, today's intelligent automation involves a new way of organising production, data collection and innovation systems, which constitutes an essential step towards the full digitalisation of Industry 4.0 (Doms et al., 1997; Sung, 2018).

The present paper looks at firm-level factors determining the adoption of industrial robots and the resulting different deployment in production – i.e., the ‘how’ of robotisation. Academic investigations into robots' adoption have primarily focused on labour replacement, and the related labour displacement effect, as main driver of robotisation, while overlooking other elements that may play a critical role (Graetz and Michaels, 2017; Acemoglu and Restrepo, 2017). In addition, the labour-based argument leads to the belief that robotisation is mainly driven by high wages, thus supporting the idea that robots are 'coming for our jobs', especially in Western countries characterised by higher wages (Krzywdzinski, 2021). Less consideration has been given to the fact that robots may also involve significant changes in the organisation of production operations

(Dixon et al., 2021) and that, as a result, from an organisational integration perspective, deployment of the same technology might be highly heterogenous even *within* the same sector.

Several studies try to understand determinants of technology adoption beyond the labour substitution argument. Khin and Kee (2020) discuss a series of facilitating and impeding factors related to skills, finance, and ecosystem enabling factors. Havle and Ucler (2018) introduce three dimensions of technologies enablers: human, organisational and technology. Impediments (or obstacles) are also widely discussed. For example, Moktadir et al. (2018) showed that lack of technological infrastructure represents the most pressing challenge hindering Industry 4.0, while Herceg et al. (2020) found that lack of competencies and financial resources are the greatest barriers. Such contributions are important as they shift the focus towards operational, managerial and organisational capabilities and firm level determinants that are highly complementary to other market and business determinants (and opportunities).

Far less attention has been given to what we could call 'shopfloor-level determinants' inducing industrial robots' adoption – or more in general digital production technologies adoption – and the potential heterogenous deployment of this technology from an organisational integration perspective. In fact, contributions have often stepped away from the shopfloor analysis of robotisation to focus more on smart manufacturing (Ghobakhloo, 2018; Enrique et al., 2022). Even when shopfloor level analyses have been conducted, they hardly look at robots in particular. Scannell et al. (2011) discuss shop level dynamics of technology adoption through the theory of planned behaviour. They include in their study technologies such as computerized numerical control (CNC) and direct numerical control (DNC) machines, material working lasers and robots, yet they purposefully exclude a subset of AMT (Advanced Manufacturing Technologies) such as material handling technologies, automated inspection and testing equipment.

In this paper we fill these gaps and contribute to a growing literature on the dynamics of industrial robots adoption through a theory building process informed by a set of case studies that are particularly illuminating for the process of theory building (Eisenhardt and Grabner, 2007). Specifically, we focus on the automotive sector where more than 35% of all industrial robots in manufacturing are used (according to International Federation of Robotics data), and on those firms in the sector who are the most important adopters of robots – i.e., final assemblers (from now on OEMs). To fill this gap in the literature on shopfloor level determinants of robotisation and heterogenous organisational approaches to their integration into production, we draw on several rounds of semi-structured interviews conducted between 2019 (April and September) and 2022 (September), involving six out of the seven OEMs in South Africa, and two system integrators firms.

We identified three interdependent determinants of robotization: (i) the degree of modularisation of production processes at the firm level; (ii) the degree of flexibility in the use of automation technologies; and (iii) the degree of stability in product design, which is the extent to which product design features remain invariant along different product cycles. We find that these elements interact, and their interaction gives rise to two distinctive manufacturing approaches to organisational integration of robot technology across multinational OEMs operating in South Africa. The first model is mainly associated with the German final assemblers (OEMs) BMW and VW and, to a certain extent, with the American OEM Ford. The second model characterises Japanese OEMs Toyota, Nissan and Isuzu. These two different organisational integration models result in high heterogeneity in robots' adoption, in the intensity of such adoption, and in the level of retrofitting capabilities needed to deploy robot technologies effectively. We also find confirmation of the existing evidence highlighting how deployment of industrial robots is affected by different institutional, cultural and managerial contexts (Lazonick, 1990; Jürgens et al., 1993; Krzywdzinski, 2021).

This paper is structured as follows. Section 2 reviews the literature identifying the main contributions focusing on factors driving robotisation and on the automotive sector and some sector specific dynamics regarding robotisation. Section 3 presents the research design and the data collection process. Section 4 introduces the main findings and discusses the two different integration models across the business firms interviewed for this study. Finally, section 5 discusses the theoretical and industrial contributions and concludes.

2. Literature Review

Determinants of robotisation

Two main strands of the literature have attempted to analyse determinants of industrial robots' adoption. First, mainstream economic literature focuses on capital substituting for labour and tests empirically the extent to which automation and robotisation are replacing jobs (Graetz and Michaels, 2017; Acemoglu and Restrepo, 2017). This literature has mainly advanced by introducing more refined hypotheses supported by task-level analysis and skill-biased technological change arguments, an attempt to overcome the shortcomings of initial studies that looked at jobs rather than at tasks with different skills intensity. Second, the management literature has focused more closely on the determinants of robotisation, however mainly looking at innovation ecosystem types of factors, such as skills, access to finance, technological infrastructures, and capabilities (Khin and Kee, 2020; Matt et al., 2021; Pillai et al., 2021 on auto components; Boyer and Kokosy, 2022).

The management literature acknowledges that technological change is highly firm-specific, and the ways in which firms adopt and deploy new technologies is shaped by how firms seize technology-value opportunities through organisational change (Teece, 2018; Müller et al., 2018). One of the widely used framework to assess why new automated technologies are adopted is the TOE (Technology Organisation Environment). TOE has been deployed to explain the implementation and adoption of innovation (Depietro et al., 1990; Pillai et al., 2022). For example, Choi et al. (2018) use TOE to explain the adoption of intelligent robots in manufacturing SMEs. There are two main issues with the TOE framework; first, the three dimensions considered - technology, organisation and environment - are defined in general terms and, as a result, they can be specified differently depending on the context and level of analysis. Second, TOE tends to be static, that is, it provides the same interpretative framework even though relationships among variables considered evolve and change over time (e.g., advanced manufacturing technologies in the 1990s is characterised by different dynamic from digital production technologies in more recent times) (Bryan and Zuva, 2021). Furthermore, the organisational element of the framework neglects aspects of organisational learning, which are key to firms' productivity and to create flexible and adaptable learning mechanisms when technological and organisational changes are required.

Organisational learning is central to the resource-based theory of the firm (Barney, 1991; Penrose, 1959), where particular emphasis is given to firm specific resources that cannot be imitated by others, and that can be deployed to create profits and to initiate competitive advantage (Chang et al., 2015). The resource-based view directly links the effectiveness of the firm to its resources and their abilities to operate, learn, adapt and reconfigure when organisational and technological changes occur (Baden-Fulle and Haefliger, 2013; Andreoni, 2014; Martinez-Caro et al., 2020). Particularly, such theory stresses the interdependencies between labour and capital, as well as between technology and organisation, and the development of individual and collective capabilities that are key to further technology adoption and increase in productivity at the shopfloor level (Lazonick, 1990). Although the resource theory of the firm does not provide a detailed framework to study specific technologies (and automation technologies such as industrial robots), this theoretical approach focuses on the shopfloor level as the place to analyse organisational integration of new technologies. In addition, this theory accounts for the fact that technologies can be integrated differently from an organisational perspective, even when firms adopt the same type of technology to produce similar products within the same sector. For example, the automotive sector is characterised by highly diverse use of technologies by final assemblers: firms like Toyota are known for their lean production methods and their approach to cost and waste reduction, which are aspects that are reflected by a more flexible and continuous use of production technologies (Jürgens, 2021; Krafcik, 1988).

The automotive sector and robotisation

The automotive industry is a critical one in the study of technology adoption decisions because it is a sector where process automation, and specifically robotisation, is more advanced due to some intrinsic sectoral characteristics such as its capital intensity, high economies of scale and high skill requirements to perform specialised tasks. The sector has been a fertile field both for technology innovations, such as the fully automated machines and industrial robots since the first introduction by General Motors in the 1960s (Michalos et al., 2010), and for organisational innovations such as Taylorism and the Toyota-led lean production organisation (Sjoestedt, 1987). Regarding determinants of automation technologies there are few contributions that explore this relation. On industrial robots specifically, Anzolin et al., (2020) look at what drives the adoption of industrial robots in the automotive sector, and they find that ecosystem variables such as the competitiveness and the innovativeness of the country matter more than foreign direct investments for industrial robots use. A recent contribution by Pillar et al. (2022) looks at AI empowered industrial robots to find that perceived compatibility, perceived benefits, external pressure and support from vendors are significant predictors of adoption. Compatibility refers to the degree to which a technology such as industrial robots is consistent with the existing business process, practices and value systems (Roger, 1995). Benefits are both direct – e.g., operational savings and firm level efficiency – and indirect – e.g., impact of the technology on business processes and relationships (Iacovou et al., 1995) and they are part of the expected advantage that can occur at the organisational level following the adoption of technology (Oliviera and Martins, 2010).

In the automotive sector, the interrelation between technology and organisation, discussed in the previous section, and the feasibility of automation from a material-technical conditions perspective are key elements impacting automation and robotisation processes. For example, the complexity of product and production process, the varieties of parts and the variability of production environment, together with volumes, flexibility and business strategies are all critical aspects that determine the use of robots, and automation more in general (Fujimoto, 1997; Krzywdzinski 2021). Among these factors, the literature focusing on microlevel dynamics of robotisation in the automotive sector has discussed three elements – i.e., flexibility, design, and modularity.

First, flexibility intended as producing a wide variety of products adapting to market segments and changing demand and, second, deploying continuous flow principles, are both important source of competitive advantage for Japanese OEMs. Japanese OEMs consider the cost reduction potential of robots only if the desired flexibility can be maintained (Jürgens et al., 1993; Katobe et al., 2011). Differently, German companies such as VW see high-tech process automation and robotisation as a prerequisite for high product quality and overall productivity, while flexibility is considered less important (Krzywdzinski, 2021).

Second, there is also a relationship between product architecture/design and automation technologies, with the literature suggesting that a product design that tends to be more stable across time allows for a longer use of existing production technologies (Sjoestedt, 1987; Shivankar and Deivanathan, 2021). Recent case study evidence supporting this argument comes from Germany where the level of automation, in the VW plant in Zwickau, increased from 12% to 30%. The plant is producing new electric cars, whose drivetrain is much simpler than combustion engine' cars, which are a product characterised by fewer parts and less production process complexity (Krzywszinski, 2021).

Lastly, also the simplification of production process that was promoted by the emergence of modularization in the 1990s played a role in increasing automation, yet only if it is associated with high level of technological capabilities (i.e., abilities to adopt and learn from new technologies) (Kotabe et al., 2011). With modularization (see Takeishi and Fujimoto, 2003 for a comprehensive review on the concept of modularization in the automotive sector), the number of parts of the final product has been reduced and the structure simplified, improving the applicability of industrial robots and providing benefits from mass production (Kah et al., 2014).

Despite the ongoing debate on industrial robots and their adoption in the automotive sector – along with other major manufacturing industries' adopters – there has been little attention on studying what are the interrelations between technical material conditions and organisation process. Most of the company level studies well documented the automation process until the 1990s – especially within the Gerpisa network in Europe and few programs in the United States. For example, the MIT International Motor Vehicle Program was a clear attempt to overturn the common myth in the automotive industry that productivity or quality performance is predetermined by location and/or ownership (Krafcik, 1988), and that production and product specificities are the core of automation decisions. We contribute to this research stream by 'updating' the literature focusing on two main goals, providing: (i) an analysis that looks at shop floor level elements (product and production process characteristics) that induce the adoption of robots; (ii) an analysis about how the process of technology adoption/automation may differ across firms that produce similar products within the same sector.

3. Research method and research setting

3.1 Research design

This research has been conducted through a qualitative data-gathering process, an approach that allows understanding better how shopfloor-level specificities and dynamics contribute to the adoption of industrial robots. The development of our study is based on grounded theory (Corbin and Strauss, 1990), and we built our theoretical framework based on qualitative data collection because existing theories do not explain all important factors that influence firms' decisions to adopt industrial robots. Qualitative research is recommended in exploratory and early stages of research (Yin, 2009), and particularly multiple case studies provide more robustness for the inductive theory-building process.

We follow Eisenhardt and Graebner (2007) to provide robustness for our theoretical contributions and particularly we:

i. Engaged in a deep and cross-cutting field literature review that allowed us to identify the research gap; since academic studies on digital production technologies are novel (Arnold et al., 2016), our analysis enabled an inductive approach where we aimed at a process of theory-building from our case studies.
ii. Engage with multiple case studies that allow a replication logic; we used multiple cases as one would consider multiple experiments to follow a 'replication' design rather than a sampling logic (Eisenhardt and Graebner, 2007; Yin, 2009).
iii. we recognised patterns of relationship among/within cases and their logical arguments; this process was facilitated by our engagement with firms that operate at the same level of the value chain.
iv. within our case studies we interviewed multiple actors (i.e., informants) that could have different perspectives on the phenomenon at study, thus limiting the informant bias.

This study on the determinants of robotisation and the use of new technologies was part of a broader analysis conducted along the automotive value chain in South Africa during a five-month period in 2019 when we conducted 11 in depth interviews across six (out of the seven present in the country) OEMs[1]. Follow up interviews were conducted in September 2022 at the OEM level for further validation of the results and their framework. To conduct semi-structured interviews, we developed a questionnaire based on policy documents review, industry association reports, and previous literature on technology determinants, such as the MIT work done by Sjösdedt (1987), where shop floor elements investigated in this research are partially explored. We built our initial guide for interviews by framing our questions sufficiently to give researchers flexibility, focusing on why and how types of questions (Edmondson and Mc-Manis, 2007).

Once there was a final draft with several questions, it was reviewed by two South African automotive industry experts that provided feedback on the extent to which the questions were clear and meaningful to industry players – the majority of which was already met by the two experts.

3.2 Data collection

This study emerges from the main research questions, aiming to identify determinants and constraints for technology adoption. The breadth of our research questions allowed interesting, unexpected findings. For example, the interviews soon revealed that the relationship between modularity of the production process, flexibility in the use of automation technologies and stability in product design played an important role in the quantity and the quality (i.e., how) of industrial robots' adoption. Our study used purposive sampling, which involved selecting cases that could allow the best comprehension to understand further industrial robots' adoption (Smith and Noble, 2014). Interviews were conducted with multiple individuals from different areas of the same firm to have different perspectives on the adoption of new technologies and how these are used, e.g.,

[1] These OEMs represent globally almost 40% of the production (37.12%). Calculations based on OICA 2017.

CEOs, managing directors, general managers and production or operation managers. Once the interviews were conducted, we managed to have plant visits, which laid out the value of visiting the shopfloor to gain unexpected, new and empirically grounded insights into key economic processes. Interviews lasted between one and four hours, and informants were encouraged to provide more details when their descriptions were brief – and some elements given for granted – or when novel strands of narrative emerged (Strauss and Corbin, 1990).

Data from 11 in-depth interviews with six OEMs and two interviews with system integrators were triangulated with secondary data such firms' websites, industry databases and documents provided by the interviewees, particularly with non-public data provided by the institutional organisations. The interviews were of an open nature where the interviewees could elaborate on their responses, and follow-up questions were asked to understand the discussion topic fully.

Although the starting point of each interview had a more general perspective on the adoption of digital production technologies, the findings presented in this paper regard industrial robots. They are the most widely diffused technology that stimulated further investigation into the relationship between production organisation, flexibility, and product design. Industrial robots are an evolution of the robotic arm system, with more flexibility in computer reconfiguration but older constraints in task variety. To have a clear understanding of the technology, industrial robots for the purpose of this study are defined as "an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications (ISO 8373:2012)". All the interviews followed the same structure. After a general introduction of the firm given by the interviewee, the questions were divided into two parts. First, we asked about the introduction of new technologies in the last decade, with reference to industrial robots (e.g., when was it introduced, in which part of the production process – press shop, body shop, paint shop, final assembly). Second, the interview focused on the shopfloor aspects that play a central role as determinants and/or bottlenecks for the adoption of new industrial robots. This discussion revealed different ways in which technologies are used, and interesting insights regarding the interdependency between organisation modularity, technology flexibility and product design stability.

Case study descriptions

All OEMs active in South Africa were contacted, and we managed to have in-depth interviews with six of the seven final assemblies in the country. The variety we observed in firms operating in the same sector and at the same segment of the value chain depends mainly on the product they produce (i.e., the specificities of that product) and their ownership, which reflect different business strategies. Although OEMs engage in similar types of operations (i.e., press shop, body shop, paint shop and final assembly) their plant have different volumes, different employment levels, different management priorities that influence the product and how it is produced. For example, German and American firms have been better in rationalising their production and their strategy seemed to be towards the one plant one model. In contrast, Japanese firms – which also produce more for the internal/regional market – have more variety in their production lines, yet with products – i.e., motor vehicles - that tend to be more stable.

Firm	Shopfloor visited	Model produced	Production capacity	Interviewee functions	Type of technology	Product design
BMW	Body shop	3 Series and X3	80,000 - 90,000	Plant manager and body shop manager	Brand new technologies (e.g., last generation laser welding robots)	Radical changes every 7-8 years (length of product cycle)
Ford	Body shop, Final assembly	Ranger/Everest	100,000	Vice president operations	Brand new technologies, each one performing single, easy, tasks.	Radical changes along different cycles
Isuzu	n/a	KB and D-MAX	19,000	Manager business strategy	Technologies that have been used along different product cycles.	Stable product design
Nissan	Body shop	NP 200 and NP 300	25,000-30,000	General manager purchasing and body shop plant manager	Old technologies, some of them worked along three product cycles.	Stable product design
Toyota	Body shop	Toyota Corolla, Hilux, Quantum Fortuner	148,000	Vice president production planning and general manager	Old and new technologies together, some of them in use for 25 years.	Stable
VW	Press shop, Body shop, Paint shop, final assembly	Polo and Polo Vivo	115,000	CEO, head of Production, and director of production	Mainly brand-new technologies, different technology lines for different products.	Changes that require the setup of new technologies.

Table 1. OEMs interviewed. Source: Author based on case studies

A further important source of primary data comes from interviews we collected from two system integrators companies: Yaskawa and DESign. System integrators are crucial actors in the local ecosystem, which gain precious and granular understanding of products and production processes during their core activities of setting up production lines across different firms. We used interviews with system integrators both to triangulate our findings and to validate the framework presented below.

5. Findings and discussion

5.1 Findings: 'shop floor determinants'

The empirical findings based on the interviews with different actors at the OEMs level and with two system integrator firms reveal several aspects that automotive assemblers consider critical in their decision on the adoption of industrial robots. There were two main questions related to determinants of robot adoption during our interviews:

1. *During the past decades, what have been the most critical determinants of industrial robots' adoption?*
2. *What is the relationship between industrial robots and flexibility – the latter, being one of the most discussed potential benefits of new digital production technologies?*

Plant visits and interviews revealed high heterogeneity in the organisational integration of robots – i.e., the 'how' robots are used, as well as the existence of potential tensions between robotisation and flexibility. We spent a minimum of two hours and a maximum of seven hours in each production facility. This was essential to clarify and unpack key insights from our interviewees (almost all of them engineers or operations managers) on the factors determining robotisation.

The first question (1) received similar responses across OEMs, although with different emphasis. All OEMs identify three types of determinants of robotisation: (i) the need to increase the quantity to be produced (i.e., volume); (ii) the need to improve (or to change) the task performed (for example, when a new model enters production cycles); (iii) the ergonomics of workers. In the discussion of the relationship between robotisation and flexibility, none of our interviewees identified flexibility as a determinant of robotisation; on the contrary, three companies revealed a technology-organisational tension between robotisation and flexibility. Specifically, in discussing the second question (2), it emerged that what really differs from company to company is the level of flexibility with which industrial robots can be used and reconfigured to execute different tasks on the line, rather than flexibility aimed at more diversified output of products.

To further clarify, interviewees discussed flexibility intended as 'machine flexibility', the machine's capability to execute different operations without incurring high effort from one operation to another, given a certain product. This concept is measured by the number of operations a workstation performs and by the changeover time needed to switch from one process to another (Koste and Malhotra, 1999; Jain et al., 2013). With specific reference to this type of flexibility, heterogeneity in the use deployment of robots emerged, with some companies using robots in a rigid way – i.e. to execute the same task in the same stage and cell - while others in a more flexible way – i.e. to execute several tasks. Specifically, the interviewee at Ford and the two German manufacturers revealed that they tend to use robots very rigidly, and thus they set up a robot that performs the same task for a specific production stage for its entire life cycle. When we visited the Toyota shop floor, we saw a much-diversified set of robots, some very new and some quite old, continuously adapted and reconfigured to operate on different cells and stages on the line and – where possible – tasks on the same stage.

We conducted a deep-dive on this striking difference to understand what technology-organisational conditions allowed to use robots in a flexible way, hence solving the tension between robotisation and flexibility. It emerged that those OEMs that can re-deploy and re-configure robots, hence be more flexible around their production process, have product designs that are more similar across different production cycles. We call this element 'product design stability', referring to the fact that some firms radically change their product design while others apply small incremental changes that can better fit existing production processes.

The product design stability was referred to the necessity of maintaining a production process characterised by small incremental changes, which are followed by minor adaptations to the design, and, relatedly, costs. The latter point is important, especially for some OEMs where waste reduction and production efficiency are critical. Toyota and Nissan's plants are characterised by a wide variety of products produced in the same plant (and sometimes the same line), yet cars and/or pick-ups with similar design models characterise. Our finding finds support in previous literature which suggested that Japanese firms succeeded in maintaining flexibility because of "well-thought-out product architecture" regarding their manufacturability (Fujimoto, 1997).

Finally, interviews with system integrators suggested that these differences are also related to the fact that companies organise their production process differently, with different degree of modularity intended as a more 'buffered' systems with high inventory levels, high repair areas and built-in buffers to keep on production if a problem occurs. German companies and Ford are the companies that are closer to a more 'buffered' system, while Toyota and Nissan are characterised by higher attention for lean process and, when possible, a continuous flow of production.

5.2 Organisational integration models

Following from our interviews, we advance a conceptual framework (Figure 1) to systematise and explain how the three factors mentioned in the previous section – as well as their interdependencies – determine the use of industrial robots; we then applied this framework to the two emerging robotisation models that came up from our interviews. This framework grounds robotization decisions in shop-floor level manufacturing management decisions, hence revealing interdependencies between integration of technology, organisation and product design.

Figure 1. Integration models for robotisation

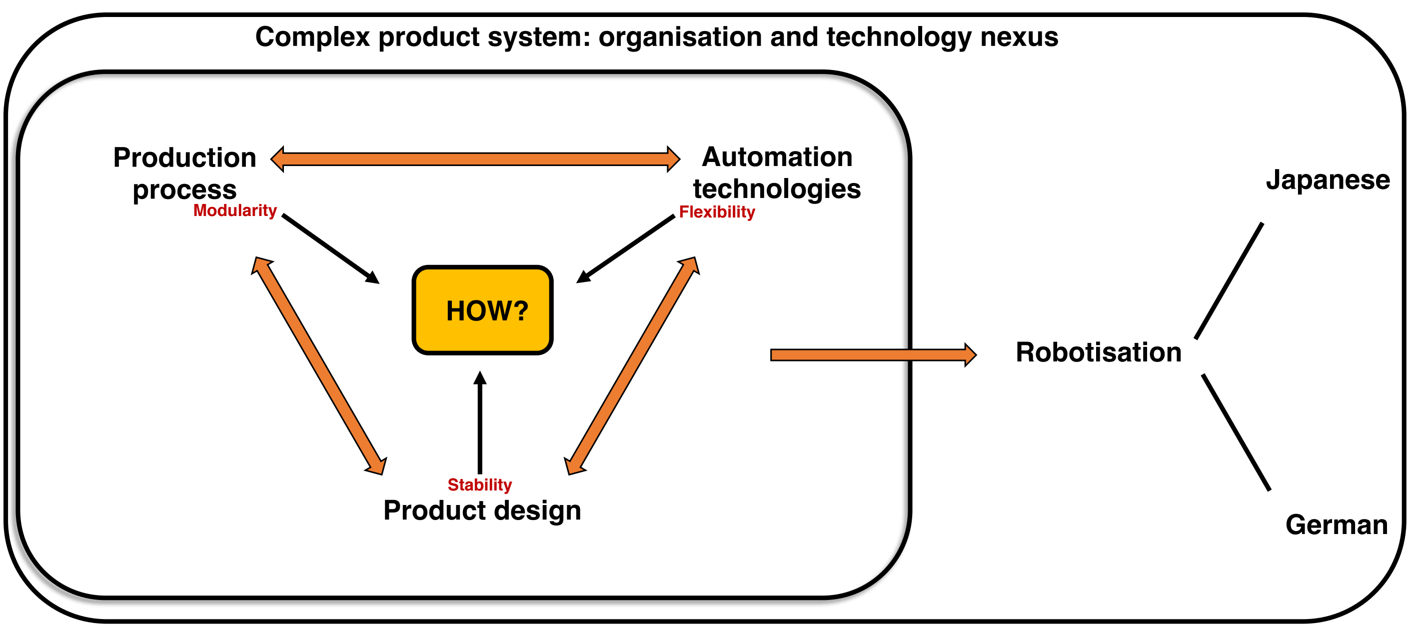

Figure 1. Source: Authors

Figure 1 indicated the three elements of modularity in production process, flexibility in automation technologies and stability in product design, showing that each of them contributes (black arrows) to a specific type of robotisation (the 'how' at the centre of the figure), and that each dimension interrelates with the other two (orange arrows); such interrelation gives rise to a model of robotisation. The rest of this section discusses the orange arrows. First, the relationship between product design stability and automation technologies' flexibility indicates that more stability would allow a more flexible use of automation technologies, as similar design makes it possible to use and adapt previous technologies; conversely, new products are more likely to require new technologies, especially when such technologies directly increase the quality of the product (e.g., specific welding robots on new material metal sheet). The second relationship is between product design stability and production process modularity (diagonal orange arrow on the right). Longer and more similar product (design) cycles are accompanied by less modularity to accommodate small product variety while relying on the same production platform. In addition, little change in products also enables better use and re-use of some technologies in a constant integration process between design and production requirements (Von Hippel, 1989). Third, as for the relationship between automation technology's flexibility and production process modularity (orange arrow at the top), it is less clear whether higher automation technologies enhance modularity in the production process. In the relationship between modularity and flexibility the former opens for more complementarities between scope and scale, while the former often seems to challenge existing production processes.

Our findings indicate not only the existence of such relationships, yet also how they tend to be 'similar' across firms that have headquarters in similar countries. On the basis of our interviews, we propose two different models of robotisation, adapting Figure 1 to what we define as a 'Japanese way' and an 'German/American' way of robotisation (Figure 2). The Japanese model (a) is characterised by a higher degree of design stability, which allows for a longer use of industrial robots that are reprogrammed and deployed in a more flexible way. A low stability of product design characterises the German/American model (b) in Figure 2: different product cycles are characterised by a high degree of heterogeneity in their design, preferring brand-new lines and often preventing the deployment of already in-use technologies. As confirmed by the literature, German OEMs tend to have a lower degree of production modularisation while opting for a more rigid and at full capacity use of technologies. The thickness of the black arrows in Figure 2 highlights the intensity of modularisation (which can be intrafirm or modularisation in production), product design stability and a flexible use of the machine.

Figure 2. Models of Robotisation – examples from South Africa

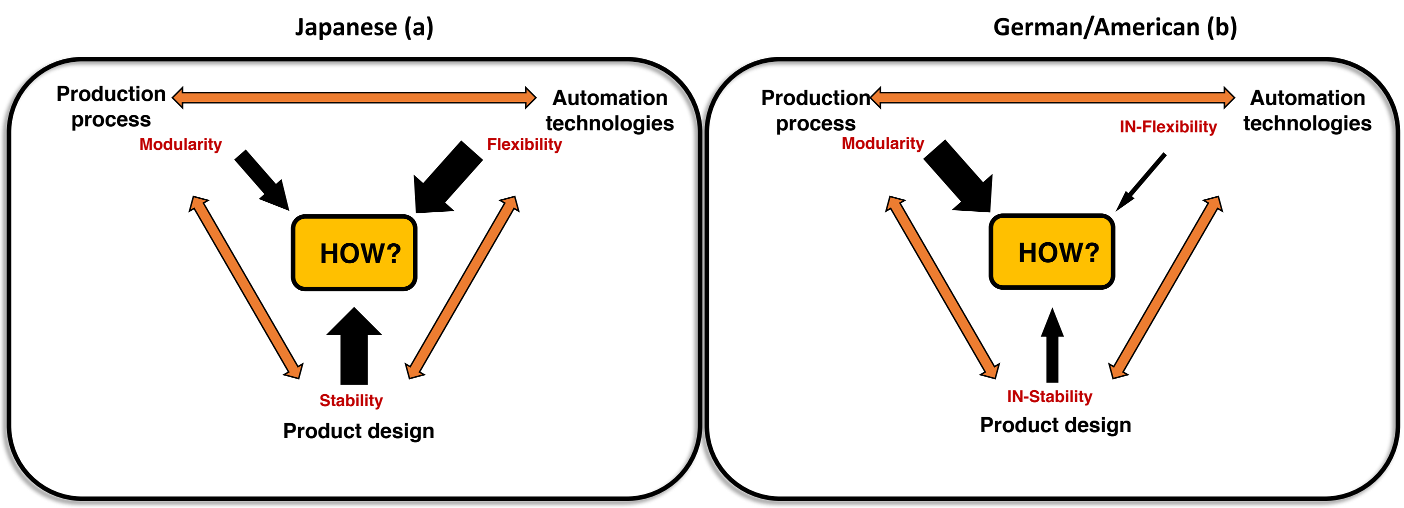

Figure 2. Source: Authors.

Technology deployment sheds further light on the degree of flexibility in using automation technologies and how this is intended within different production systems. For instance, German (and American) OEMs' automation levels are higher than the other OEMs. These three OEMs present a rigid use of industrial robots that tends not to be reprogrammed. “We never reprogramme, we don’t want to reprogramme, it’s all about volume”, mentioned the interviewee from BMW. And again, "we required absolutely no deviation or variability in our process", reported the interviewee from Ford. Automation levels for the Japanese OEMs are lower, as production technologies are used across different production cycles and tend to be more flexibly.

On one hand, the Japanese model struggles to maintain a high level of automation with the organisational necessity of maintaining a high degree of flexibility. During the Toyota plant visit, we saw an industrial robot that was about to be moved and reprogrammed. The shopfloor manager explained that it is common that a machine previously used to do a specific task could be used to do something else. This flexibility clearly presents a trade-off between the full utilisation of the machine (that is, three shifts for seven days a week) and its flexible use. Japanese are more flexible, but they also use technologies "accepting" longer idle time when the machine is not in use between one task and the other. Toyota plant manager interviewee reported that "we do incremental change in the kaizen way, new technologies [for Toyota] is retrofitting, which entails an entire set of different capabilities compared to the setting up of a new body shop".

On the other hand, the German (and American) model prioritises a high level of automation at the expense of flexibility. The production organisation is structured in such a way that a higher portion of components is entirely outsourced to suppliers (in some cases even the press shop is outsourced to metal sheet companies located nearby). A stronger inter-firm modularisation is reflected in a rigid production process where machinery is only seldom reprogrammed; it is utilised at full capacity to perform the same task for the entire product cycle. German and American firms confirmed that industrial robots become spare parts once the cycle is concluded and replaced with entirely new sets of robots. The rigidity and full utilisation of the machine inevitably leads to a more rigid process with little room for flexibility. The interviewee from Ford reported: "we want the robot to be rigid; with the volume and the huge number of issues you have, the more rigidity I have, the easier it is for me to put my fingers in any issue. I can't deal with variability".

5.3. Discussion

The research question addressed in this paper focused on determinants of robots' adoption. We investigated heterogeneity in industrial robots' adoption and identified two main manufacturing approaches to robots' organisational integration. These two ways of robotising reflect two different ways of approaching interdependent relationships among production process modularity, flexibility in automation technologies and stability in product design.

There is a strong relationship between technology flexibility and product design stability, and these aspects are both influenced by production process modularisation, which is stronger in Japanese firms. As our interviewee with Ford mentioned, "Japanese tend to design products with the operators in mind but we [referring to the Western manufacturing view] are not that good at that; we design the car, and we try to understand where the operator fits".

The flexibility advantage of 'designing a product around a certain robotised process': the Japanese way

Our findings confirm that flexibility regarding how to manufacture a product lies in how the product is designed. Maintaining a less complicated design would facilitate the effort in integrating and modularising small material flows to a certain pre-assembly station, which increases flexibility and shortens final assembly. Japanese OEMs have been much better at this, as shown by the pace at which they design new models. "It is no accident that the development of a new model may take up to seven years in Daimler and just three in Nissan" (Sjoestedt, 1987). German firms, by contrast, tend to prefer a higher level of automation and new design for their product at the expense of flexible production systems (Landahl and Johannesson, 2018).

If Japanese firms tend to produce with the operator in mind, German firms are not required to have flexibility in their equipment as they will simply change it. While the design of Japanese product tends to remain more stable throughout different production cycles, also to use similar (if not identical) platforms, German platforms change every seven to eight years. Japanese succeeded in maintaining flexibility not because of sophisticated digitalisation but because of "well-thought-out product architecture" regarding their manufacturability (Fujimoto, 1997). This happens to the point that both BMW and VW confirmed the tendency to change almost the entire body shop with new production cycles.

Japanese OEMs use robotics for two or three production cycles; "we tend to maintain it for 25 years" said our interviewee at Toyota, who also confirmed that the firm makes slightly different types of platforms in a single line (for example, single cab, double cab, SUV), thereby exploiting robotics flexibility for model derivatives. Machines are moved around the plant, and there is a huge component of continuous retrofitting. In addition, Japanese OEMs use specific gripping that tends to be universal during welding, to the point that they can weld eight different models in one line (Jürgens, 2020).

In line with the waste reduction approach of the just-in-time methods, cost reduction was always a common trait of technology adoption for Japanese firms that use to see a new machine adoption only if accompanied by flexibility (Jürgens et al., 1993; Krzywdzinski, 2021), and if it is low-cost automation (McCarthy and Rich, 2004). This also implied a preference for simpler and more robust solutions and, sometimes, for giving up with automation, as happened in the 1990s when Japanese OEMs, after having automated the final assembly process, went back to less automation due to diseconomies and a lack of flexibility (Hedelind and Jackson, 2010; Krzywdzinski, 2021). Our interviews with Toyota and Nissan confirmed what previously emerged in the literature, that Japanese firms pay particular attention to cost reduction and flexibility; in this sense, higher automation either moves the process towards lower costs or more flexibility, or it does not materialise. Toyota interviewee confirmed that "Japan works on a different cost structure from the rest of the world; if you can afford you can have it, otherwise you can't. For the German, the volume doesn't matter as they would automate anyway".

The technology advantage of 'designing a process around a certain product design': the German way

On the other side of the spectrum, European firms always saw high-tech, up-to-date automation as a pre-requisite for high quality and productivity. At the same time, flexibility has been considered less important and more problematic due to complex reprogramming. The attention that German OEMs have given to technology is confirmed by previous literature defining BMW as a high-tech company. Birkunshaw et al. (2016) reported the following extract from an interview: "the excitement for new technical solutions is strongly present on all levels in the firms. This is the glue that holds us together".

This was confirmed during our interview and our body shop visit with BMW, where the lines are almost completely automated and replaced for new car models, indicating different cost priorities and ways to deal with variety. These companies are substituting entire lines of machines more often means that they are required to have fewer retrofitting capabilities, intended as those of integrating new machines and technologies in existing lines. BMW interviewee also discussed how the Japanese tend to invest more and to have better machine maintenance, which allows longer and more flexible use of the machines. Having more machines at their disposal for longer periods enhances flexibility as more machines can be interchanged. This is consistent with the Japanese' eliminating waste' approach, which is part of lean production's manufacturing philosophy that addresses waste elimination and makes the production process flow more streamlined and efficient (Bhasin and Burcher, 2006; Jasti and Kodali, 2014).

Implications for Manufacturing Technology

These different ways of robotising – what we called 'the Japanese way' and 'the German/American way' – correspond to different manufacturing strategies, defined as "supporting corporate objectives by providing manufacturing objectives [e.g., including costs, quality, flexibility] to offer a competitive advantage and focus on a consistent pattern of decision making within key manufacturing resource categories" (Kim and Lee, 1993). Technology, and more critically, how it is utilised, is one of the most important areas to focus on when preparing a manufacturing strategy, not the technology itself but how it is utilised (Samson, 1991; Orr, 1999). An interconnected element often discussed during the interviews was the importance of manufacturing cultures, as cultural differences emerged as crucial to achieve cross-cultural (i.e., across countries) technology transfer (Nguyen et al., 2015). Culture affects manufacturing strategies through various sub-criteria such as attitude, motivation, and complexity (Erensal and Albayrak, 2008).

The evidence points to companies' priorities and the core principles that inspire their production. Japanese OEMs are more focused on process efficiency, which includes production techniques and efficient organisation of the whole value chain. On the other hand, German OEMs focus more on product technology, on the art of designing and constructing a car, also due to the more recent history of Western producers in responding to a high-performance luxury market in segmented national economies (Sjöestedt, 1987; Cole and Yakushiji, 1984).

6. Conclusions

By highlighting the differences in the deployment of industrial robots across different OEMs and by stressing the emergence of two main varieties of robotisation – the Japanese way and the German way, this paper has shown that the presence of different models influences automation decisions on industrial robots, with crucial implications for the study of technology adoption. Furthermore, this research allowed us to advance an organisational and dynamic approach to studying interdependent firm-level factors determining technology adoption.

6.1 Theoretical and managerial implications

The findings illustrate the key role that three firm-level determinants – process modularity, technology flexibility and design stability – play in technology adoption. The extent to which technologies like robots are adopted depends on how firms find a unique and value-creating organisational integration model that optimises relationships between process modularity, technology flexibility and design stability. OEMs follow different incentives and business strategies when adopting new technologies, as highlighted in Figure 2 for the automotive sector. Technology adoption depends on two interrelated dynamics: a) prioritising one of the three firm-level determinants of robotisation – modularisation, flexibility and stability – and b) organisational integration between these determinants.

Our research reveals that firms that operate in the same sector and segment, are highly internationalised and have similar processes may introduce and deploy industrial robots in very different ways. Such heterogeneity in robotisation confirms the importance of looking at organisational integration issues and the importance of these determinants in explaining the speed at which industrial robots – and possibly other types of technologies – will be adopted in the automotive sector and beyond. This paper extends current research by showing that heterogeneity in technology deployment is a fundamental aspect of a dynamic way of looking at the advent of new technologies for three main reasons. First, there is a relationship between industrial robots and firm-level organisational models, which is relevant to understand the firm's priorities and if, and to what extent, they are automating. Industrial robots are deployed differently across different firms, emphasising that organisational theories and different ways of producing and organising business are important in the analysis of technology adoption. Second, differently from what some authors argue (e.g., Graetz and Michaels, 2017; Acemoglu and Restrepo, 2017), our findings would call for a more cautious approach rather than the equation where robots equal fewer jobs. Robot adoption could be a business choice in line with a firm's strategies, for example, the production of a completely new model that requires new robotic lines. The fact that German firms change their technologies along production lines more frequently is a sign of their willingness to deploy new technologies that better fit their design priorities rather than a sign that they automate more. Third and relatedly, product design cycles matter when deploying new technologies, such as industrial robots. This matters because the relationship between product design and flexibility reveals that firms face trade-offs in adopting these technologies and may struggle to see the advantages deriving from industrial robots.

On practical implications, the findings show that managers must consider the interdependencies between the three elements analysed: modularity in the production process, flexibility in technology automation and product design stability. Rather than adopting an isolated perspective on the determinants and the conditions that allow for industrial robots' adoption, our framework serves as a tool to analyse the different interdependencies that can lead to more industrial robots in production processes. In addition, this paper could also serve managers in firms that provide inputs/goods and services to the OEM to understand better the priorities of OEMs and how these may change in the near future as a response to present and future constraints. A fragmented perspective on technology flexibility, modularisation and product design cycle could create problems, especially since the industry and the manufacturing sector are moving towards more integration and technology adoption. A comprehensive analysis of these factors should be considered, bringing practitioners in the industry to focus on these three shopfloor-level determinants and to rethink the manufacturing interdependencies that characterise the process.

6.2 Limitations

Our study also presents a series of limitations that future studies could address. The qualitative nature of our research allows for restricted and partial generalisability, an aspect that we tried to attenuate by interviewing six of the seven OEMs in the country. Regarding the research setting, this is a study of how the South African subsidiaries of international firms operate in an emerging economy. Although the literature about the similarities that subsidiaries have in foreign countries, the findings apply to the South African context and could constitute a tool to formulate hypotheses on what happens in other countries by the same firms. Future investigation is strongly encouraged to analyse how adopting industrial robots – and other Industry 4.0 technologies – differs based on organisational models along different firms, sectors, and countries.

Statements

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