Barreiras à digitalização industrial e como enfrentá-las: evidências do setor de máquinas e equipamentos brasileiro

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Resumo: Nos últimos anos, um conjunto de tecnologias digitais tem ganhado relevância devido às suas aplicações inter-setoriais e efeitos potencialmente disruptivos. Isso inclui a Internet Industrial das Coisas (IIoT), Inteligência Artificial, impressão 3D e robótica inteligente, sendo aqui denominadas Tecnologias Digitais de Produção (DPTs). O setor de Máquinas e Equipamentos (M&E) é crucial para essa tendência, uma vez que muitas dessas tecnologias estão incorporadas nos produtos desse setor. Este artigo investiga o envolvimento da indústria brasileira de M&E com as DPTs por meio de uma sondagem e entrevistas semi-estruturadas com gestores de empresas. A pesquisa destaca as barreiras para o desenvolvimento e integração das DPTs nas máquinas e equipamentos e para sua implementação bem-sucedida em empresas clientes. Também questiona sobre as políticas públicas utilizadas e desejadas pelas empresas de M&E, obtendo insights importantes sobre as políticas de digitalização industrial no Brasil e como elas poderiam ser aprimoradas. A pesquisa confirma muitas das descobertas de trabalhos anteriores no Brasil, como as lacunas em infraestrutura digital e as dificuldades enfrentadas pelas empresas brasileiras para acessar fontes de financiamento e recrutar trabalhadores com as habilidades necessárias. No entanto, também fornece nuances e esclarece muitas dessas descobertas com a ajuda de entrevistas semi-estruturadas. O artigo conclui que o aspecto de fusão tecnológica das DPTs intensifica a importância da colaboração governo-indústria-academia, a necessidade de habilidades multidisciplinares dos trabalhadores, e a necessidade de implementar sistemas de produção completos em vez de soluções fragmentadas. Também mostra que o Brasil possui um forte ecossistema com capacidades relacionadas às DPTs que podem ser alavancadas. Em particular, identifica que empresas integradoras são atores importantes que poderiam ser aproveitados para impulsionar os processos de digitalização industrial no país. No entanto, o artigo também identifica que as políticas do governo brasileiro até agora têm sido insuficientes para promover uma transformação digital fundamental das empresas brasileiras e fornece algumas direções possíveis para melhorias.

Palavras-chave: Indústria 4.0; Digitalização industrial; Máquinas e equipamentos; Política industrial; Política de inovação.

Código JEL: O31, O32, O38

Área Temática: 1.6 Novos temas - Indústria 4.0, Internet das coisas, outros

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Barriers to industrial digitalisation and how to tackle them: evidence from the Brazilian machinery and equipment sector

Abstract: In recent years, a set of digital technologies has been gaining relevance due to their cross-sectoral applications and potentially disruptive effects. These include the Industrial Internet of Things (IIoT), Artificial Intelligence, 3D printing, and Smart Robotics, and are here referred to as Digital Production Technologies (DPTs). The Machinery and Equipment (M&E) sector is crucial for this trend, as many of these technologies are embedded in this sector's products. This paper investigates the engagement of the Brazilian M&E industry with DPTs through a survey and semi-structured interviews with firm managers. It highlights the barriers to development and integration of DPTs in M&E products and to their successful implementation in client firms. It also inquires about the public policies used and desired by M&E firms, obtaining important insights about Brazilian industrial digitalisation policies and how they could be improved. The research confirms many findings of previous works in Brazil, such as the less-than optimal digital infrastructure, and the difficulties faced by Brazilian firms in accessing funding sources and in recruiting workers with the necessary skills. However, it also provides nuances and clarifies many of these findings with the help of semi-structured interviews. The paper finds that the technology fusion aspect of DPTs leverages the importance of government-industry-academia collaboration, the need for multidisciplinary worker skills, and the need for implementing whole-factory systems instead of piecemeal solutions. It also shows that Brazil has a strong ecosystem with DPT-related capabilities that can be further developed. In particular, it identifies that DPT integrators are important players that could be leveraged to drive industrial digitalisation processes in the country. However, the paper also identifies that the policies of the Brazilian government have so far been insufficient to promote a fundamental digital transformation of Brazilian firms, and provides some possible directions for improvement.

Keywords: Industry 4.0; Industrial digitalisation; Machinery and equipment; Industrial policy; Innovation policy.

1. Introduction

In recent years, a set of industrial technologies has been gaining relevance due to their cross-sectoral applications and potentially disruptive effects. These include the Industrial Internet of Things (IIoT), Artificial Intelligence, 3D printing, and Advanced Robotics, and are often clustered together in expressions such as "advanced manufacturing", "Industry 4.0", "digital transformation", and others. Here they will be referred to as Digital Production Technologies (DPTs).

While there are many studies about the diffusion of DPTs in developed economies, there are only a few about developing ones (exceptions are KUPFER; FERRAZ; TORRACCA, 2019; and (CALZA; FOKEER, 2019). Even fewer studies exist focused on the firms responsible for the development and integration of these technologies. This paper seeks to help fill this gap by investigating the engagement of the Brazilian Machinery and Equipment (M&E) industry with DPTs. In addition to a review of previous surveys about the level of digitalisation of the Brazilian industry, the research for this paper included an online survey and semi-structured interviews with firm managers from the Brazilian M&E sector.

The research confirms many findings of previous works in Brazil. However, it also provides nuances and clarifies many of these findings with the help of semi-structured interviews. It differentiates itself from previous studies by providing original insights into the engagement of the Brazilian M&E industry with DPTs, including the obstacles faced by firms, the public policies used and desired, and the impact of DPTs in the firms implementing them.

2. Context: level of digitalisation of the Brazilian industry

Surveys have been carried out seeking to identify the level of DPT usage in the Brazilian industry. Table 1 summarises their findings. Overall, the surveys show that firms in Brazil are still at an early stage of adoption of DPTs, with significant barriers such as a lack of qualified workforce, less-than-optimal infrastructure, and difficulties in accessing funding, although with some perceived improvements over time. On the positive side, firms are increasing their adoption of digital technologies over time, and the firms that have been doing so have been accruing positive results in terms of productivity, flexibility, and the quality of products and services. The sectors that are driving digitalisation in Brazil are the high-tech (i.e., ICTs) and medium-tech sectors (i.e., Chemicals, and Automotive). The Machinery and Equipment sector has had contradictory findings, with the CNI surveys signalling a high involvement of the sector with DPTs, while the Indústria 2027 one indicated a poor performance. In any case, the sector has been active through its industrial association ABIMAQ in searching for knowledge and ways to join the digitalisation trend.

These findings are consistent with what the international literature on the topic has identified concerning developing countries, i.e., that the adoption of DPTs is small and hampered by the lack of infrastructure, qualified workforce, and funding sources (DA SILVA et al., 2020; and (VEILE et al., 2019). The few "surprises" came mostly from the Indústria 2027 survey. This survey highlighted that in Brazil digital technologies were being more applied for supply-chain management improvements than for production process improvements and that having a high number of qualified workers can work as a barrier to adopting new technologies[2]. Interestingly, the second CNI survey saw a reduction in the importance of barriers related to funding relative to its first survey. This was attributed to the creation of dedicated funding lines such as BNDES Máquinas 4.0 and FINEP Inovacred 4.0. Overall, the surveys show that Brazil has a high potential to reap the benefits of DPTs and that there is great interest by firms in adopting such technologies.

[2] This would occur as highly skilled workers can be specialised in older technologies and be unwilling to adopt new ones. Previous works mainly saw having a high number of qualified staff as a positive thing.

Table 1 - Summary of surveys on the digitalisation of the Brazilian industry

Research	Sample	Benefits from DPTs	Barriers to adoption	Other relevant results
CNI (2016)	2,225 manufacturing and extractive industry firms	- Process improvement - Product development (in high- and medium-high-tech sectors) - Reducing operational costs - Improving productivity	- High cost of implementation - Lack of qualified workforce - Insufficient telecommunications infrastructure - Difficulty to find technologies and partners - Lack of appropriate funding lines - Market is not ready (clients and suppliers)	Leading sectors in DPTs are high- and medium-high tech Priority policy areas: - Developing infrastructure - Investing in new models of education and training programmes - Creating specific funding lines
CNI (2022)	1,691 manufacturing and extractive industry firms	- Process improvement - Product development - Productivity increases - Reducing operational costs - Quality improvements - Improvements in decision-making	- High cost of implementation - Lack of qualified workforce - Difficulty to find technologies and partners - Market is not ready (clients and suppliers)	Significant increase in the share of firms that use DPTs, although most are still at an early stage. Reduction in the importance of barriers related to funding and infrastructure (although still relevant).
IEL (2018)	711 medium, medium-large, and large firms	- Supply-chain digitalisation prioritised over internal processes	- Lack of skilled staff - Being small (potentially related to lack of financial resources for investments) - Being in a low-technology sector	Only 1.2% of firms in Generation 4 of digital technologies. Consumer goods performing well and Capital Goods performing poorly in DPT adoption.
TORRACCA; BRITTO; FERRAZ (2022)	Panel of 299 firms that answered both the IEL 2018 and 2022 surveys	-	- Having few skilled staff - Having skilled staff too specialised in older technologies - Being small - Being in a sector with low digital intensity	On average, significant advances in digital technology usage. However, many firms stood still and many *regressed* in digital technology usage
CARMONA; AMATO NETO; ASCÚA, (2020)	15 Brazilian manufacturing firms	- Increasing the efficiency of a function or process - Development of new products - Reducing costs - Improving quality	- Lack of awareness/knowledge of firms about these new technologies - Lack of the necessary internal infrastructure and connectivity - Lack of qualified workforce - The existence of other projects that require more urgent attention - The culture, organisational habits, and resistance to change in the firm - Difficulties in accessing funding and the large size of required investments Instability of the economy and unfavourable macroeconomic context - Deficiencies in the formation and capability-building system	-
REIS (2021)	194 manufacturing firms in Brazil	-	- Security and privacy issues - The need for new skills - Lack of infrastructure - Standardisation - Organisational resistance	-
ABDI (2023)	2,000-2,572 Brazilian SMEs (not only industrial firms)	-	- Lack of resources to invest in digital transformation - Difficulty in accessing people and companies with capacity to help the company to digitalise - Difficulty in understanding what the investment priorities should be for the digital transformation of the company - Lack of enterprise strategy for digitalisation - Resistance to change by directors and managers - Lack of basic technologies in the company the enable the use of more advanced technologies	The main objectives of industrial SMEs when digitalising is to innovate quicker and more collaboratively and to create a data-oriented organization.

Source: Own elaboration.

3. Research methods

3.1 Choice of sector

In this paper, the Brazilian Machinery and Equipment (M&E) sector was chosen for analysis. The importance of the sector for innovation and economic growth was well investigated by Nathan Rosenberg (1963) in his seminal piece "Technological Change in the Machine Tool Industry 1840-1910". Rosenberg notes that the sector was of crucial importance for the economic growth of the US in the 19th century. According to him, two characteristics make the sector important for innovation and economic growth: 1. The fact that innovations in other sectors require the machinery sector to produce a new product; 2. The fact that price reductions in this sector affect investment activities and technology diffusion throughout the economy (ROSENBERG, 1963, p. 416).

The M&E sector is also important for developing countries since economic growth increases the demand for capital goods and can lead to large trade deficits (and potential balance of payment crises) if most of them are imported. Developing an M&E industry is thus key to reducing a country's import dependence, as many classical development authors have pointed out (HIRSCHMAN, 1968; TAVARES, 1983). As such, the M&E sector is crucial for sustained economic growth and for the generation and diffusion of innovations in other sectors of the economy.

It can also be argued that the M&E sector is crucial for industrial digitalisation. Most DPTs need to be integrated in solutions, and then integrated into the production environment of firms. These activities are carried out largely by M&E firms. In addition, the M&E sector serves all other industrial sectors of an economy. As such, analysing the DPT activities in the M&E sector gives us insight on what is happening with DPTs in all other industries.

In addition to being an important developer and diffuser of DPTs, the M&E sector is also an avid *user* of these technologies in its own production processes. A key characteristic of the machinery industry is that it requires the capability to design and manufacture products according to the varied specifications across the clients and DPTs play a key role in that capability. For example, 3D printing can be used to manufacture small batches of complex design parts at a low cost; AI-powered generative design can help in the development of solutions adapted to the clients' needs. Moreover, connected machines enable servitised business models in which clients have more flexibility in the usage of the machinery.

Finally, the M&E sector is also an important sector for Brazil. The Brazilian sector is composed of 8,623 firms, with an annual turnover of R$299 billion (US$55.5 billion), employing 372,000 people directly and over 7 million indirectly, while offering an average salary that is 30% higher than the Brazilian average, and 37% higher than that of the manufacturing industry as a whole. Due to its strong linkages to other sectors, it is estimated that, for every R$1.00 of additional demand for the sector, R$3.52 is generated in production in the whole economy. It is also a sector that has considerable exports, with roughly 20% of its production being channelled to exports and 53% of the firms of the sector being involved in exporting activities. This represents 13% of Brazil's manufacturing exports (ABIMAQ, 2022).

In terms of the M&E sector's engagement with DPTs, the existing surveys are somewhat ambiguous, as discussed previously. To help solve this ambiguity, a study bringing more granular information on the Machinery and Equipment sector was carried out in 2021 by an engineering research group of the Federal University of Rio Grande do Sul (NEO-UFRGS). It published a survey done in partnership with ABIMAQ with 135 firms of the Brazilian M&E sector (ABIMAQ & NEO-UFRGS, 2021). As the survey is very detailed, here only some key findings are presented.

The survey found that the Brazilian M&E industry is still at an initial stage of digitalisation. It was found that 40% of surveyed firms did not use any of the four DPTs inquired (cloud computing, IoT, Big Data, and Analytics or AI) and that few firms use systems like MES[3] (Manufacturing Execution

[3] "Manufacturing execution systems (MES) are software solutions that connect, monitor, and control complex manufacturing processes that take place on the factory floor. The system collects real-time data on all events and processes that take place. This data can then be used as key performance indicators to help the manufacturing team optimize their production efficiency." (ARENA, 2023)

Systems) and SCADA[4] (Supervisory Control and Data Acquisition) – systems that reflect an advanced level of digitalisation of production. It showed, however, that there is significant integration of DPTs in firms' products and services (i.e., connected machines) for performance monitoring and detection of flaws and maintenance needs. Concerning supply-chain digitalisation, few firms (less than 15%) use real-time data on product availability from suppliers and distributors. In terms of the firms' organisational processes, most firms evaluate that they have the necessary organisational structure for implementing DPTs. However, they admit that improvements are needed in terms of the skills of the workforce and of their internal digital infrastructure. Moreover, an important result is that almost 70% of firms reported using their own resources as the main source of funds for investment in DPTs. This may reflect a difficulty in accessing funding and other government policies for the acquisition of more advanced technologies – a point highlighted in the surveys discussed previously.

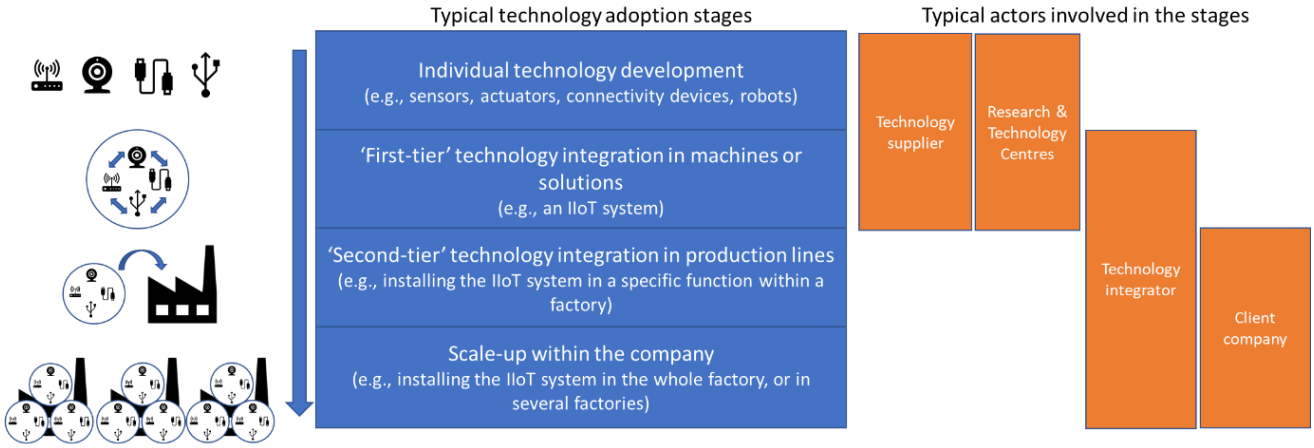
Finally, positive results were reported by firms that implemented digital transformation solutions, with improvements observed in all dimensions inquired, including in the quality of products and processes, in the flexibility to adapt to changes in the market, productivity, innovation in the products and services offered, safety and security of the work processes, and in entering new markets with the products and services offered.

My research builds on the results of the survey by NEO-UFRGS, to assess the engagement with DPTs in Brazil's M&E sector. It offers additional information to their research in two ways. First, it investigates some important issues that were not addressed by the NEO-UFRGS research, namely, how DPTs were developed or integrated, and the governmental policies used or desired. Second, in contrast to the NEO-UFRGS survey, my research also includes semi-structured interviews, which provide relevant qualitative information that helps us interpret the quantitative findings in a more nuanced way.

3.2 Methods used

A mixed quantitative-qualitative method was used. The quantitative part consisted of an online survey with firm managers from the Brazilian M&E sector. The survey was developed with a focus on two dimensions of firms' engagement with DPTs. First, the process of development and integration of DPTs in the firms' products and services (e.g., smart machines). Special attention was given to the modes of development used (internal efforts, collaboration, acquisition of start-ups, etc.), to the barriers faced in their development and integration, and to the policies used (or desired) to support this process. Secondly, the process of implementation of DPTs in the firm's clients. Here, attention was given to the different obstacles that exist for M&E firms in convincing clients to adopt DPTs, and to implement DPTs successfully. Figure 1 describes the typical stages of DPT development, integration, and implementation.

Figure 1 - Typical stages of DPT development, integration, and implementation



Source: Own elaboration

[4] SCADA is a computerised system capable of gathering and processing data and applying operational control over long distances (NIST, 2023)

3.2.1 Survey development and contact with firms

The survey was developed using the online tool Qualtrics, and its design took inspiration from the several surveys discussed before. A first draft was then discussed with senior analysts of the Policy Links Unit of the Institute for Manufacturing, University of Cambridge – a consulting unit that has experience in designing industrial surveys on the topic of digitalisation. Next, the survey design was discussed with two analysts from the Capital Goods department of BNDES and one analyst from the department responsible for registering firms for the BNDES Finame Máquinas 4.0 programme. Their feedback was incorporated into the design of the survey.

An important point raised in these discussions was the need to make sure that the respondent had deep knowledge about the firm's strategic decisions, including technology. This would mean avoiding, for example, respondents from the accounting or marketing departments or low-level employees that do not have a global view of the firm. This was sought to be solved by adding an initial question to the survey in which the respondent had to explicitly confirm they had the necessary knowledge about the firm's strategic priorities, including technology. The high number of responses by CEOs indicates that this was a successful strategy.

Another important issue when designing the survey was the differentiation that must be made between DPTs and the "4.0 machines" produced by these firms. A machine is a system composed of many technologies and DPTs are just one of them, and not necessarily the "core" one of the machines. To avoid confusion, it was defined and made explicit in the survey that: *a "4.0 Machine" is a machine that contains at least one DPT or is the DPT itself.* Indeed, that is why we speak of the *development* and the *integration* of DPTs separately – some firms can do little or no development and simply buy DPTs (e.g., IoT kits) from suppliers and integrate them into their machines – making them '4.0'.

Contacting firms was a more challenging process. Firms were initially contacted through BNDES, but due to low responses, the Brazilian M&E Industrial Association (ABIMAQ) was subsequently contacted and agreed to send the survey to their associates. In total, 22 valid responses were recorded, with half of them being the CEOs of the companies. Overall, responses were received from 10 August 2021 to 15 December 2021. Although not a representative sample, the survey highlighted relevant topics that served as a basis for the discussions in the qualitative part of the research.

3.2.2 Semi-structured interviews

The last question of the survey asked the respondents if they would be willing to be contacted for a subsequent phase of the research. Eleven firms demonstrated interest and were invited for an interview. Out of the 11, five agreed to the interview.

The interviews were carried out to explore the qualitative aspects of the engagement of firms of the M&E sector with DPTs and thereby provide a more nuanced view of issues discussed in the DPT literature and by previous surveys. Focus was given to issues that the survey highlighted as relevant.

The interview followed a standardised structure in which respondents were asked to give more detail about their responses to the different parts of the survey. However, as these were semi-structured interviews, follow-up questions and clarifications were asked, seeking to explore the interviewee's specific knowledge and interests. The interviewees were also asked to discuss in more detail the questions in which their responses to the survey were at odds with the responses of other firms. This was done to explore the variety of experiences of firms with DPTs.

To preserve the anonymity and non-identifiability of respondents, the results of the interviews are presented below using fake firm names. The five firms' names and their characteristics are described in Table 2. There is a significant variety of firms' sizes, ages, and activities, allowing us to explore a rich variety of points of view on DPTs in the Brazilian industry.

Table 2 - Names attributed to and description of interviewed firms

Fake name	Description
MajorMachinery	Large, mature (pre-1985) national machinery firm, internationally competitive.
Integrator Inc.	Small, young (founded post-2016) national firm, focused on the integration of technologies from major international technology providers in large Brazilian firms.
Lowcost-Sensoring	Small, mature (founded in the early 2000s) national firm specialised in low-cost (approximately US$1,000 per machine) sensoring and connectivity solutions for Brazilian firms.
RobotImporter	Small subsidiary of a foreign robotics firm, new to Brazil (has been in the country only a few years). Installs imported robots in Brazilian firms.
SmartTextileMachines	Medium-sized, mature (founded in the early 1990s) national firm focused on producing smart machinery and software systems for Brazilian textile firms, with their own proprietary technology.

Source: Own elaboration

4. Results

4.1 Results related to the development and integration of DPTs in machines and equipment

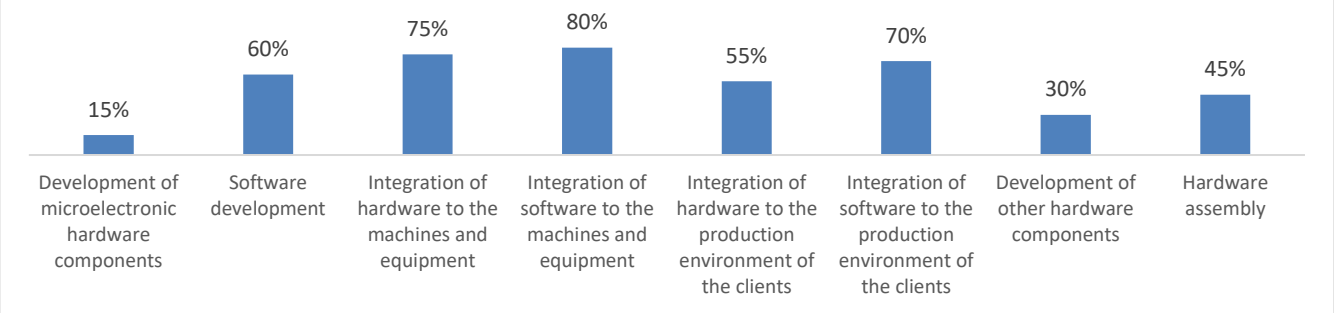
The surveyed firms are in their majority medium-sized (45%) and national capital (68%). Most of them export (67%) and the most common destination of exports is Latin America (94%). The sectors that the firms serve are mostly manufacturing (64%), followed by agriculture (41%) and agro-processing (41%), although they also serve several other sectors. The firms surveyed perform a wide range of activities in the country from research, development, and design to component production, assembly, distribution, and post-sale services (i.e., they are not purely assemblers).

In terms of the characteristics of the respondents, half of them were the CEOs of the companies, 18% had a business management function, 14% had a function related to planning, strategy, or operations. In terms of their background/education, most of them were engineers (64%).

Firms were asked which DPTs, or DPT-related services were contained in their products and services. The DPTs mentioned the most were performance monitoring technologies, integration of equipment and components for connectivity, software and implementation services, and programming for data collection and analysis. Overall, these are DPTs mostly based on software. The technologies with the lowest presence were augmented reality (9%) and autonomous transport (18%).

When asked about the importance of DPTs in their 4.0 machines, the firms' response was varied, with 39% saying they were a marginal technology, 39% saying they were important, and 22% saying they were the main technology of their 4.0 machines. The firms were then asked about the activities they carry out relative to the development and the integration of DPTs into their products. The results of Figure 2 below show that the surveyed firms are mainly *integrators* of the software and hardware components of DPTs. This was confirmed in the interviews, with two firms defining themselves explicitly as integrators.

Figure 2 - Production activities related to DPTs (n = 20)

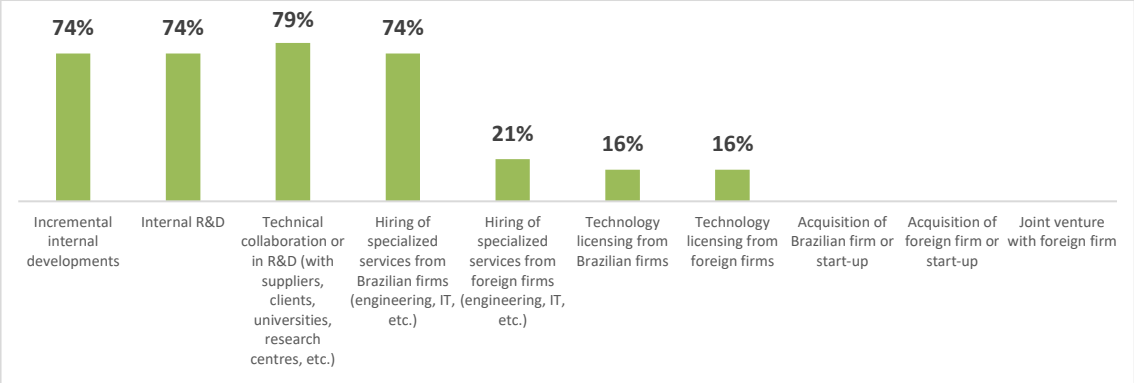


Source: Own elaboration based on survey results

4.1.1 Modes of development and integration of DPTs

In terms of the modes of development and integration of DPTs, the ones used the most by firms were technical collaboration in R&D, incremental internal developments, internal R&D, and hiring specialized services from *Brazilian* firms. Hiring specialized *foreign* firms, and technology licensing were modes used to a much lesser extent. The acquisition of start-ups – be they Brazilian or foreign – and joint ventures with foreign firms were not used by any of the firms that responded (Figure 3). This shows that DPT development and integration are mainly *domestic* and to a large extent *internal* efforts in the surveyed firms.

Figure 3 - Mode of development or integration of DPTs (n = 19)



Source: Own elaboration based on survey results

In the cases in which collaboration was made, these were mainly done with Brazilian suppliers, and to a lesser extent with Brazilian clients, universities, and (private or public-private) research centres. Start-ups (be they foreign or Brazilian) and foreign clients were not relevant partners in the surveyed firms' DPT-related efforts. In addition to collaborating directly with firms, suppliers also worked as intermediaries between the firm and relevant organisations with whom they collaborated – although, overall, intermediaries were not that relevant for DPT development or integration.

The interviews shed light on different types of collaboration that occur in DPT development and integration. Regarding collaboration with suppliers, Integrator Inc. explained that often it is the technology supplier that puts them in contact with the client, to help them adapt and implement the solution in their specific production environment.

In terms of collaboration with universities, MajorMachinery mentioned that they often realise that they do not have the physical or intellectual capacity to carry out their projects and therefore they reach out to universities. SmartTextileMachines also mentioned that the first thrust towards making their machines 'smart', was made in partnership with a university. Universities benefit from the collaboration, as they have the mandate to be aligned with the demands of national companies – to make sure the skills they are teaching are demanded by industry. The firm, in turn, benefits from the knowledge generated in the collaboration, which is sent first to the company and only published later or is agreed not to be published.

Regarding collaboration with research and technology centres, two interviewed firms mentioned the key role of the Informatics Law in promoting this. One of the conditions to benefit from the Law is to collaborate with Brazilian centres. Often, thus, the nature of this collaboration is in developing DPT solutions or in adapting DPTs to the specific conditions of client firms and integrating them into their production and management system.

MajorMachinery attributes the benefit of collaborating with universities and technology institutes to the complexity and variety of DPTs:

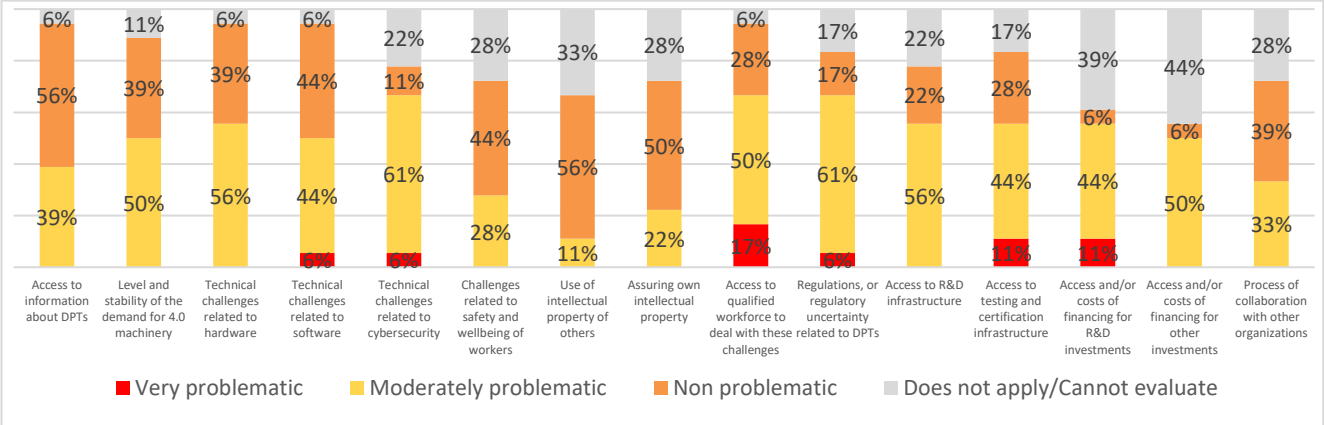
"There are a lot of technologies, or there are a lot of new products that need to be developed and we don't

have people or knowledge enough to do everything at the same time. There is a big risk. If you spend all of your money to develop one of the technologies and it does not pay off in the future, the risk is very high. That is when the government steps in to finance various lines of research, often with non-reimbursable funds. And the industry is interested that this happens." (MajorMachinery interview)

4.1.2 Obstacles faced when developing and integrating DPTs

Concerning the obstacles faced when developing and integrating DPTs two of the main ones were access to qualified workers and access to and costs of financing for R&D investments. These obstacles are also prominently identified in the existing literature. However, the survey has identified another obstacle that is not mentioned in the literature: access to testing and certification infrastructure. Other obstacles that were mentioned as relevant (although not as important) were the technical challenges related to software, the technical challenges related to cybersecurity, and issues related to DPT regulations (or regulatory uncertainty) (Figure 4).

Figure 4 - How problematic were the obstacles to the development and integration of DPTs?



Source: Own elaboration based on survey results

Interestingly, intellectual property issues (both securing their own and using those of others) were seen as the least problematic of potential obstacles. This is somewhat surprising given the importance this topic is often given in the academic literature. This issue was explored in the interviews and the interviewees clarified that intellectual property disputes are not common in the machinery sector because most firms prefer an open-source strategy to help the spread of their technology. After all, most key technologies are already established (i.e., patents expired), and the technologies are not easily copied anyway, making reverse engineering very hard. One company mentioned that patenting is more of a *marketing strategy* – i.e., having a patent is a "status symbol" and can be used as a signal of the quality of the firms' products – or is a requirement of the research partner (e.g., a university). It can also be used as a way of proving the ownership of a technology, thus protecting the company if others decide to patent a similar technology and then sue them for patent infringement.

> "Normally, the software is open, and what is intended is a massification of the use of technologies and not a restriction. Why? The firms that follow the restriction path end up with a very small share of the market." (Integrator Inc. interview).

> "Despite not being patented, [the technologies] are very secret in our machines. If a competitor buys one of our machines and disassembles it, they will not be able to generate knowledge from that. There is a lot of tacit knowledge that is specific to the company. Patenting in our field is very rare. It is not necessary to earn money, and it is not that necessary to protect our interests (…).

> "When the company patents and there is an external researcher, they have their names on the patent, and sometimes this is important for the university." (MajorMachinery interview).

> "Intellectual property in the context of my company is to demonstrate that I have a production of intellectual property, which is important for the valuation of my company (…).We do it because we understand that it is almost a *branding* for my company (…). And of course, if one day we need to sue someone, we can do it." (SmartTextileMachines interview, emphasis added).

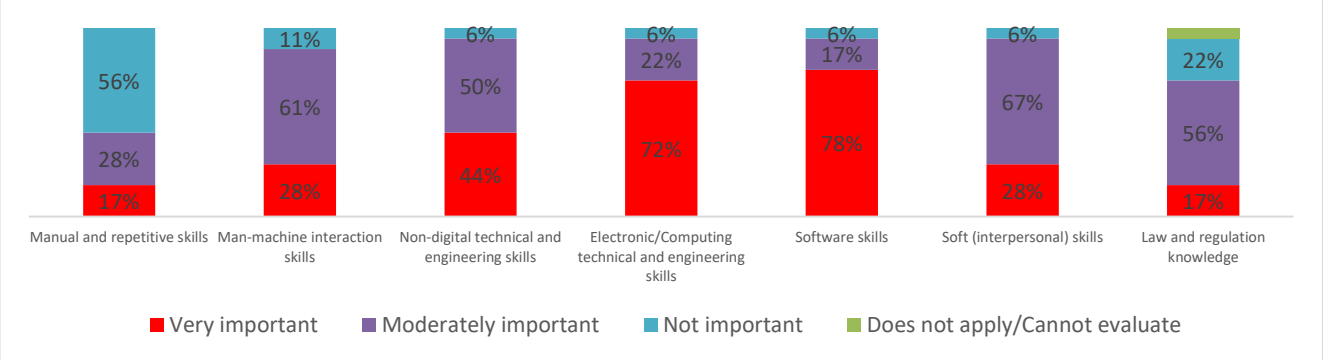
> "It is not for us to knock on someone's door and say: 'You copied us'. It is the other way around. In case someone knocks on my door and says 'You copied me', I can say: 'No, this is mine'. (…)" (Lowcost-Sensoring interview).

In terms of the workforce skills needed for DPT development and integration, there were no surprises. The skills pointed out in the survey as the most important were: (i) software skills, on the one hand, and technical and engineering skills in electronics and computing, on the other hand (Figure 5). However, the interviewed firms qualified this finding, highlighting that, for DPT implementation, technical training is often more useful than engineering skills and that DPTs require technical skills that are more multi-disciplinary rather than specialised – that is, combining knowledge from different technical areas, rather than being focused on one specific area.

> "For the first level of implementation, technical courses sometimes produce professionals that are more qualified than engineering courses. (…) SENAI has a specialised course in automation that is very competent. These professionals serve us well. Engineers are normally better for functions like project management, and management activities in general. And the professionals that both have the technical training and are also engineers start to [positively] differentiate themselves from others." (Integrator Inc. interview)

> "Today we see very few people being trained as a generalist. We see a lot of specialists. But Industry 4.0 involves many disciplines and many areas, so you don't see a professional that can speak of cloud computing and also deal with integrated circuits. There is a guy focused on automation, and a guy focused on IT, and you need to have a team to do it. You don't see the 'capsule' of Industry 4.0 knowledge being taught to professionals in the market." (SmartTextileMachines interview)

Figure 5 - Importance of different skills for the development and integration of DPTs



Source: Own elaboration based on survey results

Despite highlighting that finding workers with the right skills are always an issue, the interviewees did not see this as a major bottleneck in Brazil, highlighting the existence of strong training institutions in the country, and the responsibility of firms in training the professionals that they need.

> "Today, this [lack of qualified workforce] *is not what is holding us back*. (…) We have a very strong institution, SENAI. The whole of Brazil has SENAIs that train young people that can operate [DPTs] (…)." (MajorMachinery interview, emphasis added)

> "[If the] professional has a technical basis, for example, if he has done a technical course, they can be ready to implement one of these technologies within a year. If you have the energy, the strategy, and the interest to do it like that, *it is not an insurmountable problem.* What may lack (…), and technical schools could help with this, is basic training. This we cannot do. We need to take someone with at least some technical knowledge so that, from there, we can train him/her in the practical exercise of the profession. But, at the

> moment, *this type of professional is not lacking* – at least not in our region. (…) But now, if you only want [a professional that is] ready, graduated, with experience, then this becomes more difficult." (Integrator Inc. interview, emphasis added)

4.1.3 Public policies used and desired

Regarding public policies, 27% of firms said in the survey that they had not used any. The ones used the most by the surveyed firms were BNDES Finame Máquinas 4.0, Lei do Bem (Goods Law), Lei de Informática (Informatics Law) and other unspecified BNDES policies. Some firms also used FINEP's Inovacred 4.0, and other unspecified EMBRAPII policies. Access to these policies was considered either moderately problematic or slightly problematic, but none was considered very problematic.

This lack of usage of public policies was reflected in the perception of the interviewed firms. Two of them – Lowcost-Sensoring and SmartTextileMachines – said that they had basically no support and that DPT development was "an *isolated initiative* of our company" (SmartTextileMachines interview). The only thing that has worked a few times for them was BNDES and FINEP's funding for buyers. These policies were seen positively because the government pays the M&E firm in full upfront for the acquisition of the machine and finances it for the client. From 2019 onwards, however, they claim, the BNDES line had not been working because the interest rates charged by them had not been attractive to clients.

SmartTextileMachinery put this point even more bluntly:

> "There is no policy related to Industry 4.0 in Brazil (…). [Although] some [funding] lines benefit you. (…) I can't see this policy. (…) The only thing I see is this FINEP line that I know exists and comes from the government. Other than that, I don't know of absolutely anything. I know that in the MCTI there are people focused on Industry 4.0 but there is no visibility of what they are doing from the point of view of what is being applied, sincerely. And I spend my whole day listening to the news. (…) If this had any type of repercussion we would know. We receive communications from ABIMAQ, but at most, you see a lecture or a discussion about this. Nothing, nothing."

When questioned about BNDES Finame, they said:

> "There was a time that we used to sell a lot of machines through Finame, but the lines are not attractive (…) The commercial banks are giving more attractive [credit] lines to the clients."

The SmartTextileMachinery interviewee asked during the interview his financial department how many Finame operations they had used and received the answer that it had been used in only 10% of their sales in 2021. He then finished off with a surprising statement for a CEO of a smart machinery firm:

> "I don't even stop to think about these things. (…) [Industry 4.0] is not a subject that we discuss. In the last two years, you are the person that I have spoken to the most about this. This topic is somehow entangled in our day-to-day, but as any good Brazilian, we just try to get by." (SmartTextileMachines interview).

According to MajorMachinery, Brazil was very late in making policies for DPTs when compared, for example, to Germany and Japan. The government eventually carried out studies to adapt international policies to the local context and put forward some policies, for example, the funding for the acquisition of machines at subsidised rates (such as BNDES Finame, and FINEP Inovacred 4.0). However, the funding for them has been reduced a lot in recent years and the interviewed firms clearly do not think it is enough, especially after the pandemic:

> "The main obstacle in my opinion is the lack of funding to clients to buy machines. The pandemic worsened this a lot, as firms became even more reluctant to spend" (MajorMachinery interview)

Having an international presence, MajorMachinery also expressed its discontent with the Brazilian policy when compared with those of other countries. The interviewee from the firm claimed

that funding for the acquisition of machines is very common in Germany, Italy, France, and Spain. According to the interviewee, in Spain, as they don't have a lot of machinery producers, they just allow firms to buy Industry 4.0 machinery regardless of where they come from.

SmartTextileMachinery also evaluated Brazil negatively in international comparison:

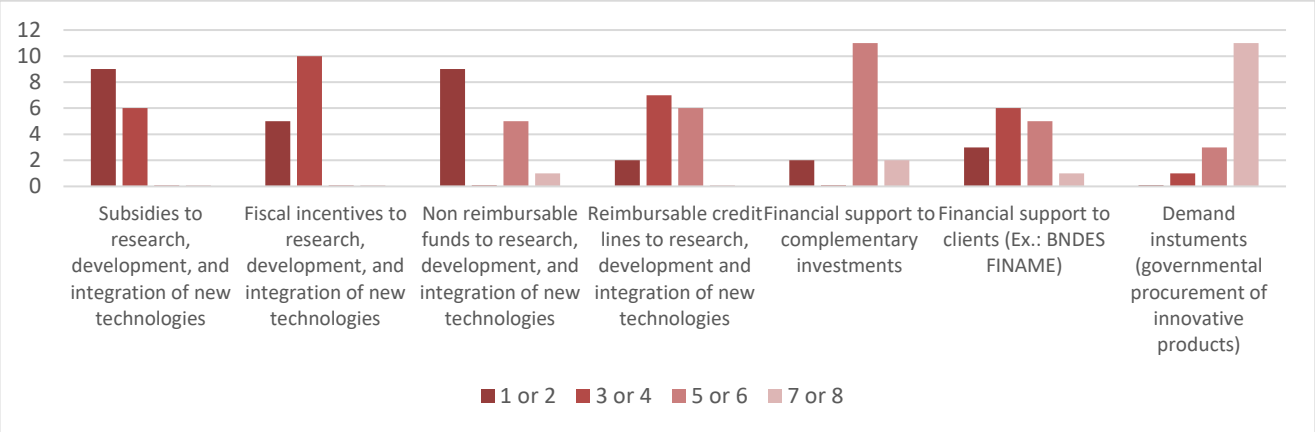
> "In Italy, the governmental incentive is an effective reduction in taxes for you to have projects or investments in Industry 4.0. While in Brazil… not to say that there isn't anything, there is a project by FINEP through which some firms can bring this to clients, but it is a super-bureaucratic process. *It is not something (...) that the firm around the corner can benefit from* if it does an Industry 4.0 investment – no, you must have a whole project to access funding of this level. (…) In Italy, the client that buys from me [a product] that has Industry 4.0 receives a benefit [from the government] and the investment comes out almost at zero cost, so it is an enormous incentive. (…). [Accessing FINEP's benefits] is something that requires a lot of work, it is complex, and it is complicated. We have almost a whole department working just to fit projects to the requirements of FINEP (…). And it is not a line hyper-mega filled with money. For a country like Brazil that has thousands of industrial firms, it should be much bigger – 15 times or even 150 times bigger." (SmartTextileMachines interview, emphasis added).

The Italian policy that SmartTextileMachinery was probably referring to is the country's Industria 4.0 plan which provides one of the most attractive tax frameworks for innovative companies in the world (CENTRE FOR EUROPEAN ECONOMIC RESEARCH, 2017). In terms of machinery, Italy's policy allows for a super-depreciation of 40% for new machinery and a hyper-depreciation of 150% if the industrial equipment acquired is of an "Industry 4.0" type. These schemes effectively lead to a substantial, long-lasting reduction in taxable income, and thus of the effective tax rate for the company. Italy's policy has the benefit of being automatically available to any type of company, thus reducing uncertainty and red tape.

Relatedly, the survey showed that the main source of capital for investments in the development and the integration of DPTs was by far the firms' own capital (72%), against 17% private (e.g., loans from private banks), and 11% public (e.g., loans from public banks or funding from government agencies). This is consistent with what was found in previous surveys and in the previous chapter about the lack of support from the government.

The survey then asked firms which financial and non-financial policy instruments would be most useful to help them develop, integrate, and commercialise DPTs or 4.0 machinery. In terms of financial instruments, the most frequently cited were subsidies and tax incentives for R&D, followed by non-reimbursable (grants) and reimbursable funds (credit) for R&D. Interestingly, financial support to clients (e.g., BNDES FINAME, FINEP Inovacred 4.0) was not mentioned as very useful, despite being one of the main instruments available to firms in Brazil. Also, demand instruments (e.g., public procurement), which are often highlighted as relevant in the innovation literature, were seen as the least useful for the surveyed firms (Figure 6).

Figure 6 - Which financial instruments would be the most useful to help develop, integrate, and commercialise DPTs or 4.0 machinery?



Source: Own elaboration based on survey results

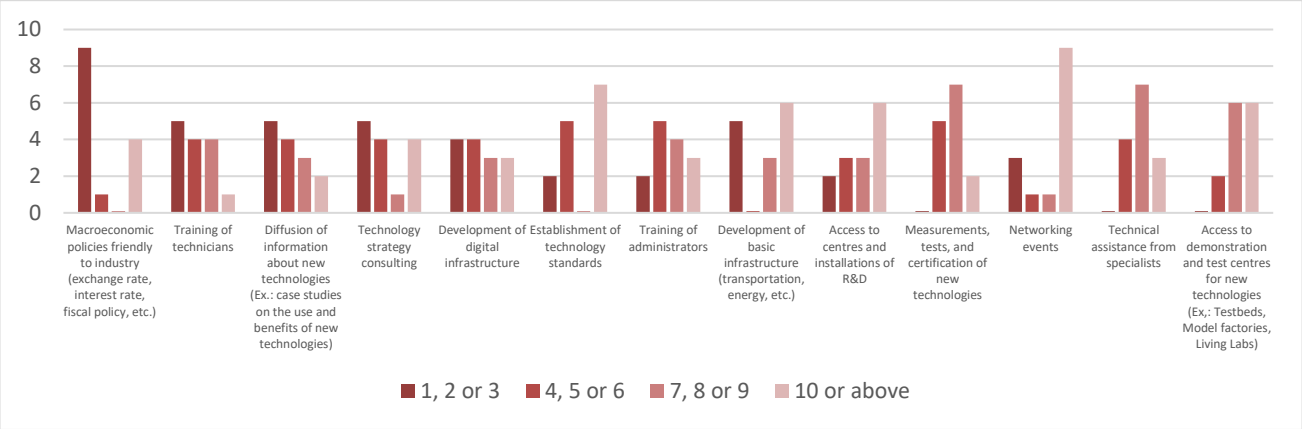
MajorMachinery, somewhat in contrast with these survey findings, highlighted that funding to clients is fundamental and, in their opinion, is the most important policy to be further developed. According to the interviewee from MajorMachinery, Brazil already has good incentives for R&D, and his firm is always able to somehow fund their innovation efforts (it should be remembered that he is speaking from the point of view of a large, mature, and internationally competitive firm). However, the interviewee argued that the Brazilian industry (their clients) find it hard to modernise their equipment. According to the interviewee, this can be seen by the fact that the average age of machinery in Brazil is 16 years, compared to 3 years in Germany and 6 years in the US. A policy desired by the interviewee would be a *programme of machinery modernization* in the Brazilian industry, something along the lines of: "hand over your old machinery, and buy a new one at a discount" (MajorMachinery interview).

In a similar vein, for SmartTextileMachines what is missing is an incentive or *pressure* for domestic firms in Brazil to modernise their technologies:

> "If you say something like: 'Firms in Brazil, if you prove that you have an investment in Industry 4.0, you will have [tax] reductions of 1,% 2%, 3%, or 5%', this becomes *a state to be sought*. Today, *there is no pressure of this type*. The pressure comes much more from the entrepreneurial level, rather than the governmental level. And we perceive that, if this is pursued at the governmental level, the companies have effective gains, become more competitive in the market …. These basic policies in Brazil are something that we almost don't hear about, except when they are being retrenched, especially in the current [Bolsonaro] government." (SmartTextileMachines interview)

Regarding non-financial instruments, the one most frequently cited as the most relevant was macroeconomic policies friendly to industry (Figure 7). This has been highlighted by Brazilian scholars as a fundamental problem for Brazilian industrialists (see, for example, RONCAGLIA, 2020), and has remained a problem in recent years.

Figure 7 - Which non-financial instruments would be the most useful to help develop, integrate, and commercialise DPTs and 4.0 machinery?



Source: Own elaboration based on survey results

MajorMachinery mentioned that the exchange rate, for example, needs to be set at a competitive level. If not, it becomes too cheap to import parts from abroad, for example from Europe, China, Thailand, or Malaysia, making it hard for the company to be competitive. Interest rates are also important. When interest rates are low, businessmen see that their investments in the bank are yielding less than what they could earn with a new machine. According to the interviewee: "These two [exchange rate and interest rate set at the right level] *are much better than any government funding support*" (MajorMachinery, emphasis added).

On this topic, it is also relevant to see the point of view of a subsidiary of a foreign firm (so fundamentally an importer), which shows the other side of the coin. RobotImporter claims that:

> "What is interesting for us would be a policy of reducing or eliminating import tariffs. Of course, not done in a disorganized way, but maybe for new technologies which cannot be supplied 100% by the national industry. You give benefits to attract external firms that will help develop, through competition, the local companies. But obviously, also thinking about the future: I'll give you this benefit, but I need a local investment plan because what I want is that as you gain space, you also invest." (RobotImporter interview).

Moreover, the survey revealed that a policy for technician training was seen as very relevant, as well as the diffusion of information about new technologies, technology strategy consulting, development of digital infrastructure, and establishment of technology standards.

On the diffusion of information about new technologies, Integrator Inc. explained:

> "The more people with enough knowledge to implement [DPTs], the more successful cases are applied, and that leads to larger support and investment in this direction. I think it is at this stage that we currently are in Brazil. Since projects started being applied a few years ago (…) the firms are believing more in the success of these technologies." (Integrator Inc. interview)

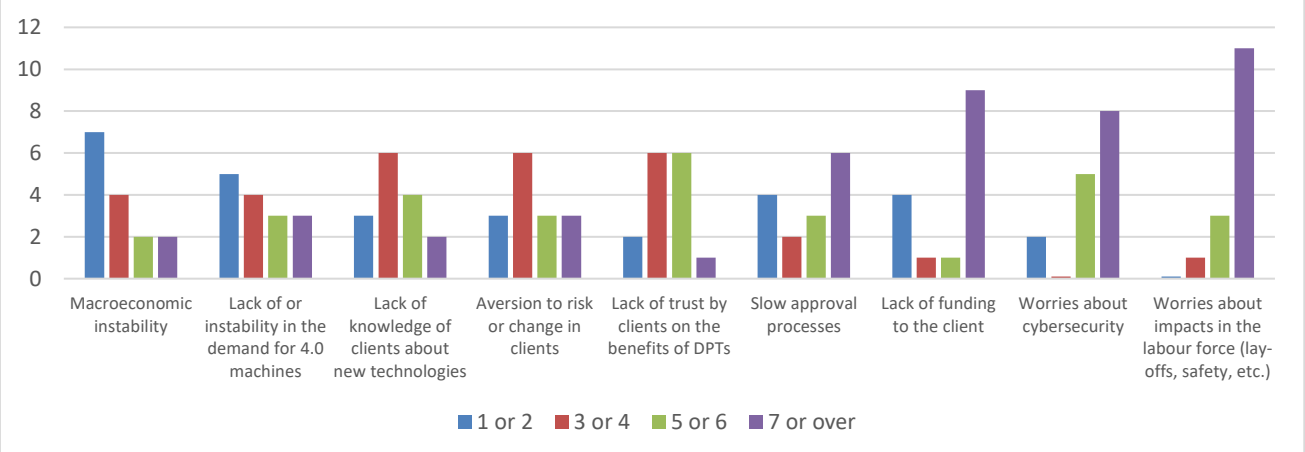
Finally, a potential contradiction appears to have emerged in the survey responses. The firms mention a lack of testing and certification facilities as a relevant obstacle, but access to demonstration and test centres for new technologies (testbeds, model factories, living labs) was cited as the policy with the least importance. Since these are relatively new policy instruments, it may be the case that firms simply do not know what they mean or entail.

4.2 Results related to the implementation of DPTs in client firms

Firms were also asked about the installation process of 4.0 machinery in their clients' production environment. Half of the surveyed firms do the installation process themselves, and half do it jointly with third-party engineering firms (which are mostly Brazilian). When asked if the implementation process was problematic, 67% of firms said it was only slightly problematic or not problematic at all.

Implementation processes can be divided into the *pre-installation phase* (i.e., the sales and commissioning phase), and the *installation phase* (i.e., when the technologies are installed in the production environment of the client). When asked what the main problems in the *pre-installation* of 4.0 machines were, the message was clear: macroeconomic and demand instabilities are the main problems. These were followed by the lack of knowledge among potential clients about new technologies, the clients' aversion to risk or to change, and the lack of trust by clients in the benefits of DPTs (Figure 8). This helps explain why these firms deem publicly-supported diffusion of information about new technologies a necessary policy.

Figure 8 - What are the main problems found pre-installation of 4.0 machines in clients?



Source: Own elaboration based on survey results

According to RobotImporter, the first barrier when implementing DPTs is to convince potential clients that it makes sense to invest in the technology. That becomes a challenge as most clients have a limited vision and only look at the benefits of DPTs in terms of reduction in the number of workers and equipment rental costs. However, the benefits of their technologies – autonomous robots – go way beyond these and include benefits that are harder to measure, such as the reliability of the equipment, reduction of accident risks, reduction of medical leaves of workers due to less repetitive and physically straining tasks, etc..

Lowcost-Sensoring described a similar difficulty, but has perceived a change in the market:

> "When we started 20 years ago, no one talked about this [type of technology]. It was something unknown. Many companies did not believe in it and thought that we were crazy. (…) Today, we hardly need to go knocking on any company's door. We don't even manage to serve the companies that come knocking on our door. So, the scenario has changed. Not only that, but the competition has also increased. Before, it was us and two more. Today, I've lost count of how many start-ups are out there doing something similar." (Lowcost-Sensoring interview).

This change in the market has also changed the potential clients' perception of cost, and the hype around Industry 4.0 seems to have contributed to that:

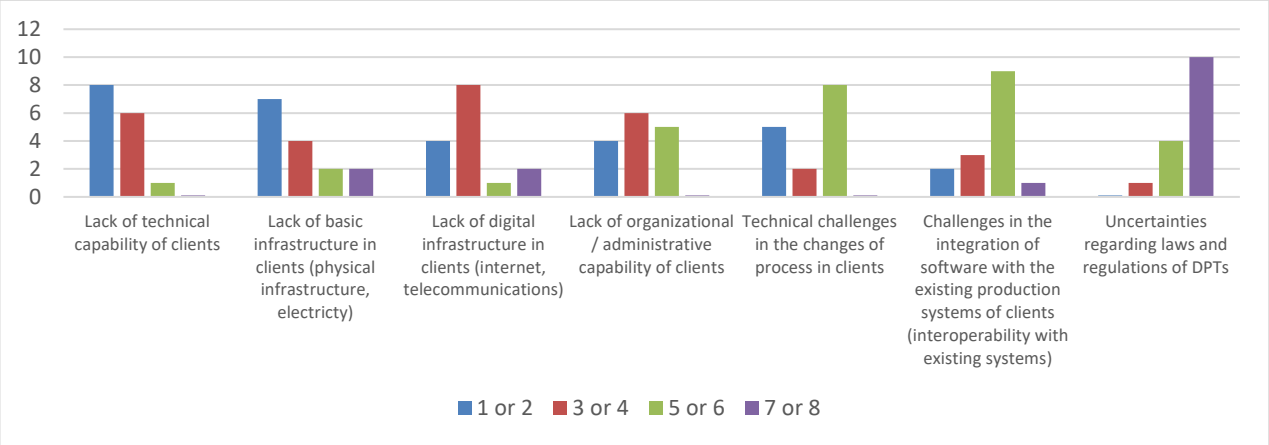
> "Before, we showed how much the system cost and they would say: "What? All that?". Today people come to us and when we say the price, they say: "Cool. It's cheap!". The scenario changed completely after this whole Industry 4.0 thing started" (Lowcost-Sensoring interview).

Also, the technology has advanced over time, and today it is much better and more user-friendly:

> "Before, to make this system we had to literally [sic] wring water from stones. Communication between our data collectors used RS485 communication, which is something that had already been in the market for some time but was very primitive, hard to use, and complex. Today, you put a small chip that costs one dollar [in the sensors] and it communicates using Wifi – a standard that anyone can use. It is much easier to do it today than 20 years ago." (Lowcost-Sensoring interview)

During the *installation phase* of 4.0 machinery, the main issues found were the lack of technical capabilities in clients, the lack of basic and digital infrastructure in client firms, and the lack of organisational/administrative capabilities of clients (Figure 9).

Figure 9 - Main problems found in the installation of 4.0 machinery in clients (n = 15)



Source: Own elaboration based on survey results

The interviews highlighted that this lack of technical capabilities (i.e., their *absorptive capacity*) is not exclusive to clients but also encompasses the technology providers and integrators themselves

(i.e., their *emitting capacity*). According to Integrator Inc., there is a learning curve for the effective implementation of DPTs:

> "We are still at the start of a process of massification of these technologies. Even in the contact with technology suppliers, whom we still rely a lot on, often they do not even have technical assistance available in Brazil (…). So, sometimes it was difficult to get access to correct information here in Brazil. This should change, and is changing, as you continue applying the technologies. The first project we developed in Industry 4.0 was very difficult. Today, it is easier, because of the development of our own capabilities and those of technology suppliers themselves. 5-10 years is a short time to develop a technology." (Integrator Inc. interview).

4.2.1 Impact of DPTs on the clients' production processes, as perceived by the M&E firms

In terms of the impact of DPTs perceived by the M&E firms in the clients' production processes, the ones underscored by the survey were productivity increases, improved control of production, reduction in defects/errors, and higher quality of products and services. To a lesser extent, but still important, were reduction in labour costs, improvements in planning and decision-making, and reduction in energy and other resources costs. This puts in question the common narrative that DPTs have a strong impact on jobs and shows that, instead, the main impact of these technologies is in increasing the efficiency of processes and the quality of products.

Lowcost-Sensoring argued that the main benefit of their technology was the improvement in the effectiveness of the client's existing machinery, measured by its Overall Equipment Effectiveness (OEE). SmartTextileMachines agrees that the main effects of DPTs are in improving control of production, rather than saving on labour costs:

> "[In the typical Brazilian industrial firm] there is very little control [of production]. There is a lot of paper circulating, a lot of people talking to each other, and the visualisation of the inefficiencies of this process is very opaque. When you use Industry 4.0 to connect, intercalate, measure, and evaluate what is happening in the process, you have gains that are very interesting for production. (…) (SmartTextileMachines interview)

The range of information that can be generated by DPTs is endless. However, it is pointed out that a lot of benefits can come from very basic DPT applications, and Lowcost-Sensoring even joked about clients becoming overly ambitious about sensoring possibilities:

> "I can tell you that 70-80% (…) of the Brazilian industry *does not do the basics* – they do not know if their machine is running or stopped. (…) I go crazy because we visit some places and people say: 'Ah, with Industry 4.0 we will measure the curve of this and that'. Buddy, you don't even know if your machine is running or stopped, and you are worried if the wind outside is strong or weak – oh stop it! [Laughs]" (Lowcost-Sensoring interview, emphasis added)

Indeed, often DPTs don't "do" anything, but simply provide better information that can lead to better decision-making and action:

> "The system itself doesn't do anything. It only shows what is happening, so that people can take adequate action. But by knowing what the correct information is (…), they can take much more assertive action and increase the productivity of the company. This can have outstanding results" (Lowcost-Sensoring interview).

Accordingly, this better information brought about by DPTs can lead to a "cultural"[5] change within the firm. As Lowcost-Sensoring described, when the system is implemented, there is a shock, a "reality check", that leads to a "witch hunt" for the responsible for the newly observed

[5] Culture here refers to the formal and informal rules and "ways of doing things" of a company.

underperformance, and this can be transformative of the routines and beliefs within the firm:

> "Imagine, you are the factory manager. You report every month to the directors that the OEE is 80%. Suddenly, a guy that had never stepped foot in your factory implements a system and says it is not 80%, it is 60%. The first thing the director will do is to turn to the manager and say: 'You have lied to me all these years'. But the manager did not lie. He worked with the data that he had at hand (…). This leads to *a general change in behaviour*, for the whole company (…). Some operators do not adapt and are let go, other operators adapt, and others are forced to adapt. This happens. But it is an important transformation" (Lowcost-Sensoring interview, emphasis added).

This "cultural change" creates even tensions with traditional machinery manufacturers:

> "See how it is controversial: if I have 40 machines, and I implement this system (…) in three months I will turn two of them off. I will not buy the 41st. I will increase productivity in a way that I will do the same things I was doing before but with 38 or 36 machines. This is a concept that people are still far from understanding. What happens is that most Brazilian businessmen (…) prefer to use R$100,000 to buy a new machine rather than to use that R$100,000 to improve the productivity of the 40 machines they already have. (…) This is a mindset that is harder to change." (Lowcost-Sensoring interview).

In some interviews, an important issue that was raised was that the full effects of DPTs are only achieved *if the entire factory or production line is connected*. There is little benefit in having only one connected machine. RobotImporter mentioned that it is a common practice for clients to do DPT investments piece-by-piece instead of doing it for the whole factory or firm. The problem is that by digitalising bits and pieces of the factory or firm, you run the risk of creating interoperability issues, and later you may have to spend a lot of resources to adapt the different parts of the firm to talk to each other.

A curious situation was described by Lowcost-Sensoring, in which some companies with whom they partnered would insert connectivity functions in their machines simply to be eligible for the government's incentivised funding. However, this never worked well, because having connectivity functions in only one or a few machines (among several others that are not connected) does not lead to any gain. "For our system to work, you need to change the culture of the company. The person needs to register their machines, they need to register their products, they need to train the operators… *They need the requirement of productivity improvement*" (Lowcost-Sensoring interview).

This has important policy implications because at least one Brazilian policy – BNDES Finame Máquinas 4.0 – incentivises companies to acquire individual machines that have connectivity functions. However, it appears that the "unit of incentive" should not be the machine, but the entire production line, the entire factory, or the entire company. For the DPT benefits to be achieved, the policy must be more general.

When asked directly about the impacts of DPTs on jobs, 44% of firms said that with DPTs their clients would use fewer workers, 39% said they would use the same number of workers, and 17% said it did not apply to their case (or did not know how to evaluate).

The interviewees were unanimous in explaining that a reduction in the number of workers was not the main benefit of their technologies. Some of them saw lay-offs as a potential outcome of implementing their technologies, but in a much more nuanced way, as described below. More importantly, workforce reduction is still one of the main *commercial* arguments, and one of the main factors that clients are looking for when deciding on their investments.

> "The question of the reduction of the headcount – or the cost of labour – is evidently taken into account. But there are other gains associated with the implementation of automation: such as visibility [of the production process] and predictability. These are much more relevant than the reduction of headcount. However, the reduction of headcount is a more measurable, more palatable payback, and thus is often used [by firm managers] as the rationale for the investment… However, it is obvious that everyone is analysing the overall context: the gains in quality, visibility, predictability of productive planning, and supply chains… These are the main gains. But the reduction in the number of workers is still effective as a *commercial argument*." (Integrator Inc. interview)

> "The majority [of Brazilian firms] – I would say 90% and would not be exaggerating much – only consider

> the workforce and the equipment hiring components (…) in their cost calculation (…). This is a search almost directly for a substitution of labour (…). [However,] many components of cost are not measurable but bring much more value than simply substituting a worker (…), a series of things that should be included [in the cost calculation], but that, unfortunately, are not." (RobotImporter interview)

The interviewees also highlighted that adopting new technologies mostly leads to changing the role of workers within the firm, rather than firing them. Lowcost-Sensoring, for example, mentioned that usually even the person that manually collects data before the implementation of the system is not laid off, but simply has their role changed and starts analysing and interpreting data, rather than manually collecting it. This certainly leads to a change in the skills needed in the workforce, but also frees workers from menial tasks, redirecting them to perform tasks that are much more fulfilling.

> "In the vast majority of the companies, this person is not fired. They end up being adapted to do another much better activity. Instead of collecting data and making graphs, they simply take the data and graphs that are made for them. They end up going after the raw materials that are missing, seeing which improvements can be made, studying improvements to the layout (…). You put a person to actually think about the improvements that can be made, and not to collect paper or to type information in Excel. (…)" (Lowcost-Sensoring interview).

> "At the same time, [4.0 machines] create more occupations for people that will work with the data from those machines. It can be in the same company. You can then have two machines with one operator, and the other person will work on understanding the data that the company is generating. The impact on employment is that you will need a workforce that is more qualified and prepared to deal with these new tasks. You have to know about computing, you have to know screens, you have to know more about production engineering (…). The machine operator, who is also someone that studied and trained a lot, will have to change a bit (…). They will have to study more about data, computing, etc." (MajorMachinery interview).

> "For some things, humans are essential, but for other things, they are almost a mechanical piece in the process. From this point of view, we need to use humans to do something better. If the process can be automated, why keep someone in daily suffering, doing something in which they do not think, do not act, and do not interact? In this aspect, will they lose jobs? Yes, and this is irreversible. But from the social and human point of view, we need to lead people to use other types of capacity– to do things in which human intervention, the need for human intelligence, can capture something very hard to capture – even though they say Artificial Intelligence one day will do this too." (SmartTextileMachines interview).

The only way in which Lowcost-Sensoring sees its technology affecting the number of jobs significantly is through productivity gains and not through direct labour substitution. The productivity gains enabled by the system may lead a company that works three shifts to reduce to two shifts – and that leads to many people being laid off. However, normally the company in which this happens grows, or the market grows, and after a while, the need for increased production leads them to reactivate the third shift – thus compensating for the initial negative impact on the number of jobs. It was similarly noted by SmartTextileMachines that the adoption of automation technologies also has expansionary outcomes. Productivity gains keep the firms in the market, and may even allow them to increase their production and open new factories, so the overall effect on employment might as well be positive[6]:

> "When you, within an industry, keep a firm in the market because it is more efficient, how many jobs – direct and indirect – are preserved? So, it [labour displacement by technology] is a very ambiguous concept – you lose here, and you gain there (…). *It is a very short-sighted view to say that you will lose people because of this [implementation of new technologies]*. You have to think of the chained impact." (SmartTextileMachines interview, emphasis added).

5. Discussion and conclusion

Brazil has a significant M&E industry, characterised by the presence of large multinationals in the

[6] This mechanism has been pointed out in many other studies on the effects of innovation on jobs. See, for example, (Bessen, 2015; 2019; Parschau & Hauge, 2020)

technologically sophisticated segments, while domestic players, with a few exceptions, mainly focus on the lower-technology segments focused on the domestic market. This paper revealed that currently Brazilian M&E firms are seeking to engage with DPTs, but have been facing difficulties in doing so – both related to the very challenging characteristics of DPTs themselves, and to the challenges of running an industrial business in Brazil.

In terms of the characteristics of DPTs, it should be emphasised that the technology fusion aspect that underpins these technologies has many consequences. First, its development requires knowledge from different areas and thus makes collaboration between firms, universities, and research and technology centres essential. Secondly, due to the integration of different technologies, they require more "multidisciplinary" technical skills, rather than ultra-specialised ones. Thirdly, this fusion of different technologies often creates interoperability issues, and thus the need to implement DPTs in entire production lines or factories, rather than in just a few machines (raising the minimum capital requirements for adoption). Fourthly, the integration between different technologies means that DPTs are easily integrated with legacy equipment, making retrofitting possible, and indeed a common occurrence.

In terms of the Brazil-specific challenges and opportunities, this chapter shed light into how two processes of technological catching-up in DPTs are happening in the country: technology development and technology adoption. Regarding technology development, this paper revealed that Brazil has an enormous potential due to the existence of Brazilian providers of DPT solutions – especially integrators – and the existence of a domestic innovation ecosystem with capabilities in DPTs. Still, strong barriers were identified in terms of access to qualified workforce (despite strong Brazilian institutions of worker training), adequate infrastructure, and access to funding (especially for SMEs).

In terms of technology adoption, macroeconomic and demand turbulence were highlighted as one of the highest barriers, followed by issues concerning the absorptive capacity of adopting firms. This highlights that if Brazil is to advance in its technological catching-up in DPTs, coherence between industrial and macroeconomic policies is needed.

Moreover, this chapter gave us the point of view of M&E firms on the Brazilian DPT policy landscape. First, it can be observed that firm managers see the current policies as insufficient and many perceive that there simply *does not exist an DPT policy in the country*. Of the programmes that exist, some are viewed as too complicated, making them inaccessible to most firms. In other words, there are no adequate incentives or "pressure" for firms to modernise by adopting DPTs. These findings are relevant not only to the Brazilian M&E sector, but to all Brazilian industrial sectors given that adopting digitalised machinery and equipment is an integral part of the digitalisation process of all industrial sectors.

In summary, despite its potential, Brazil appears to still need very significant efforts to overcome the barriers to catch-up technologically in DPTs, and the policies it has put forward so far are not strong enough to drive this change. This creates a context in which DPT investments are mostly isolated efforts by highly capable firms, often entering collaborations with universities and research and technology centres, but without an overarching framework to guide their efforts in a coordinated manner.

5.1 Policy recommendations to boost the diffusion of DPTs in the Brazilian industry

Based on the findings of this chapter, some policy recommendations can be made to help boost the diffusion of DPTs in the Brazilian industry. First, keeping the exchange and interest rate at levels that are favourable to industry seems to be crucial as this "*is better than any government funding support*", as one of the interviewed firms put it.

Secondly, create an *industrial machinery modernisation plan*. As part of this, provide an incentive for companies to implement DPTs. If done well, the effect of seeing competitors benefiting from the government incentive would create the necessary "pressure" for firms to adopt DPTs – which is currently missing. This should not be, as it is done now, conditioned on elaborating complex innovation projects that only a few firms can do. It should be something *diffused massively*. As one

interviewee said, it should be something that any "*firm around the corner*"[7] can access. If a firm can prove that it is effectively implementing DPTs, it could receive a benefit from the government, possibly via a subsidy or tax reduction – since these are policy tools deemed to be most useful by firms in the survey. This would make DPT adoption something that firms would actively seek.

Third, the "unit of incentive" of policies should not be single machines, but the whole production line, factory, or company. This is meant to induce changes not only in production processes but also in the *culture* of firms to create a "*culture of productivity increases*", as mentioned by one of the interviewees. Fourth, since Brazil has a large machinery sector, with many of them providing 4.0 machines, some prioritisation of national technology could be considered, given that developing indigenous technological capacity is an important aspect of technological catching-up.

5.2 Policy recommendations to stimulate DPT development and integration

Recommendations can also be made for policies that seek to stimulate DPT development and integration. The first one is to increase the funding available for DPT-related R&D in universities, research and technology centres, and private companies, especially SMEs (as they are the most budget-constrained). The current levels are too low, as perceived by the survey and interviews of this paper.

Second, maintain the current incentives for collaboration with universities and research institutes but expand this to *international research and technology centres and universities*. For one of the interviewed firms, overseas collaborations have allowed them to be in touch with the latest technologies and the frontier of scientific developments and to stay ahead of the competition. This does not mean prioritizing foreign universities or research (or technology) centres over the Brazilian ones, but simply *adding* that source to the pool of knowledge that firms and entrepreneurs can draw from. If Brazil is to improve its industrial competitiveness, it needs to expand its networks of contacts with the centres producing frontier technological knowledge wherever they are in the world.

Lastly, the existence of good quality technology integrators in Brazil points to a potential opportunity for upgrading them into internationally competitive firms. These firms have access to frontier technologies and competencies to use and eventually improve upon them. This would mean supporting their upgrading from their current software and hardware integration activities to the provision of original technologies. As an DPT integrator put it: "If my company had the capital and the will to make a robot, we could". The capabilities exist, they just need to be channelled forward.

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[7] This Brazilian expression could be translated to "any old firm" or "run-of-the-mill firm", or simply by "any common firm" or "the average firm".

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