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Digitalization, Industrialization, and Skills Development

Opportunities and Challenges for Middle-Income Countries

Antonio Andreoni, Justin Barnes, Anthony Black, and Timothy Sturgeon

12.1 Introduction

The world economy is undergoing a period of structural and technological transformation, driven by the increasing digitalization of economic activity. Digitalization is influencing innovation, production, trade, consumption, and a host of business processes, though to what degree is an empirical question that will yield different answers across industries and geographies. Part of this transition, sometimes described as the 'fourth industrial revolution' (variously referred to as Industry 4.0 and 4IR) relates to the digitalization of production. The key technologies are at different stages of maturity; they include advanced robotics and factory automation, data from mobile, and ubiquitous internet connectivity (variously referred to as the internet of things, IoT, and industrial internet of things, IIoT), cloud computing, big data analytics, machine learning, and artificial intelligence (AI). Associated with this technological transition is the development of new 'platform' business models and modes of value creation (Schwab, 2016; World Bank, 2016; UNCTAD, 2018; UNIDO, 2019; Andreoni and Roberts, 2020; Sturgeon, 2021).

The technologies and business models emerging in this 'digital economy' have already disrupted traditional industries and created entirely new ones, such as social media. Aside from these dramatic developments, ongoing digitalization is raising concerns about the dislocation and job losses that might result from technologies such as robotics and artificial intelligence. Since many of the relevant technologies are skill-biased, the ability of developing countries to compete in traditionally labour-intensive industries that have supported their industrialization may be undermined (Ford, 2015; Hallward-Driemeier and Nayyar, 2018; Rodrik, 2018; Clifton et al., 2020).

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Digitalization is being experienced differentially across the globe, reflecting the range of opportunities it offers as well as the challenges specific countries face in investing in and successfully adopting advanced technologies. In South Africa, digitalization is occurring in an economy that has prematurely deindustrialized and where the digital capability gap in terms of infrastructure and skills is wide. Like many resource-dependent economies, the country has failed to fully diversify and move to higher productivity and more complex activities (Bell et al., 2018; Andreoni and Tregenna, 2020; and Chapter 11). Unemployment remains at extremely high levels, while societal inequality continues unabated.

Despite this, South Africa has islands of excellence in which firms are embracing the opportunities provided by digitalization to achieve greater efficiency, process innovation, and supply-chain integration. These examples point to what is possible, while at the same time revealing gaps and shortcomings. Both the potential and shortcomings are evident across firms (in terms of investment rates) and public institutions (in terms of services and policies). The development of digital skills in cross-cutting fields such as data science and software engineering, and complementary services, will clearly be of heightened importance.

This chapter examines the opportunities and challenges of digital industrialization in middle-income countries, mainly through the lens of South Africa. In doing so, the chapter advances a framework for understanding digitalization and how it can be harnessed as part of a broader structural transformation. This framework includes the identification of key transversal enablers, including digital skills, data connectivity, supplier and quality assurance management, investment in productive capabilities for digitalization, and the development of appropriate public policies and regulations. The emphasis is on locating the digitalization challenge at both the firm and broader societal levels. In this way a digital industrial policy for South Africa can act as a *catalyst* for more inclusive and sustainable industrial growth.

The rest of the chapter is comprised of four sections. Section 12.2 introduces the key transversal technologies and business models driving structural transformation in the digitalization context. Against this backdrop, section 12.3 discusses the South African digitalization experience and highlights challenges faced by middle-income countries as they seek to benefit from digitalization, especially in the areas of digital skills. Section 12.4 provides a set of digitalization policy principles and identifies key industrial policy and associated institutional priorities to support the successful transition of the South African economy as it embraces digitalization. Section 12.5 concludes.

12.2 The New Digital Economy: Transversal Technologies and Business Models

Digitalization brings together a range of new and established technologies, including robotics, sensors, machine learning, and IoT, all of which are transversal in that they have applications across and along sectoral value chains. Table 12.1 provides a summary of the main transversal technologies underpinning the new digital economy.

These technologies are enabling major economic changes, albeit unevenly. Changes can be incremental (e.g. improving output quality or maintenance predictability in a single machine) or disruptive (e.g. fundamentally changing the way products and services are created and delivered). The combined impact of these changes has the potential to yield manufacturing systems that respond in real time to conditions in the factory, supply-chain disruptions, and changes in demand.

Though digitalization is most often discussed in the context of manufacturing (the 'smart factory'), changes are also occurring in agriculture (such as 'precision farming'), and in mining or construction (such as autonomous vehicles and machinery). Precision farming, for example, combines high-resolution satellite or drone imagery to tailor the application of irrigation or fertilizer and monitor crop health metre by metre across the field (Chapter 6). Similarly, real-time 3-D modelling of construction sites and mines using photogrammetry collected from drones or small aircraft can allow earth-moving equipment to function without human operators.

Table 12.1 Transversal technologies in the digital economy, with key features

Transversal technologies	Key features
1. Advanced manufacturing: learning machinery; networked and autonomous factory automation systems	• Digital simulation, augmentation, and virtual reality • Rising functionality in entry-level machinery and software (e.g. low cost 3-D printers, drones, robots) • Ubiquitous monitoring and measurement of processes (sensors), connected factories and supply chains
2. New mobile and internet-connected data sources	• Industry (IIoT) and consumer (IoT) connected products and services, sensors, clickstreams, location data, etc.
3. Cloud computing	• Storage, SaaS, mobile access and constant updating of software and systems
4. Big data analysis	• Huge data storage, with sample sizes that can lead to robust results, new insights, and high fault tolerance
5. Artificial intelligence (AI)	• Machine learning, prediction, self-maintenance, regulation, and replication, autonomous visual recognition

Source: Authors.

12.2.1 The Main Features and Technologies of the Digital Economy

The collection of vast volumes of data is a key feature of digitalization. For example, data can be collected through sensors during production, when a product or service is in use, and from online search and purchasing activities by consumers. When aggregated, this 'big data' can be analysed and fed into to machine-learning algorithms, making it possible for firms to gain novel insights into production processes, supply chains, and consumer behaviour. This is often referred to as the internet of things (IoT), and in industrial settings as an industrial IoT (or IIoT). IoT-enabled digital systems make use of cloud storage, big data analytics, and, increasingly, artificial intelligence, each running on a nested set of platforms, as depicted in Figure 12.1. Digitalization enables a dynamic cycle of continuously improved efficiency that is increasingly being driven by the rapid advance of machine learning (a form of artificial intelligence).

The more members or users in a production system or platform, the more data are collated and the greater its value in respect of data aggregation and analysis—i.e. 'network effect'. However, network effects can give rise to high levels of concentration and potential abuse of market power, such as barriers to entry for smaller and independent competitors attempting to enter the market, in the absence of an appropriate regulatory and policy framework. Data are becoming

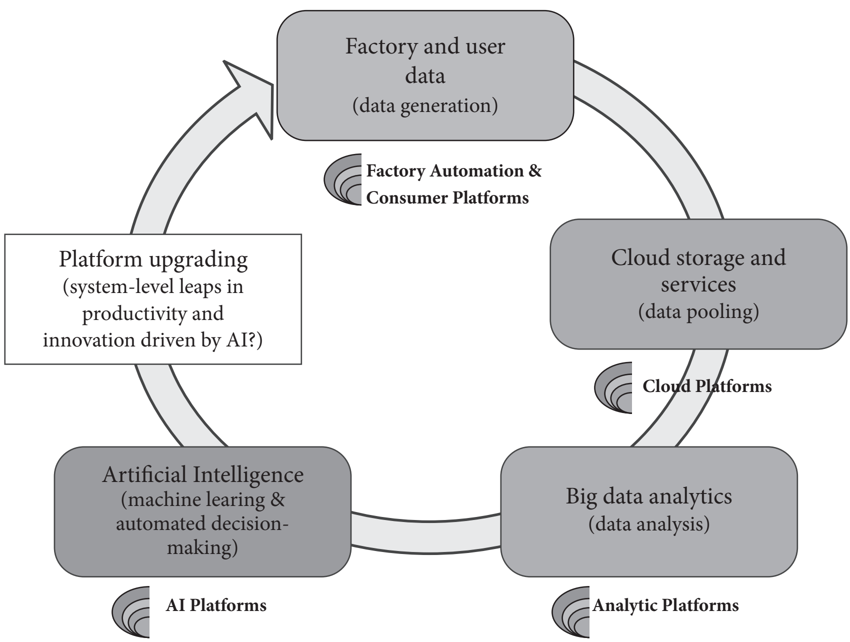

Figure 12.1 Data flow across key transversal technologies in the digital economy
Source: Sturgeon, 2021.

an asset and the ownership and control of data of dominant platforms an important determinant of power relations in value chains and markets (Andreoni and Roberts, 2020). This is more likely to be the case in the digital systems underlying consumer services (e.g. ride hailing and e-commerce) because consumer needs tend to be similar. In these cases, the influx of digital services can be very rapid and disruptive. In industrial and producer services industries user needs tend to be more complex and variable, and this appears to be dampening network effects in these sectors.

12.2.2 Digitalization of Production Technologies in Manufacturing

In industry, digitalization can improve a range of business processes through the convergence of existing technologies such as ICT and enterprise-level manufacturing software and systems (Box 12.1) with newer technology such as sensors and then connecting this IoT to 'the cloud' where it can be analysed and acted upon, as shown in Figure 12.1. Thus, through retrofitting existing equipment as a transition towards fully blown advanced digital manufacturing, incremental improvements are possible.

Advanced digital technologies can enable greater coordination efficiencies, condition monitoring, and process optimization, both within firms and along supply chains. Indeed, when firms can exchange information across various business functions, monitor processes in real time, and track operational performance at the level of individual products, data are produced that can allow machines and

Box 12.1 Enterprise-level manufacturing software and systems

Enterprise resource planning (ERP) refers to an integrated suite of compatible and interlinked software applications that cover a range of core business processes, such as finance, human resources (HR), distribution, manufacturing, purchasing, services, and supply-chain management.

Manufacturing execution systems (MES) are computerized systems used in manufacturing to track and document the transformation of raw materials to finished goods. They provide visibility into the performance of individual lines and workstations, often delivering analysis to management in easy to read 'dashboards' in real time.

Product lifecycle management (PLM) is a product-level information management system that can track and collect data about a product throughout its entire lifecycle, from ideation, design, and manufacture through service and disposal.

other resources to be allocated more efficiently, problems and bottlenecks to be identified more quickly, processes optimized, and defects reduced. Manufacturing execution systems (MES) for example, can deliver a kind of radical transparency that can disrupt long-standing routines for the better (Box 12.1). If mismanaged, however, they can create a climate of fear and resentment, both at the level of operators and line managers.

Digital technologies can manifest in demand changes (such as the emergence of autonomous vehicles), entirely new processes of design and production (3-D printing), increasing automation of production technologies, entirely new sales and marketing models (channel access, pricing, and packaging), and the emergence of alternative business models (for example, the rise of the sharing economy). Still, in manufacturing, the variability of requirements and the importance of physical manipulation limits the easy scalability of digital systems, resulting in more incremental adoption, and creating opportunities for the implementation of industrial policies aimed at fostering spillovers.

In product design, the combination of automated design software, additive manufacturing, and breakthroughs in material science have significantly reduced the time it takes to develop prototypes and produce tooling (Ferraz et al., 2019; Andreoni et al., 2021). Additive manufacturing, in particular, presents an opportunity to 'leapfrog' in the area of tooling. Though additive manufacturing is mostly used for pre-production activities, for example, producing design prototypes, it is increasingly being used for production and post-production activities. Because parts are produced in high-mix, low-volume production environments, additive manufacturing can be well suited for aircraft, shipbuilding, and after-market (replacement) vehicle parts. The benefits of 3-D printing have been well proven in terms of process and product upgrading, including product development through rapid prototyping, and reduction in tooling costs, material waste, supply-chain costs, and lead times to market. Still, a few firms are experimenting with connecting 3-D printers in 'swarms' to produce at higher volumes, which has the potential to disrupt the organization of value chains (Rehnberg and Ponte, 2018).

If additive manufacturing has opened up new possibilities for design, prototyping, and customization, large-scale manufacturing production has been undergoing a different set of changes with high potential for an increasing degree of automation. Automated systems are increasingly multi-purpose and multitasking (reprogrammable on the fly), and are networked, to aggregate data from production. However, the high costs of such systems are beyond the reach of the medium- and small-volume producers that might benefit the most from their flexibility. Indeed, the adoption of industrial robots internationally has been mainly concentrated in a few industries, especially automotive (accounting for 40 per cent of the total), computers and electronic equipment, electrical equipment, appliances and components, rubber, plastics and chemicals, and industrial machinery (Andreoni and Anzolin, 2019).

12.2.3 The Digital Economy and Innovative Business Models

The digital economy is not only about machinery and software—it operates according to a particular set of distinct business models. The following are the three most important ones.

Open innovation refers to the pre-competitive pooling of R&D activities and design criteria, either through consortia, or though the voluntary 'crowdsourcing' efforts of engineers and technologists interested in creating free resources for their technical communities. For example, nearly all the world's major computer programming languages, such as Python, are open sourced and free. Like modularity, open innovation helps firms 'vertically specialize', that is, develop a strategic focus on a specific bundle of competencies, while still providing customers with a rich set of fully functional products and solutions. Open innovations are by definition widely available, including to firms and researchers in South Africa.

Modularity describes a business model based on interchangeability, where subcomponents can be added or subtracted without redesigning entire systems. On the factory floor, different subassemblies with shared interfaces can be substituted in the assembly of larger products. In product design off-the-shelf or lightly customized modular components can be designed-in as elements of larger systems. By defining and publishing the application programming interface (API) for third parties to create platform-compatible applications, platform owners can provide access to, and collect fees from, thousands of compatible applications, deepening network effects. This is evident at both the consumer (e.g. software for PCs and mobile handsets) and industrial levels (cloud computing applications). Indeed, the digital economy can be seen as a set of nested platforms, each with multiple sub-systems and applications operating on the principle of modularity, which, viewed in aggregate can be characterized by 'deep modularity' (Sturgeon, 2021).

Platforms provide services for networks of users. There are typically different groups of users such as those using the platform to sell (for example, hotel bookings) and those looking to find and purchase goods and services, who typically use it for free. The platform owners can charge fees from both parties across this 'two-sided' market, generate revenue from third parties (such as advertisers), channel consumers to the platform's preferred services, and benefit from aggregating user data, both for analysis that improves services (see Figure 12.1) and for sale to others. Once established, network effects make it very difficult for later entrants. This is one reason that regulating, and even breaking up, dominant platforms has become a policy priority in many jurisdictions (UNIDO, 2019).

These three business models are integrated in advanced manufacturing systems. These systems are mainly comprised of modular components and machinery, and benefit from, or are even based on, inputs from open innovation. They can act as platforms upon which third-party complementors can offer specific fixtures and tools. Cloud computing services are then used to integrate production and design data, with the cloud itself operating as a platform upon which additional modules, such as data analytics and AI services, can be developed and distributed.

12.2.4 Digital Technologies and Global Value Chains

The recent wave of technological change and the emergence of new business models has been taking place in the context of globalization and the fragmentation of production systems in global value chains (GVCs). In goods production, this is reflected in the rising share of international trade in complex intermediate goods. Because of the technical specificity of inputs, this type of trade requires 'explicit coordination,' typically carried out by large and internationalized corporations (Gereffi et al., 2005). While participation in GVCs can provide firms in developing economies with opportunities, incentives, and tools to upgrade capabilities, create employment, and support more inclusive growth, the emerging evidence is that GVCs have tended to benefit narrow segments of the industrial base (often the foreign-invested part), deepening polarization of income and wealth distribution (UNCTAD, 2018). There is indeed increasing evidence of 'thin industrialization', characterized in part by specialization in low-value-added segments of the value chain (Whittaker et al., 2020; and Chapter 13).

As *digital* GVCs become more important, the effects of global-scale technology platforms and the business models that underpin them also need to be considered. One possibility is that less-developed economies might experience rising technological dependency and further isolation and exclusion from high-value segments of these fast-moving and sometimes oligopolistic platform-based digital value chains. Another is that multinational firms operating in these countries are adding another layer to the digital divide by deploying state-of-the art technologies ahead of local enterprises. On the other hand, advanced digital technologies hold great promise for increasing productivity; creating opportunities for local firms to learn by customizing, adapting, and integrating global technologies; and may be providing powerful new tools for accelerating innovation as well (Andreoni and Roberts, 2020; Sturgeon, 2021).

12.3 Digitalizing South Africa: Opportunities and Challenges for a Middle-Income Country

Overall, the deployment of digital production technologies in South Africa has been mixed. Islands of successful digitalization have emerged and firms have captured some of the digital dividends associated with improved design, customization, and reduction in costs and entry barriers. Specifically, some lead firms have begun to leverage customer data to improve products and services. For example, firms in the construction, agriculture, and mining vehicles industry have been monitoring the conditions of vehicles on a real-time basis for an extended period,[1] while the mineral processing industry is using digitalization together with machine learning for condition monitoring and predictive maintenance.[2] As a result of these technological changes, a lead mineral processing machinery manufacturer interviewed for this study reduced its product development times from six to eight weeks to two to three days.[3] This is important for industries demanding a high degree of customization and where speed to market is crucial for competitiveness. Some firms have already made substantial investments in additive manufacturing, but there has been slow uptake of robotics, although it varies greatly by industry.[4] For example, in addition to automotive, the large lead firms in the food processing industry have adopted robotics in their packaging lines, which has allowed for more precision and flexibility.[5] Here, robots are substituting low-skilled labour.

While advanced digital technologies offer a wide range of opportunities for re-industrialization and inclusive growth in middle-income countries like South Africa, their limited diffusion points to challenges for both firms, public institutions, and government. The research and industry dialogues undertaken as part of this study provide a rich tapestry of digital transformation evidence across key South African value chains. They highlight a tension between firms grappling with potentially existential technology-induced value chain shifts (e.g. the emergence of autonomous vehicles, and ride-hailing applications)[6] to the efficiency-seeking digital disruptions that are likely to significantly shift the position of firms within value chains (e.g. the adoption of digital technologies that enhance services, products, and processes). Somewhere in the middle of this spectrum are new technology developments, particularly those adopted by multinational corporations (MNCs) and leading local firms, which will require suppliers and service providers across the value chain to invest in digitalization capabilities to maintain their position within value chains. In all cases, firms wanting to digitalize clearly need to operate in a digitally enabled environment that is equipped with appropriate digital skills and infrastructures. This is essential for South Africa to benefit from applications such as AI-based machine learning, virtual reality digital twinning, and additive manufacturing that are rapidly transforming businesses in developed economies.

[1] Automotive industry dialogue, 25 October 2018.

[2] DIPF policy brief 1 and Machinery dialogue, 11 October 2018.

[3] DIPF policy brief 1.

[4] Of the four hundred firms that responded to 'The Mobile Corporation in South Africa' survey, only 6 per cent indicated they were using robotics while 13.4 per cent indicated using big data and machine learning, 13.6 per cent virtual reality, and 33.9 per cent IoT.

[5] DIPF policy brief 4.

[6] See for example Arbib and Seba (2017).

12.3.1 The Inherent Tensions and Challenges in the Adoption of Digitalization

While South African industrialists have been aware of the potential for digital disruption in the value chains within which they operate, uncertainty about the extent of the emerging disruptions (its speed, scale, and scope) has often resulted in a reluctance to make new investments. The risks and rewards associated with embracing new digital technologies have not seemed to be sufficiently understood to support more aggressive investment in these technologies, which partly explains the continued dominance of traditional industrial processes, products, and service models. Some firms have been experimenting with new technologies in narrow areas, and some have been achieving good results, which could inspire more wide-scale use and adoption.

Key cross-cutting themes and challenges fall into four main categories:

1. the extent to which digital disruptions are likely to be efficiency-enabling as opposed to only value-chain disrupting;
2. the extent to which digital disruption will impact economic activity in the purely digital space as opposed to the cyber-physical space;
3. the extent to which entirely new value-chain models develop; and
4. the extent to which digital disruption will shift the structure of GVCs, and the role of lead multinational firms in organizing their global activities.

It is also important to understand how these cross-cutting issues dynamically interact with industry- and sector-specific digitalization drivers and constraints.

Efficiency-Enabling versus Value-Chain Disrupting

The transition to digitally enabled firm-level business models is likely to incorporate both major and minor adjustments, and it is critical that these are both understood. If not, South Africa is likely to end up with a divide between universities and government operating and promoting digitally disruptive technologies on the one hand, and firms operating in the realm of more subtle incorporation of digitalization technologies to enhance competitiveness.

An example of dramatic digital disruption within value chains is the advent of autonomous electric vehicles. This would inevitably cause upheaval not just in automotive manufacturing and vehicle consumption, but across the entire automotive ecosystem. This includes at the level of energy supply and the broader transport sector, and the South African automotive industry would undoubtedly be affected. South Africa's leading articulated dump truck manufacturer, Bell Equipment, has started to explore the development of fully autonomous vehicles.

At the opposite end of the spectrum, many of the positive examples of digital progression in South Africa are less dramatic, encompassing efficiency-enabling interventions. These include improving the effectiveness of cold chain management within the agriculture-food processing value chain using IoT (see Chapter 6), improving machine reliability through the application of machine learning, or supplying fashion retail markets with more desirable products on the basis of IoT-enabled data analytics and supply-chain coordination. For example, Atlantis Foundries, which manufactures commercial vehicle engine blocks for several major international engine brands, is an excellent case of the application of AI to predict sub-surface defects. Its use here has reduced internal scrap and rework rates by up to 90 per cent.

Digital Disruption across the Cyber-Physical Space

The extent of digital disruption is linked to how digitalization transverses the purely cyber versus the cyber-physical and mainly physical value chains. For example, digital books or games that can be downloaded are primarily digital transactions (although recognizing that a physical product is ultimately required to read or play). Cyber-physical products are items such as household appliances, electronic goods, or vehicles, where an increasing amount of digital technology is embodied within these products. Finally, there are also primarily physical products or services which may be significantly augmented by digitalization in future but that will remain primarily physical activities.

Seen through this lens, certain value chains are likely to be more disrupted than others. Firms have recognized the extent to which these disruptions would be appropriate for their business. For example, having tested several innovations across the business, one of South Africa's leading clothing retailers has taken a relatively cautious view on 'digital disruption'. Its advances into e-commerce have not yielded the anticipated results, although the group is seen as a leader in this space in South Africa. The focus of its digitalization effort has, therefore, increasingly been on big data analytics to enhance marketing and supply-chain strategies in response to rapidly changing consumer preferences and the need to improve on customer experiences.

In mineral-processing machinery, digitalization enables machinery manufacturers in partnership with engineers to provide mines with a total cost of the processing service. Systems and processes are customized to specific mines, the wear of parts is tracked, enabling optimal replacement, and performance is monitored across plants. While the firms are moving to selling this as a service, competitive capabilities still involve embodying knowledge in the physical products being manufactured. The lead firms have been increasingly employing additive manufacturing and simulation in design and product development to optimize the mineral processing solutions being supplied (Chapter 3).

The Potential for New Value Chain Models

A critical consideration that emerges in respect of all the industries studied is the extent to which new value-chain models will evolve because of digitalization. The role of machines will likely increase (displacing the centrality of human-to-human interaction), platforms will take a greater share of economic activity from products (pay-for-use displacing merchandise transactions), trade will become more embodied by data rather than goods, and market intelligence will shift from tightly controlled company cores to the 'digital crowd' (McAfee and Brynjolfsson, 2017). These changes can fundamentally alter how GVCs function and are organized. And there is great risk that power is concentrated among platform leaders and the places in the world from where dominant platforms are emanating.

The primary challenge that South African industrialists face is not only the need to understand individual digital technologies and the individual business-model shifts they enable, but rather how the technologies and associated business-model shifts combine in the value chains within which their firms operate. For example, rapidly advancing automotive telemetry, which effectively plugs vehicles into the IoT, while also allowing vehicles to 'see' their immediate environment through advanced sensor technology, could provide the basis for the development of autonomous vehicles. This might change the components and materials cars are made of. Even more fundamentally, the technical dimensions of the autonomous vehicles may become superfluous to the passenger, such that vehicle ownership no longer remains important.

Global Value Chains, SMMEs, and Policy Challenges

A final set of critical cross-cutting considerations relates to the position of South African firms within complex GVCs. Many larger South African-based manufacturers are subsidiaries of MNCs, operate under licence to MNCs, or are independent but supply MNCs. These firms often have limited agency regarding the technologies they use and the products or services they offer, as these are prescribed by lead firms and parent organizations. For many South African firms, the only scope for embracing new digital technologies is in process improvements that fall into their ambit of control. For the balance of opportunities, the South African firms are ultimately dependent on how the lead firm in their GVC embraces the new digital technologies and then 'trickles these down' through their global networks. In these arrangements it would be very difficult for South African technology providers to gain entry.

On other hand, digitalization can also facilitate GVC fragmentation. For example, in the automotive industry, a key issue is the diffusion of new technologies beyond the better-positioned first-tier suppliers to the second and third tier. Increasing the share of local content in domestically assembled vehicles is a key objective of the recently developed South African Automotive Masterplan (Chapter 5; see also Barnes et al., 2017). This in turn, can facilitate the expansion of opportunities for independent SMMEs.

The use of new technologies is opening up space for innovation. In clothing, textiles, and footwear, for example, advances in digital fit software combined with rapidly advancing additive manufacturing technologies, such as vat polymerization, will have a significant impact not only on product development but all the functional areas of the value chain, from design to prototyping, and ultimately volume production. With this technology, it is possible to go directly from computer-aided design of a shoe, to the sharing of that design to anywhere in the world, to the printing of the shoe last on an additive printer; and for the upper part to then be prototyped, with the sole being also printed on an additive printer.

These inherent tensions place the South African industrial ecosystem at something of a crossroads. Will digitalization result in further consolidation of GVCs and the continued growth and dominance of MNCs as lead firms, or will it facilitate GVC fragmentation, and the expansion of opportunities for independent SMMEs? The central point of this analysis is that there is ample space for policy intervention in the digital economy. The challenge is intervening in a way that allows South African industry to move down the technology adoption curve, innovate, and avoid being trapped in low value-added segments of digital GVCs. This has proven difficult in goods-producing GVCs. Whether the road will be easier or harder in digital GVCs remains to be seen.

The Interplay between Cross-Sectoral and Industry-Specific Factors

The dynamic interplay between cross-cutting and value chain-specific digitalization issues is one of the most striking aspects of this analysis. This suggests that forms of cross-cutting support, such as skills development, need to be combined with industry-specific responses to digitalization as embedded in sector strategies.

In food value chains it appears that changing market and regulatory conditions, particularly concerns around food safety, are the key drivers of digitalization. In fresh fruit, while there is huge potential to grow exports and employment with the application of digitalization, export market access and related standards are a major obstacle. Blockchain technology and radio frequency identification (RFID) tags are causing some disruption in the food industry by addressing the core challenges around transparency and traceability along the value chain. For example, a local grower and producer of citrus fruits, Katlego Sitrus, is exporting fruit with stickers which have a quick-response barcode that consumers can scan to know the provenance of the product (Chapter 6).

The ability to absorb new digital technologies depends in part on the factor-cost profiles that dominate activities within specific value-chain linkages. For example, where labour costs represent a small proportion of total production costs, and are comparatively cheap internationally, the incentive to invest in new digital technologies is greatly reduced. While the introduction of AI-enabled robotics is growing rapidly in automotive assembly plants located within high labour-cost, developed economies, the most advanced automotive plant in South Africa still has no co-bots, despite its sister plant operating with dozens of them. Similarly, the South African clothing and footwear industries, which have low comparative labour costs, only have automation in key capital-intensive nodal points, like materials cutting and plant performance monitoring. All assembly activity is still being undertaken manually.

In mining machinery, the growing regional market in Southern Africa provides an important base from which locally based firms have been able to build capabilities. The advantages of proximity and location-specific knowledge require partnerships with the engineering procurement and construction management firms which lead mine design. The firms must simultaneously learn from global developments and provide regional solutions in, for example, predictive maintenance which requires reliable data transfer (Chapter 3).

In those value chains where data are the main source of value, especially in consumer applications, concentration in digital platforms and control of data have played a key role. Data often provide platform owners with their power and associated commercial value in areas such as search, ride hailing, performance monitoring and management, e-commerce, and social media (McAfee and Brynjolfsson, 2017; Polson and Scott, 2018; Singh, 2018; UNCTAD, 2018; Andreoni and Roberts, 2020). There are also important implications for international trade. The USA has pushed for multilateral commitments (the so-called 'Digital 2 Dozen') which would prevent measures that support local businesses in competing with currently dominant platform owners, such as a prohibition on customs duties for digital products.

12.4 Basic and Intermediate Capabilities, Digital Skills, and Infrastructure

In South Africa and other middle-income countries, a number of structural issues can hinder the adoption of advanced digital technologies by firms that are not MNCs or internationally competitive. The lack of basic and intermediate digital capabilities—digital skills in particular—and enabling infrastructural capabilities undermines domestic firms' technology efforts, specifically their absorption of digital technologies, their integration into existing production systems, and their retrofitting (Ferraz et al., 2019; UNIDO, 2019).

As discussed in section 12.1, the fact that 4IR technologies build on and co-exist with 3IR technologies means that firms will have to equip themselves with a broad array of capabilities and skills from both 3IR and 4IR. Indeed, to the extent that it is possible, for a company it would not make any sense to try to develop advanced capabilities in data analytics, for example, if the same company is still struggling to effectively deploy basic ICT; similarly, data cannot be harvested if the firms' production technologies have no sensors and, thus, connectivity. Similarly, IoT would not be feasible without the development of coding skills and standardization capabilities, as well as access to reliable connectivity infrastructure. As a further example, the introduction of robot cells and the effective use of robots for the execution of various tasks such as handling, welding, etc. implies that firms have effectively arranged the production flow and supply logistics and that robots can be fed with intermediate components (e.g. from forming presses) in time in a fully controlled environment and without any disruption. These production conditions are very difficult (and costly) to meet in firms operating in countries with limited access to high-quality electricity supply and connectivity. Moreover, the lack of well-trained operation management and engineering skills tend also to pre-empt the introduction of such digital production technologies and processes, as does the higher level of complexity involved in installing and running them effectively. As several respondents in the study indicated, it makes no sense to automate a substandard process (Andreoni and Anzolin, 2019).

These examples suggest that basic and intermediate capabilities are in fact preconditions for meaningful and effective engagement with more advanced digital capabilities. These capabilities are critical for creating the micro-efficiency and reliability conditions required to deploy new digital production technologies effectively. They also support the learning journey of technology absorption and adaptation, which should result in the retrofitting of the legacy production systems. These pre-conditions essentially set a threshold for the viability of more advanced digital capability, which many firms in middle-income countries find difficult to get past (Andreoni and Anzolin, 2019).

Firms in advanced countries are better positioned to capture 4IR opportunities, exactly because they have spent decades absorbing, deploying, and improving 3IR technologies. Some are also platform owners. Generally, firms in mature industrial economies have more easily overcome the digital capability threshold and can focus more directly on developing and putting to use the more advanced capabilities and skills of digital production technologies. Not only are these firms better positioned to incrementally integrate 4IR technologies and rethink their organizational models, they also operate in industrial ecosystems in which firms—while equipped with different capabilities—have been integrated in supply chains for a long time. As an example, it is easier for an original equipment manufacturer (OEM) in a developed country to introduce a new digital production technology, as its local suppliers operate with similar software and hardware systems, and are aligned in terms of their production standards and enabled by the same connectivity infrastructure.

These conditions are often not in place in developing countries, nor in peripheral regions in advanced countries. Given the dualistic structure of the industrial system in developing countries, a few major large firms and international OEMs operate as production islands in a sea of often disorganized, semi-formal, and small-scale business operations. This is a major 'structural' obstacle to the diffusion of 4IR technologies, especially those that are intrinsically based on networked systems and data.

12.4.1 The Institutional Challenge of Developing Digital Skills

Digitalization exacerbates the already-significant skills development challenges in several ways. Emerging technologies call for a new set of digital skills profiles—for example programming skills, web and application development skills, digital design, data management, visualization, and analytics—which build on advanced literacy, numeracy, and ICT skills. And given that digital technologies draw on and integrate different science and technology fields in new ways, traditional training often does not prepare for the use of integrated technologies. The need for training in the deployment of mechatronics, or design of digital platform interfaces integrating hardware, software, and connectivity solutions raises the digital capability threshold significantly (Andreoni et al., 2021).

Another important skills-related challenge faced by South Africa and other middle-income countries is institutional in nature. Specifically, the challenge for training institutions, technical colleges, and universities to develop and embed appropriate skills in the new and existing workforce is a big one. While there are some cases of excellent training provision in South Africa, overall the insufficient funding in the education infrastructure, in particular the necessary laboratories, tools, and machinery to develop industry- and productive task-specific skills has been a major constraint. This underfunding has also limited the much-needed curriculum development and upgrading of teachers' competencies in fast-evolving technology fields. This has often resulted in training institutions dishing out certificates rather than developing appropriate skills, and working in isolation, removed from the productive sector they are supposed to be working with.

Even when curricula have been updated and efforts have been put in place to provide high-quality formal training, lack of on-the-job training and work-integrated learning means that graduates are not sufficiently prepared to work in an industrial environment. Often the lack of these programmes is due to the limited number of qualified firms which can employ and train the workforce, and again provide funding to support costly training programmes. The challenges of skills provision are thus intertwined with the structural features of the productive economy, replicating its dualistic structure and reflecting the lack of a diffused ecosystem of competitive firms—in this case firms that are able to train youths effectively and to provide technology-rich employment prospects.

Skills challenges are not only technological, but equally operational and organizational. Given that new digital technologies are largely not plug and play, many require production system retrofitting and operational integration. Consequently, business enterprises require experienced mid-level technicians and directors of operations able to choose appropriate digital solutions, redesign and monitor processes, and address cyber-security and data infrastructure issues, alongside assuring overall organizational performance. These digital skills can be difficult to find as they comprise several tacit knowledge elements and experience-based competencies. A lack of domestic firms that actively promote the development of this experience means that a limited number of experienced people are available in general.

12.4.2 The Need for a Coherent Digital Industrial Policy in South Africa and Other Middle-Income Countries

The South African economy is at an important juncture. To benefit from the technological advances of digitalization, South African-based businesses need to address the tensions highlighted above and fill the digital capability gap related to skills and infrastructure. Most advanced digital technology will not be invented in South Africa, but its implementation—especially in a manufacturing environment—typically requires a non-trivial level of adaptation and integration, and provides a strong foundation for the development of local capabilities (Sturgeon, 2021). The challenge is to engage with global technology ecosystems, and to leverage them. There should be a fostering of *spillovers* from technology investments that can support a virtuous cycle of technology and capability development in the broader economy. At the same time, for local industrial and technology ecosystems to emerge, a broader social support system is needed, as well as policies to ensure the socially inclusive structural transformation of the South African economy.

Maximizing the benefits of the digital economy requires new approaches and analytical frameworks that are robust enough to accommodate technological dynamism and uncertainty. These frameworks should capture the changing reality of production systems and products, *and* their underlying technology platforms and organizational models—i.e. the *industrial ecosystem* (Andreoni, 2018 and 2020). New industrial policy principles should also reflect the need for more strategic coordination among (and within) public and private sectors; better targeting and policy alignment; and the introduction of both cross-sectoral interventions and industry-specific digital industrial policy.

The cross-sectoral interventions should focus on those opportunities and challenges faced by different firms across industries, especially those related to broader foundational capabilities, such as basic and transversal digital skills, and digital and manufacturing extension services; those related to technology infrastructure, such as digital software licensing, connectivity, and data quality and affordability; and those related to broader financing, investment, and regulatory conditions in the country.

The measures covering sectoral value-chains should address industry structure, including position and links to GVCs. There also needs to be a focus on the different needs and conditions of firms, in particular, the specific types of digital skills, digital technology infrastructures and services, challenges and barriers to linkages development, competition conditions and value capture, and sectoral regulatory frameworks and incentives, including procurement and market regulations.

Not all industries, nor the value chains in which they are located, will be affected in the same way, so there needs to be careful prioritization. The following list of seven priorities has been identified as appropriate to the South African business experience.

Priority 1: Improved Cost, Speed, and Reliability of ICT Infrastructure (Bandwidth)

South Africa has an expensive, comparatively slow, and unreliable ICT infrastructure and industrialists deem this to be a major limitation to the adoption of more advanced digital technologies. Potential value-chain efficiencies that are likely to be gained from digitalization, enabling data analysis, and tracking of performance across plants and markets, are undermined by poor connectivity. AI-enabled machine learning systems, which are particularly data intensive, appear compromised due to this limitation, especially for SMMEs that do not have the resources to invest in bespoke infrastructure, such as microwave links. The key requirement is to release spectrum for improved connectivity and exploit 'edge computing' to bypass poor connectivity.

Priority 2: Digital Skills Policy

Embracing new digital technologies in South Africa is comparatively expensive for firms because of the substantial skills gap. This requires both scaled-up skills development programmes and the attraction of skilled immigrants in key areas. These include:

- Increasing incentives for cross-cutting skills development in software engineering, programming, data science, and related ICT skills, both in respect of on-the-job training and higher education.
- The establishment of a priority skills list for essential industrial activities in digitalization, machine learning and Artificial Intelligence, CAD/CAM technologies, and the management of MES/ERP/PLM systems. The list needs to direct public digital skills expenditure and should be updated annually in recognition of the rapidly moving digital skills frontier.
- The development of sector-specific digital skills in partnership with private sector industry associations and Sector Education and Training Authorities (SETAs).
- The reform of incentives and organizational structures within technical and vocational education and training (TVET) institutions to incentivize firm-driven training beyond narrow certification-driven training. More private sector involvement is essential to create a closer alignment between

rapidly changing sector requirements and TVET skills programmes.[7] Incentivizing internships is a major opportunity in this regard.
- The linking of digital skills policy to broader technology policy to provide less resourced firms with complementary public support in training, technology absorption and associated organizational development.

Priority 3: Digital Technology Policy

The systematic restructuring of technology policy and institutions is required in four areas: digital technology absorption, standards development and dissemination, system integration, and scaling. One such opportunity is the development (or conversion) of technology centres, science councils (e.g. the Council of Scientific & Industrial Research (CSIR)), incubators, and university units into a coordinated network of 'technology intermediary institutions' organized around the main digital technology platforms and supporting technology absorption, integration, and deployment. Public-private initiatives such as the Mandela Mining Precinct offer considerable potential (Chapter 3).

The key elements of each are:

- *Technology absorption*: This requires the provision of manufacturing and digital extension services (including organizational and operational systems), demonstration projects, beta factories, access to data and infra-technology (metrology, standards), and access to additive manufacturing.
- *Standards development and dissemination*: This would be enabled through the provision of standardization services and data, infra-technologies, testing, and certification facilities.
- *System integration*: This includes retrofitting services and legacy system integration into digital platforms, rapid prototyping facilities, and virtual design.
- *Technology scaling*: This necessitates codification and dissemination of successful technology solutions and the provision of scaling-up facilities such as accelerators for digital start-ups and SMMEs.

Incentivizing firms to incorporate digital technologies in their business models is also a key requirement, and yet the evidence from the industry case studies suggests that South Africa's R&D tax-based incentives define the opportunity so narrowly that most firms do not qualify for support. This is an important legacy consideration that is likely to exist in many middle-income economies. For example, the South African government's tax-based incentive defines what constitutes R&D, but then notes numerous exclusions. These include market research,

[7] An example is the Mercedes-Benz Learning Academy in East London.

market testing, or sales promotion; administration, financing, compliance, and similar overheads; and routine testing, analysis, information collection, and quality control in the normal course of business. This definition precludes data-intensive technologies. It is important that R&D incentives support both efficiency-seeking and business-model innovation in the emerging digital space.

Priority 4: Financing and Investment

Digitalization requires investment in upgraded capital equipment and human capital. In addition, there are working capital consequences when firms shift to providing end-to-end service solutions for customers as opposed to selling products. For example, South African mining machinery manufacturers are contracting with mines to deliver processed tonnes of ore rather than the supply of machinery. This has balance sheet consequences for firms, with concomitant changes to financing requirements. Development finance institutions, such as the Industrial Development Corporation (IDC), have a lead role to play in offering the appropriate financing required. Without a comprehensive understanding of disruptive new digital business models by the industrial financing institutions themselves, such support is unlikely.

Priority 5: Linkages to Development Policy

As a country with generally weak industrial supply chains, particularly with regard to the role of SMMEs, digitalization offers a major opportunity to promote the adoption of supply-chain tools (such as ERP and MES) for better supply-chain integration. Supporting second- and third-tier firms in accessing affordable digital technology licences or creating alternative models to reduce the licencing burden is crucial. The creation of a 'Catalogue of Digital SMME Suppliers' via an open and competitive digital market platform to match specific technology and production services demand and supply along and across industry value chains could be enormously valuable to SMMEs. De-risking SMME investments in new technologies and products using combined technology services and hybrid financing models (such as matching grants and pre-commercial procurement) could also support the inclusion of these firms within South Africa's industrial value chains.

Priority 6: Economic Regulation, Competition Policy, and Data

Digitalization sometimes entails the convergence of platforms and networks across the telecommunications, finance, retail, and logistics spheres. In such instances there are substantial scale and first-mover advantages. Where there are local demand specificities, domestic platforms can rival multinational platforms, as is evident in South African e-commerce. In the industrial sector, the specificities of products, process, and business models mean that digital products and platforms tend to remain more fragmented, a characteristic that provides opportunities for the involvement of local technology vendors and system integrators. Evidence suggests that smart and flexible regulatory frameworks need to ensure that dominant platforms cannot abuse their position to undermine local rivals.

South Africa's regulatory bodies, as for most other middle-income countries, are still organized as if digitalization is not under way. There need to be appropriate regulatory and competition rules for digital platforms, including addressing data privacy and ownership, which draw on international experience, such as the measures taken recently by the EU and India to ensure a level playing field for local businesses in e-commerce and online search activities. In this regard, the 2018 amendments to the South African Competition Act have introduced provisions relating to buyer power and they do strengthen rules relating to price discrimination. However, guidelines regarding their application still need to be set.

Priority 7: Trade and Tax Policies

Middle-income countries like South Africa should be working with other countries at the WTO to resist the push by the global technology giants for digital transactions to be exempt from tariffs. The advance of digital technologies potentially weakens the position of industrializing countries as international firms can bypass import duties, local taxes, and other domestic regulations. For example, additive manufacturing may simply require the transfer of code from a data cloud to a locally based 3-D printing machine and the transfer of the code is free of import tariffs (and other taxes such as VAT and ad valorem excise taxes) or adherence to regulations relating to the safety or health properties of the end product.[8]

A key question, then, is how the South African government plans to tax imported digital products and services to enable and protect local productive activity? In principle, digital technologies do not necessarily represent a threat; they can be used to better protect the domestic market and consumers. For example, clothing, textile, and footwear products entering South Africa could be required to have radio frequency identification (RFID) tags that prove their provenance, such as where they were manufactured, and at what price they were exported from the country in which they were produced.

12.4.3 Silos Need to Give Way to an All-Encompassing Policy and Governance Framework

The effectiveness of sectoral and cross-sectoral interventions across key policy priority areas will depend on the extent to which the government is able to align

[8] See also the work on base erosion and profit shifting by the OECD, and the tax challenges arising from digitalization (http://www.oecd.org/tax/beps/).

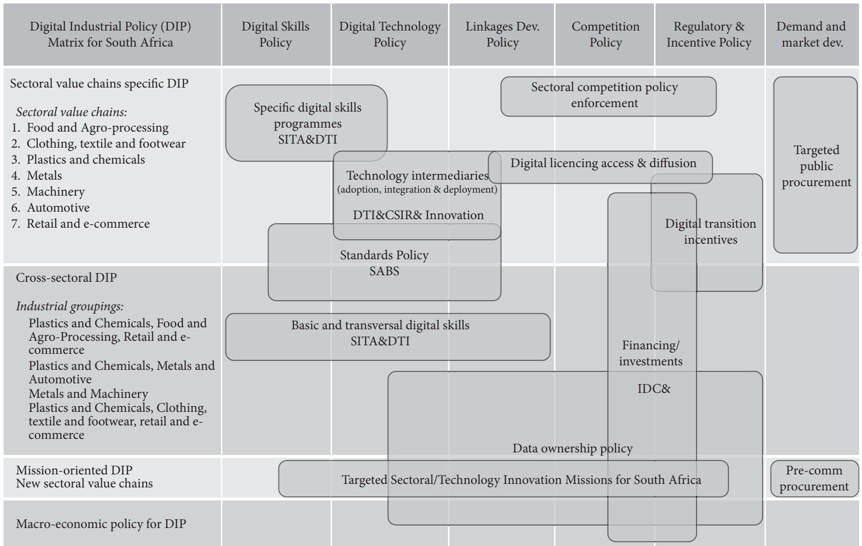

Figure 12.2 Digital industrial policy for South Africa
Source: Authors.

interventions and develop a governance framework that cuts through policy silos (Andreoni, 2016). This is a challenge facing all countries, but in resource-constrained middle-income economies such as South Africa it is more acute. This is because breaking out of policy silos is both a matter of what and how policy interventions are designed as well as what and how resources are allocated and governed. Figure 12.2 presents a potential digital industrial policy matrix for South Africa. It attempts to integrate the different key policy priorities that have been highlighted and to locate these within the specific South African context.

12.5 Concluding Remarks

The development of digital industrial policy in middle-income economies such as South Africa is an emerging field. The evidence presented in this chapter suggests that policy should aim at shaping a new industrial ecosystem in which the opportunities and challenges of new digital industrial technologies are fully seized. This means identifying and targeting areas within and across sectors in which the deployment of digital technologies allows firms to: improve products and their digital content, adapt product and system functionalities to accommodate digital transformation; move towards higher value product segments; diversify products and activities by deploying digital industrial technologies transversally across industry value chains; increase productivity via process upgrading along the value chain and the local production system; link up with other domestic and international firms; diversify market access; and develop industrial competitiveness in new global industries by leveraging domestically available resources.

While policy design and the governance framework are critical, the effective implementation and enforcement of any digital industrial policy will depend on enhanced government capacity and more effective cooperation with the private sector. Overall, digital industrialization will raise potential trade-offs and new conflicts in the economy, for example with respect to employment and new skills requirements. Given the challenges faced by SMMEs, there is a concern that digital technologies will exacerbate the existing divide between large and small firms to the detriment of the much-needed re-industrialization. Digital industrial policy must therefore actively govern these processes to ensure the digital industrial dividend is distributed across different types of firms, their employees, and broader society. This challenge is certainly not unique to South Africa. Other middle-income economies are facing the same difficulties in respect of their own industrial policy frameworks, and will need to similarly define how to incorporate digital disruption within their existing suite of policy instruments.

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