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**Robustness to shocks, readiness to change and new
pathways for resilient industrialization**

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Abstract

Countries' responses to the COVID-19 pandemic have been very diverse and have revealed sharp differences in terms of the resilience of countries, the social contracts between people and governments, and the robustness and readiness of their productive organizations, industries and institutions. Given the nature of the crisis, a renewed emphasis has been given to countries' industrial and health ecosystems. The pandemic has revealed the extent to which specific industrial capabilities needed to ramp up production of key therapeutic solutions and scale up health technologies have been lost (as in several advanced economies) or have not been adequately developed (especially among developing countries). Given the role of the public sector in developing these specific capabilities in medical technology, instrumentation, drugs, testing, data systems, decentralized service delivery infrastructures, etc., it is not surprising that this loss of industrial capabilities has occurred in tandem with a reduction in government capabilities and public health system readiness.

In this paper, we develop a Resilience Capability Framework, focusing on the specific ways in which industrial capabilities contribute to countries' overall economic resilience, and the degree to which governments are central for leveraging, coordinating and deploying industrial capabilities to respond effectively and innovatively to a systemic crisis like a global pandemic. First, we highlight the fact that resilience is a structural property of entire industrial ecosystems and made up of both public and private actors; their technical, innovative and organizational capabilities; as well as the relationships among them. Second, we discuss how various industrial and government capabilities play distinct roles at different stages of a crisis and how their alignment is critical. We point out how capabilities required to "resist, absorb, accommodate", and those required to "adapt to, transform and recover" from an extreme event like a pandemic are different and can be misaligned. This misalignment can be related to the stages of the crisis and/or the presence and distribution of capabilities between the productive sector and public institutions and government. Finally, we point out how building, developing and accumulating these different types of resilience capabilities is a long journey involving *financial commitment in key strategic assets under uncertainty, accumulation of systemic capabilities, market creation and learning from experimentation*. Committing resources to building industrial and government capabilities, including asset-specific tools and infrastructures, is critical and often challenging in adverse developing country contexts, where resources are limited.

The paper applies this framework to assess different responses across middle-income countries, and extract lessons towards new industrialization pathways in a post-pandemic scenario. We present and analyse detailed country investigations in Viet Nam, Brazil and South Africa to reflect on several lessons learned from their responses to COVID-19 as well as past pandemics.

Keywords: COVID-19; robustness to shocks; readiness to change; resilience; health-industrial ecosystem; industrial policy; Brazil; South Africa; Viet Nam

1. Introduction

Over the last year, the COVID-19 pandemic has had a dramatic impact on societies and economies around the world. From the beginning of the outbreak, responses to the crisis have been very diverse, both within and across countries. These responses have revealed sharp differences in terms of the resilience of countries, the social contracts between their people and governments, and the robustness and readiness of their productive organizations, industries and institutions. Given the nature of the crisis, a renewed emphasis has been given to countries' industrial and health ecosystems. In this area, the pandemic has revealed the extent to which specific industrial capabilities needed to ramp up production of key therapeutic solutions and scale up health technologies have been lost (as in several advanced economies) or have not been adequately developed (especially among developing countries). Given the role of the public sector in developing these specific capabilities in medical technology, instrumentation, drugs, testing, data systems, decentralized service delivery infrastructures, etc., it is not surprising that the loss of industrial capabilities has occurred in tandem with a reduction in government capabilities and public health system readiness.

In this paper, we develop a Resilience Capability Framework focusing on the specific ways in which industrial capabilities contribute to countries' overall economic resilience, and the degree to which governments are central for leveraging, coordinating and deploying industrial capabilities to respond effectively and innovatively to a systemic crisis like a pandemic. The United Nations Office for Disaster Risk Reduction's (UNDRR) definition of *resilience* points to several important resilience dimensions: "*The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.*" We build and expand on this definition to highlight three main aspects—and, in doing so, develop policy and institutional design recommendations supported by in-depth analyses.

First, we highlight the fact that *resilience is a structural property* of entire industrial ecosystems, made of both public and private actors; their technical, innovative and organizational capabilities; as well as the relationships among them. Given that many of the complementary capabilities that make a system resilient are distributed across business enterprises, public institutions and governments, an assessment of economic system resilience needs to take into account capabilities developed and accumulated by each node in the system, as well as the quality of the relationships among these nodes. This explains why countries like Viet Nam, Republic of Korea and China

managed to be significantly more resilient than some Western economies, both at the initial stages of the crisis and later during the second phase of recovery.

Second, *different industrial and government capabilities* play different roles at different stages of a crisis—and their alignment is critical. A pandemic disrupts the ways in which industrial capabilities and relationships across the ecosystem work in “normal” times to deliver social and economic outcomes. It also introduces new demands, whose scale and context-specificity call for flexibility and innovation, beyond short-term mitigation remedies. Therefore, we point out how capabilities required to “resist, absorb, accommodate” and those required to “adapt to, transform and recover” from an extreme event like a pandemic are different and can be misaligned. This misalignment is related to the stages of the crisis and/or the presence and distribution of capabilities between the productive sector and public institutions and government. During the early stages of a crisis, the *robustness* of the economy and its industries, as well as a country’s public sector and government, are critical to resist and absorb the disruption caused by a shock. For example, the presence of system-level capability redundancies is important to quickly ramp up production in critical sectors and avoid shortage of key supplies – including chemicals, drugs, medical equipment and food. However, at later stages, chances to transform the economy and steer a social recovery depend on the *readiness* of a country’s economy, industry and public institutions to innovate business models, advance and identify new government functions, and promote new strategic investments. Thus, more “dynamic capabilities” are needed in both government and business enterprises to rebuild economies more effectively. Among them, organizational and innovation capabilities within business enterprises and long-term supply chain relationships are critical to overcome the systemic uncertainty introduced by a pandemic, commit financial resources and achieve new forms of organizational integration. As for governments specifically, dynamic capabilities are about exercising “stable-agility and alignment functions, but also involve shaping markets through regulations, industrial policy and other demand-side measures such as functional procurement.

Third, we point out how building, developing and accumulating these different types of resilience capabilities is a long journey involving *financial commitment in key strategic assets under uncertainty, accumulation of systemic capabilities, market creation and learning from experimentation*. Committing resources to building industrial and government capabilities, including asset-specific tools and infrastructures, is critical and often challenging in adverse developing country contexts where resources are limited. The pandemic has called for a rewiring of the state and government functions as well as for targeting the development of strategic

sectors—in particular, medical device and pharmaceuticals—through industrial policy, including strategic and functional procurement.

The paper applies this framework (developed in Section 2) to assess different responses across middle-income countries, and extract lessons towards new industrialization pathways in a post-pandemic scenario. In Section 3, detailed country investigations of Viet Nam, Brazil and South Africa are presented to reflect on several lessons learned from the response to the current COVID-19 crisis as well as past pandemics. In particular, we will investigate different ways in which governments have collaborated with business enterprises and other actors around challenge-driven initiatives. With specific references to both short-term solutions and more strategic long-term transformation plans, we emphasize the opportunities and systemic multiplier potential of a new industrialization model built around the bio-med-tech ecosystem and other strategic sectors (Section 4). Indeed, the pandemic has pointed out how, from a socioeconomic resilience perspective, industry sectors are not all the same. Some are more critical than others. Furthermore, it has revealed that where you produce matters, and that while trade interdependence can deliver specialization and development, over-dependence and a hollowing-out of domestic industrial capabilities can result in an unsustainable economic model.

2. Resilience capabilities and challenges: Robustness to shocks, readiness to change and development pathways

The pandemic is an extreme event of systemic nature whose unfolding in specific contexts cannot be predicted *ex ante*. To be sure, pandemics are far from being unexpected events. In fact, there is mounting evidence of the increasing risks of novel infectious diseases, their links with climate change and the disproportionate vulnerabilities of different countries and regions, with tropical areas across Latin America and Africa among the most at risk (Dobson et al. 2020). To a certain extent, based on these expectations and the evidence, governments around the world have developed more or less well-funded plans and infrastructures to face these extreme events and provide immediate responses to potential crises like a pandemic.

The problem, however, is that the exact when, where and how pandemic crises manifest and develop, the new social needs that arise, and the specific impact they have on economies and institutions (and their relationships) are all complex system dynamics characterized by a high degree of uncertainty. In fact, a pandemic disrupts the ways in which capabilities in the private and public sectors—and relationships between them—work in “normal” times. It also introduces new demands, whose scale and context-specificity call for flexibility, innovation and new forms of coordination across several actors and sectors. The more the crisis presents features of a

“wicked problem” made up of “connected extreme events” (Raymonds et al. 2020), the more that strategic coordination is needed and the more difficult it is for coordination to happen.

A pandemic, therefore, can be seen as a *stress test* for a socioeconomic system, in particular for the resilience of its institutions, economy and society. As a stress test, the pandemic reveals and highlights the most fundamental structural characteristics of a socioeconomic system, including its vulnerabilities and imbalances. From a comparative perspective, it also reveals the extent to which different socioeconomic systems are more or less capable to address a systemic crisis. This is due to their trajectory of development and the set of dominant economic ideas and policies that have shaped their institutions and the role government over time.

The UNDRR defines resilience as: *“The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.”*

This definition raises two important issues. First, the fact that resilience is a structural property of systems, communities or societies means that resilience cannot be understood in isolation, focusing simply on its individual parts. Complementarity between parts of a system is critical in determining different degrees of resilience, hence the ability to respond to extreme events. This ability arises from the unique ecosystem of organizations, institutions, sectors and markets, as well as the relationship between them in a specific place. Places matter in this respect because they often define the boundaries of the system, and the political mandate and collective agency to coordinate different types of needed actions (by, for example, national, regional, local governments). The capabilities embedded in these organizations, institutions, sectors and markets, as well as the quality of the relationships among them shape, the response to hazards and extreme events like the COVID-19 pandemic.

Second, hazards and extreme events unfold over time, and at each point in time pose new challenges. Understanding these different phases and the specific challenges they pose is critical since addressing these challenges require different types of capabilities. At early stages of a crisis, capabilities to *“resist, absorb, accommodate”* are critical to reduce the negative socioeconomic-environmental impact of the extreme event. With the unfolding of the crisis, once systems have managed to absorb the extreme event, a different and more complex set of capabilities is needed to *“adapt to, transform and recover”*. These capabilities are necessarily more complex as they require looking forward and learning how to do things differently in a newly transformed system. This includes identifying ways to make the system more resilient to future shocks.

The following three sub-sections frame and further develop the concept of resilience by looking at:

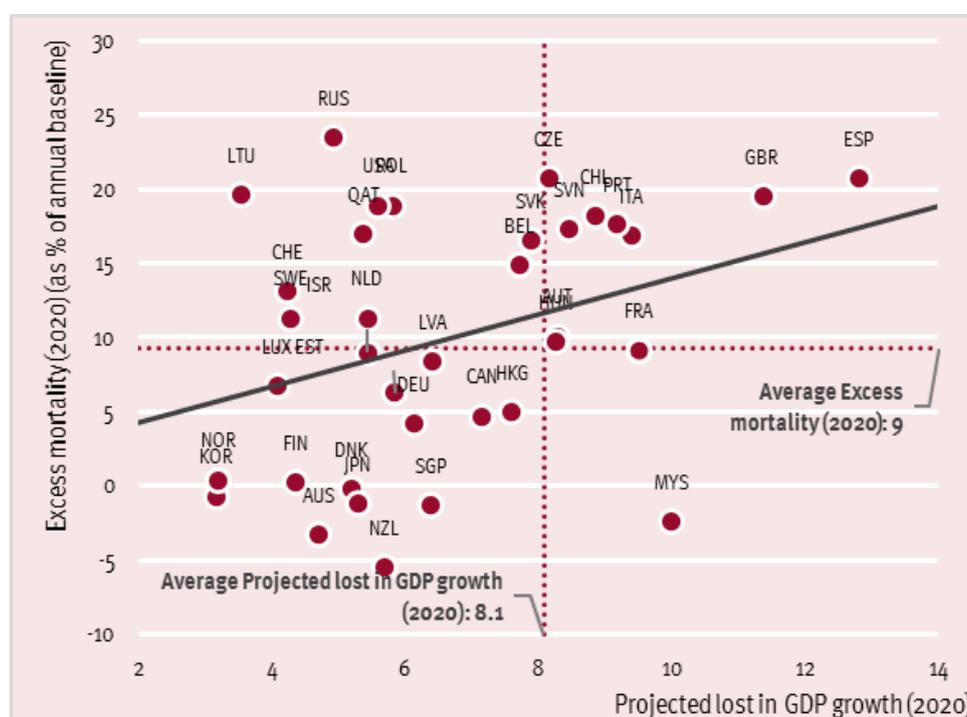
- (1) Why resilience must be understood as a structural property of entire ecosystems of organizations, institutions, sectors and markets, hence why countries that have not developed them present specific resilience challenges
- (2) Why resilience can be usefully understood by distinguishing between the ‘robustness’—the capacity to *resist, absorb and accommodate*—of government and industry, from their ‘readiness’—the capacity to *adapt to, transform and recover*
- (3) Why and how industrial capabilities are a critical factor contributing to the resilience of entire systems

2.1 Resilience as a structural property and the specific challenges for developing countries

Resilience is a structural property because it is the ability of an entire system to respond to an extreme event, and because the response is the outcome of the place-specific ways in which ecosystems of organizations, institutions, sectors and markets coordinate their different capabilities in the face of the crisis. If we think of resilience as a structural property, then, it is not surprising that responses to the pandemic and related socioeconomic crises have been very diverse, both within and across countries, and that countries’ fortunes evolve over time throughout different stages of the pandemic (Mazzucato and Kattel 2020; Klingler-Vildra et al. 2020; Chazan 2020; Thomson 2020; Gerard et al. 2020; OECD 2020). Some advanced countries and regions have found themselves better prepared to coordinate a systemic response to the crisis and leverage a wide range of capabilities across their ecosystem of hospitals, universities, research and testing labs, public procurement agencies, as well as manufacturing enterprises. Indeed, it is within each of these different sub-systems that several innovative solutions have emerged and new mission-oriented public-private partnerships have developed. For other advanced countries and regions, the stress test of the pandemic has revealed a lack of resilience in the economy—especially within its industrial ecosystems—and governmental challenges in coordinating an effective response. Finally, some countries have had mixed performances in responding to the pandemic, both over time—some countries which responded insufficiently in the beginning managed to improve, while others started strong only to falter later—and across different policy dimensions—countries that were particularly effective in containing the spread of the virus were unable to ramp up of their vaccine programmes.

A variety of parameters of resilience reflecting the impact of the pandemic on the economy and health systems can be used to highlight these different experiences. Figure 1 plots countries against two indicators of resilience: excess mortality in 2020 (as a percentage of the annual baseline) and the projected lost in GDP growth. The Republic of Korea emerges as a country outlier, with contained economic contraction and almost no excess mortality. The country is perhaps the most striking example of how resilience—based on these specific factors—played a role in successfully flattening the epidemic curve without the use of extended lockdowns and other stricter measures that were adopted by other advanced economies (You 2020; Dighe et al. 2020).

Figure 1: Selected country resilience: Excess mortality and GDP growth loss in 2020



Source: Author elaboration based on Karlinsky and Kobak (2021) and IMF (2021).

From the outset, the Republic of Korea demonstrated a unique level of collaboration across the government (specifically, the Office of the President, the Ministry of Health, and the Korean Centers for Disease Control and Prevention), the scientific community and industry. The Korean Ministry of Health and Welfare (KMHW) rapidly developed an effective testing procedure which the Korean Ministry of Food and Drug Safety prioritized for sign-off by putting it through fast review. Officials then passed this testing technology to four diagnostic companies that rapidly manufactured kits and distributed them to national and local governments. This led to the building of hundreds of high-capacity screening clinics, offering innovative solutions for mass-testing in

record time. Solutions included, among other innovations, drive-in testing stations and provision of real-time data on the evolution of the pandemic (see below). In a matter of weeks, 600 testing centres, each with a capacity of 15,000-20,000 tests per day (140,000 per week), were established to test people outside of the health system. The supply of testing equipment was made possible through strong collaboration with domestic industry suppliers.

Government capabilities turned out to be critical in the containment of the infection as well. Here, the Republic of Korea adopted a targeted and integrated approach, whereby infected patients were isolated and provided with health and economic support to increase compliance. This allowed other people to maintain businesses and enterprises. Furthermore, hundreds of epidemiological intelligence officers were deployed to implement the test-and-trace system. These officers were armed with a wealth of data, including credit-card transactions and closed-circuit television footage, to track chains of potential infections and isolate infected people.¹ Data was also made public so that citizens could reduce the risk of infection and track their own movements. Finally, the capacity of the health system was scaled up rapidly, with new health workers employed and new temporary health facilities built in the most affected areas. Supply of personal protective equipment (PPEs) was addressed through a centralized procurement process, which allowed domestic private companies to leverage and crowd-in supply of masks and other PPEs. The country's large industrial base and high level of coordination along key supply chains and conglomerates made coordination and provision at scale possible.

This high level of government readiness and responsiveness was partially the result of challenges faced by the Republic of Korea in containing the Middle East Respiratory Syndrome (MERS) outbreak in 2015. The government learned from its previous mistakes then and developed an updated and well-articulated infectious disease response plan. It is important to note that this plan does not simply provide general guidelines; it also assigns clear responsibilities across all levels of government and public institutions. It has also ensured that the country has built enough system-level redundant capabilities and structures to respond to an extreme event rapidly. Without building redundancies into the health system, these capabilities would have not been readily available to address COVID-19. Leveraging these capabilities was also the result of a process that was both centralized and decentralized. For example, citizens were involved in the coordination

¹ Specifically, as You (2020) notes, the mobilization of a large amount of data included “interviews with a patient, patient’s medical records, credit card transactions, global positioning system (GPS) data from cellular phones and cars, travel histories to highly coronavirus-affected countries, and security camera footage.”

effort to reduce potential shortages of supply and logistics problems by distributing real-time geolocated data on masks and drugs stocks availability.

In contrast to the Republic of Korea, developing and middle-income countries—with some notable exceptions, including China and Viet Nam—have been particularly affected by limited domestic capabilities and relationships between organizations, institutions, sectors and markets. Specific vulnerabilities of their economies and institutions were also due to their extreme dependence on global trade, markets and financial flows. Domestic supply shock following economic lockdowns has intersected with global demand shock and is now unfolding in both expected and unexpected ways along different value chains. The worst-case scenario is that one crisis will lead to another in a spiral of recession. African countries in particular are at risk of losing the developmental gains of the last 20 years (Sumner et al., 2020; Valensisi, 2020). This evolving scenario has introduced a high degree of *systemic uncertainty* at a time when significant resources are needed to make sure that production, technological, institutional capabilities and employment are not lost in the pandemic. Preserving and transforming these capabilities are key for shaping a post-COVID recovery.

While extremely heterogeneous from a structural and institutional perspectives, developing and emerging economies across the Global South are facing several common challenges in the face of the COVID-19 crisis. These challenges are specific to these countries' level of structural development, the existence of a relatively underdeveloped health industrial ecosystem and lack of appropriate government capabilities and state capacity.

First, limited testing capacity and development of the domestic pharmaceutical and chemical industries, especially on the African continent (with the notable exception of Egypt and South Africa), has meant that several developing countries have run out of supplies and found it difficult to ramp up the availability of intensive care units and import key therapeutic devices like ventilators (see Mackintosh et al. (2016) for an in-depth analysis of country cases across Africa). The underdevelopment of the pharmaceutical industry—especially in least developed countries—is caused by both lack of productive capabilities and lack of procurement systems that effectively promote domestic production. While several procurement models have been implemented, challenges remain in securing a reliable domestic supply of inexpensive drugs, a sufficiently widespread cold-storage facilities and logistics. Instead, inflows of drugs and counterfeits remain major obstacles in many developing countries in Western and South-Eastern Africa.

Second, the public health response in many developing countries initially involved strict restrictions on people movement and their economic activities. However, given the large informal nature of these economies and lack of formal jobs in industrial sectors, enforcement of these measures has become quickly very difficult. In some cases, enforcement runs the risk of threatening the livelihoods of economically vulnerable households, as traditional ways to earn income – through casual work and migration – have been limited. Without furlough schemes or supplemental income transfers, any lockdown or containment measures slowing economic activities tend not to work, as people need to work to meet subsistence levels. On the other hand, standard furlough schemes such as those in some advanced economies are difficult to implement when large segments of the population work informally and live in precarious conditions. Conditional and unconditional cash transfers, direct delivery of food and customized interventions reflecting local community needs tend to be relatively easier to implement and are often more effective, given the specific circumstances.

Third, in developing and emerging economies, government capabilities needed to coordinate a systemic response to the crisis are often lacking. Specifically, lack of investment in institution-building and hardware infrastructure makes it difficult to leverage existing capabilities and address an extreme event like the COVID-19 pandemic. In many developing countries, the relatively underfunded public health system was immediately put under severe pressure, given, for example, the limited availability of ICUs required to provide respiratory therapeutic treatments. The ability to provide these complex treatments is largely unavailable in remote parts of developing and emerging countries, while private health services located primarily in major urban centres are too expensive for large segments of the population. The sudden and fast-evolving spread of the virus also quickly depleted the stock of protective equipment, drugs and other medical devices such as ventilators. The public health and public financing crisis also impacted the social protection response. Given their limited industrial base, developing countries' tax revenues are already limited. Revenues were further affected by the pandemic, with shortfall in tax collection hampering short-term finance budgets, while borrowing on the open market became increasingly difficult and more expensive. Limited resources for formal and public social protection means that households are forced to take short-term decisions that will negatively affect their long-term viability—such as selling assets to finance food consumption (Gerard et al., 2020). Vulnerability has been exacerbated by the fact that social networks and mutual community support are difficult to sustain when there is a simultaneous shock affecting all members.

2.2 Framing resilience: A two-stage, two-sector capability perspective

It is helpful here to return to the UNDRR definition of resilience:

“The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.”

This definition implies that a system is resilient only to the extent that it is capable to address unfolding challenges posed by hazards and extreme events *over time*, and that the system can do so by leveraging different *types* of capabilities. It also follows that the outcomes and impact of a pandemic are going to be highly *heterogeneous and context-place specific*: these different types of capabilities are more or less available in different countries at different stages of a crisis, and that these capabilities are more or less distributed and available among different actors.

From a capability perspective, one way to operationalize this definition of resilience and analyse different experiences across countries is to distinguish between (1) capabilities that confer on a socioeconomic system the ability to “*resist, absorb, accommodate*” the emerging and unexpected needs and challenges arising from a crisis, and (2) capabilities that are needed to “*adapt to, transform and recover*” at later stages of the crisis when it becomes clear that the overall system needs more sustainable solutions addressing root causes. In this paper, we call the former capabilities conferring *robustness to shocks*, and the latter capabilities conferring *readiness to change*.

This distinction matters because some socioeconomic systems might be resilient in terms of being able to “*resist, absorb, accommodate*”—that is they can be ‘robust to shock’—but they might find it more difficult to “*adapt to, transform and recover.*” They are not “ready to change.” Indeed, all systems have some degree of robustness associated with their existing capabilities and capacity. The extent to which they are sufficiently robust depends on the systemic nature and challenges posed by an extreme event like a pandemic. Further, not all systems demonstrate readiness to adapt to the mutated circumstances and transform themselves by creating solid bases for a sustained and sustainable recovery. Readiness results from the spread of ‘dynamic capabilities’ across the ecosystem of organizations, institutions, sectors and markets. The opposite case also exists. Socioeconomic systems may be well equipped from a readiness to change perspective, but they might find themselves vulnerable to crises because they have multiple basic capabilities that confer robustness to the system.

The second step in operationalizing and developing our Resilience Capability Framework is to distinguish between two main sectors—government and industry—and assess each sector’s overall capabilities for robustness and readiness. The proposed two-stage, two-sector capability framework allows us to identify and analyse different countries’ experiences with COVID-19—their capabilities and trajectories—and assess the extent to which performance is due to specific configurations of specific systems. As shown in Table 1, a country would ideally show both HIGH levels of government and industry robustness at early stages of the crisis and HIGH levels of government and industry readiness at later stages. If both government and industry capabilities are present and are well aligned in responding to the crisis, we would expect limited socioeconomic impact and a fast recovery spurring several structural and institutional reforms that would develop resilience of the system even further. The opposite scenario—common in least-developed countries—is that low levels of government and industry robustness trigger a set of interdependent crises that over time further weaken the system with detrimental impacts for society and the economy.

However, reality tends to be more complex and depends on the extent to which:

- 1 At early stages of a crisis, necessary robustness capabilities are or not present in one or both main sectors of the system—government and industry—and the two sectors are more or less capable to coordinate and align their short-term efforts and immediate responses
- 2 At later stages of the crisis, necessary readiness capabilities are or not present in one or both main sectors of the system—government and industry—and the two sectors are more or less capable to coordinate and align their long-term efforts and strategic changes

Table 1 presents eight configurations and factors underpinning different degrees of resilience. While this is only a first order assessment, it brings focus to main areas of potential weakness and or areas that potentially could be leveraged in short- and medium-term responses to a crisis like a pandemic. Countries can be benchmarked against this framework. For example, as discussed Section 2.1 given their, generally, weakness in government, welfare system and industry base, developing countries tend to face a crisis from a Low-Low robustness standpoint. However, even in the least-developed countries there are pockets of capabilities nested in government and industry that can be potentially leveraged to increase overall robustness of the system and its response. As discussed in Section 3, even countries like Brazil and South Africa, which have demonstrated poor socioeconomic performance throughout the first year of the pandemic, contain

some pockets of capabilities. In many cases, these have been developed in previous crises. In fact, previous health crises such as pandemics, can offer the opportunity to develop robustness capabilities. The extent to which these capabilities are or not available to face subsequent crises depends on their accumulation and continuous investments (see Viet Nam case study in Section 3).

Because in both government and industry sectors there are pockets of capabilities and gaps, it is critical to develop a second-order analysis of the specific types of capabilities that confer robustness and resilience. Table 2 provides a taxonomic list of capabilities associated with robustness in both industry and government, and a list of relatively more dynamic capabilities that are also associated with industry and government.

Table 1: Industrial resilience: Gaps and misalignments in a two-stage, two-sector framework

Resilience capability	Industry robustness <i>resist, absorb and accommodate</i> LOW ←————→ HIGH	Industry readiness <i>adapt to, transform and recover</i> LOW ←————→ HIGH
Government robustness <i>resist, absorb and accommodate</i> LOW ↔ HIGH	CRISIS FIRST STAGE (0 – 6/12 months) ROBUSTNESS (TO SHOCK) MATTERS RESIST, ABSORB AND ACCOMODATE	
Government readiness <i>adapt to, transform and recover</i> LOW ↔ HIGH		CRISIS SECOND STAGE (6/12 – 36 months) READINESS (TO CHANGE) MATTERS ADAPT TO, TRANSFORM AND RECOVER

Resilience capability	Industry robustness <i>resist, absorb, accommodate</i>		Industry readiness <i>adapt to, transform and recover</i>		
	LOW ←	→ HIGH	LOW ←	→ HIGH	
Government robustness <i>resist, absorb, accommodate</i>	LOW	Low government robustness Low Industry robustness	Low government robustness High industry robustness		
	HIGH	High government robustness Low industry robustness	High government robustness High industry robustness		
Government readiness <i>adapt to, transform and recover</i>	LOW		Low government readiness Low Industry readiness		Low government readiness High industry readiness
	HIGH		High government readiness Low industry readiness		High government readiness High industry readiness

Source: Author elaboration

Table 2: Industrial resilience capabilities

Resilience capability	Industry robustness <i>resist, absorb, accommodate</i>		Industry readiness <i>adapt to, transform and recover</i>	
<p>Government robustness <i>resist, absorb, accommodate</i></p>	<p>Public health facilities for prevention, testing and containment (capillarity, agility, multi-level coordination)</p> <p>Public health facilities for care provision and treatment (capillarity, redundancies, repurposing)</p> <p>Public procurement for medical devices and pharmaceuticals (strategic control, flexibility, reliability, accountability)</p> <p>Logistics infrastructure for distribution (capillarity, reliability, agility)</p> <p>Public authority/agency for certification of medical devices and pharmaceuticals (reliability, agility, multi-actor coordination)</p> <p>Multi-level government Institutions for Targeting and Coordination (capillarity, stable-agility, multi-actor coordination)</p>	<p>Productive capabilities in strategic sectors for medical device and other equipment (domestic-based, specialized resources/tech availability, ramp-up)</p> <p>Productive capabilities in strategic sectors for pharmaceuticals (domestic-based, specialized resources/tech availability, ramp-up)</p> <p>Supply-chain redundancy capabilities for strategic sectors and inputs (access to multiple and diversified sources domestic-based, ramp-up)</p> <p>Repurposing capabilities in strategic sectors and supply chain inputs (flexibility, retrofitting, ramp-up)</p> <p>Productive capabilities in other strategic sectors</p>		

<p>Government readiness <i>adapt to, transform and recover</i></p>			<p>Public basic science and technology research institutions (university-based, industry-oriented, public-purpose driven) Public technology Intermediate Institutions for scaling up (capillarity, technology services oriented, quasi-public good technology-focused) Public procurement for bio-med-pharma Innovation and market creation (long term, strategic and functional) Public finance for innovation and industrial restructuring (long-term, public purpose/challenge driven and conditional) Public corporations and strategic control of critical technologies and production for national security (long-term, strategic, resilience focused) Public authority/agency for certification of medical Devices and pharmaceuticals (reliability, agility, multi-actor coordination) Multi-level government Institutions for experimentation and coordination (experimentation, stable-agility, multi-actor coordination)</p>	<p>Productive, technological and innovation capabilities in strategic sectors for medical device and other equipment (domestic-based, innovation driven, tech-innovation scalability) Productive, technological and innovation capabilities in strategic sectors for pharmaceuticals (domestic-based, innovation-driven, tech-innovation scalability) Supply-chain ecosystem capabilities for strategic sectors and inputs (access to multiple and diversified sources, domestic, co-opetition oriented) Innovation-chain ecosystem capabilities and risks-rewards governance arrangements (sustainable cooperation, public-purpose oriented, challenge-driven)</p>
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Source: Author elaboration

2.2.1 Industry resilience capabilities

In an ordinary context, industrial capabilities are broadly identified and defined as the personal and collective skills, productive knowledge and experiences embedded in physical agents and organizations that firms need to perform different productive tasks and adapt and undertake in-house improvements across different technological and organizational functions. These functions include investment and financing, product design, internal process organization and deployment of technologies in production, external linkages and supply chain coordination. From a “dynamic efficiency” and innovation perspective, the absorption, adaptation and improvement of given productive techniques, as well as innovations across different organizational and technological functions, depend mainly on the availability of a specific subset of industrial capabilities often identified as innovation or dynamic capabilities (Andreoni, 2011 and 2014). All these productive, technical and innovation abilities (used to produce goods and services) are individually or collectively held, but always collectively constructed and deployed within productive organizations and their industrial ecosystems under specific social conditions (Andreoni, 2018; Andreoni et al., 2021; Andreoni and Lazonick, 2020).

As highlighted in Table 2, industry robustness to shocks and readiness to change depends on a sub-set of industrial capabilities that confer resilience on specific, non-ordinary situations. Under non-ordinary situations—such as a global pandemic—we can think of a country’s industry resilience capabilities as the sufficiently redundant, widely distributed, and locally and readily available quantity of skills, productive knowledge, and experiences in strategic health-medical device sectors and complementary supply-chain activities and strategic sectors. Different degrees of industrial resilience across countries depend on the presence and mix of these resilience capabilities, and the flexibility of the productive organizations and research and technology intermediate institutions where they are embedded. Sufficient availability of these capabilities comes with some built-in redundancy into production systems, while flexibility develops at the organizational and institutional level and requires agile government coordination in absorbing shocks in the short term and reforming existing systems with a directionality in the medium-long term.

2.2.2 *Government resilience capabilities*

Government resilience capabilities are critical for coordinating and implementing a set of proactive and containment measures, and leveraging state capacity embedded in public agencies, the health sector and related infrastructures. Industry and economic activities—especially in key sectors—must be sufficiently robust to retain some supply capability, secure needed commodities and keep people employed in a safe setting. While robustness is central to coping with the immediate needs and negative impact of an extreme event, given the uncertainty that extreme events pose to socioeconomic systems, a robust system can find itself unable to weather a crisis. This is particularly the case when extreme events are unprecedented and prolonged. Robustness can deteriorate quickly, and if the system is not ready to reform—by offering innovative solutions towards a more sustained and sustainable recovery—it can collapse.

And while robustness can be partially achieved by planning—for example, by building some redundancies in strategic supply capacity or institutions like hospitals, as well as by establishing the most appropriate industry regulatory framework or standards—readiness depends on a more complex and broad set of dynamic capabilities in both governments and industries. Dynamic capabilities involve significant innovation, they rely on several sets of accumulated capabilities as well as the agility to experiment and adapt in a rapidly changing environment. For governments, specifically, dynamic capabilities involve exercising “stable-agility” and alignment functions, but also about shaping markets through regulations, industrial policy and other demand-side measures such as functional procurement. These functions are discussed in Section 4.

Historically, state formation and industrialization have been linked by a mutually constitutive relationship. Industrialization—broadly defined as a process of continuous change in the productive structure of the economy and extent of the market—has been shaped by the state via industrial and innovation policy, or lack thereof. The formation of state institutions, governance and bureaucracy structures has played a key role. By designing, implementing and enforcing state policies, these structures have constructed and mediated the continuously evolving relationship between state, industry and markets. At the same time, industrialization and the formation of new powerful organizations and interests have shaped the political economy of the state, its internal structural formation and policymaking. Conversely, lack of industrialization, pre-industrial premature de-industrialization and de-industrialization have often reduced the capacity of the state to deliver on its key functions. Thus, government and industry are linked by a mutually constitutive, historically path-dependent and dynamic relationship.

Countries that have shown the highest degree of resilience in the face of COVID-19 are those that have built resilience into the system over several years and managed to align both government and industry capabilities. Governments are in an ideal position to learn from previous experiences and coordinate distributed but highly complementary capabilities. Business enterprises coordinating long supply chains can also play critical coordination functions if regulations and policies steer them towards pursuing system interests. In the following two sub-sections we investigate the specific set of capabilities that matter, in both government and industry, to develop a resilient socioeconomic system. This more detailed second-order analysis highlights the multiple gaps and potential misalignments that can be found in all countries, as shortages of basic masks in advanced economies manifested alongside rapid development of new vaccines.

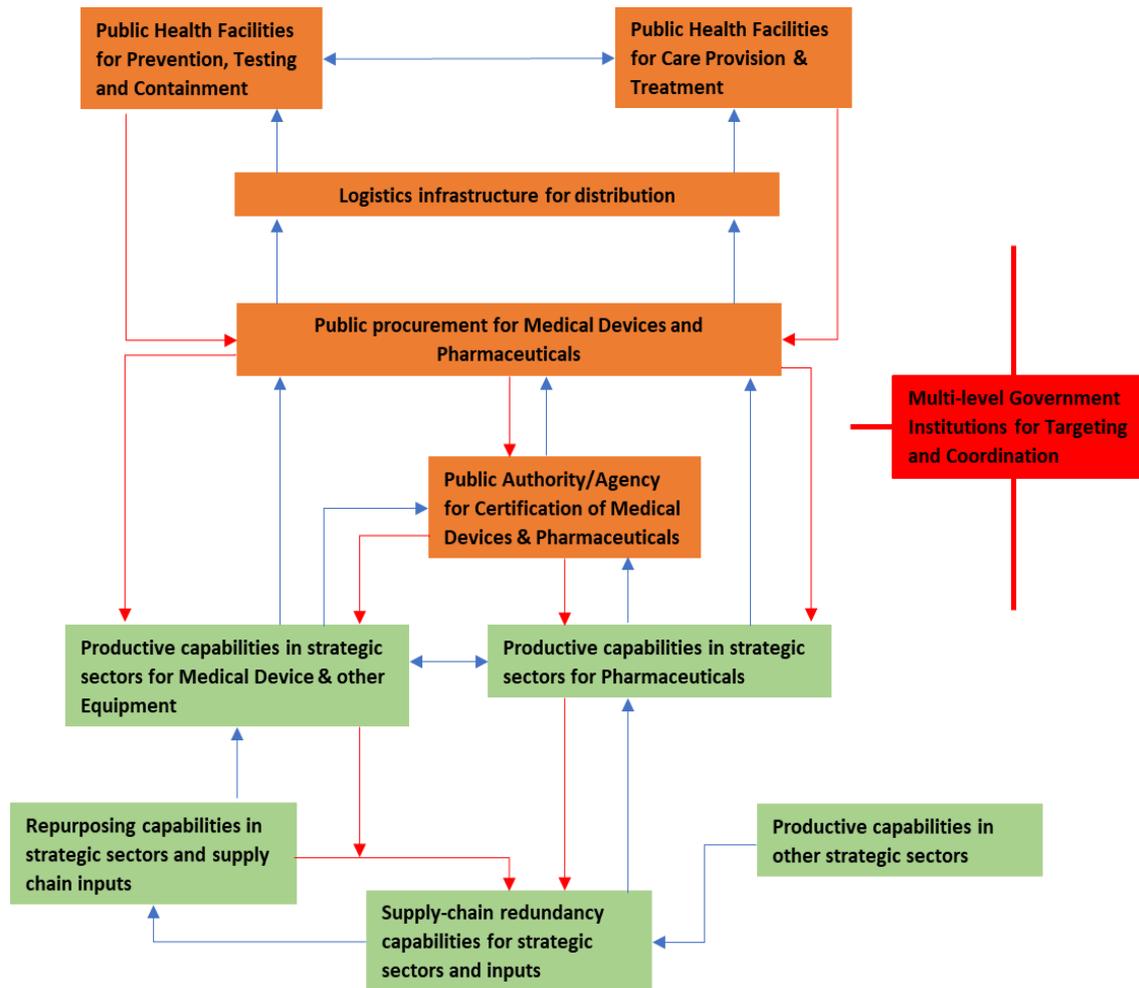
2.2.3 Robustness to shocks: Which government and industry capabilities matter?

Table 2 identifies six clusters of government capabilities as well as five clusters of industry capabilities that have proven critical for delivering a robust response to a crisis like a pandemic. A set of qualifying features for each of these is also listed to highlight properties of these capabilities that have proven to be particularly important in driving speed and effectiveness of the pandemic response. Figure 2 provides a schematic showing the interdependencies between these different capabilities and the importance of filling capability gaps and nurturing capability alignment. Given their high degree of complementarity, bottlenecks can disrupt the overall response even in the presence of some pockets of capabilities in the government and/or industry. A functioning system also presents several feedback mechanisms (red arrows) that allow for system agility to absorb and accommodate disruptions.

Public procurement and its operational logistics infrastructure are key nodes in this system.² Government capabilities and strategic control in this area are essential to provide flexible responses to the emerging needs, reliable supply to the health facilities as much as reliable and accountable contracting to the industry. When new supplies of devices, equipment and drugs are procured, the certification authority and their extended public technology infrastructure for testing and assuring reliability enter into force. At the initial stages of a crisis, however, this certification and testing process is often stressed as there is a trade-off between agility and reliability. Capabilities in coordinating multiple actors is essential here, especially when new devices such as ventilators are rapidly ramped up or repurposed (for an analysis of cases in the United States and Italy see Andreoni and Hill, 2020).

² See OECD's framework on resilient infrastructure for logistics: <http://www.oecd.org/coronavirus/policy-responses/covid-19-and-a-new-resilient-infrastructure-landscape-d40a19e3/>.

Figure 2: Robustness capability: Government and industry complementarity and alignment



Source: Author elaboration.

During a crisis like a pandemic, public procurement capabilities are challenged by the fact that demand of specific products—medical device, equipment and drugs—increases dramatically. This lack of productive capabilities and production capacity becomes even more acute when a country does not have a domestic base to leverage and must rely on the international market at a time when demand is also rising in other countries. Bottlenecks can quickly arise along the supply chains; ramping up capabilities in certain stages in the production chain can be undermined by shortages, lack of redundancies or ramp-up capabilities by other firms. These bottlenecks often come about because of highly specialized inputs and assets or highly complex processes involving tacit knowledge and difficult-to-reproduce organizational capabilities—at the shop-floor level and along the supply chain. Because their high degree of specialization and capital-intensity—such as the need for clean rooms for medical device production or highly specialized production lines for filling and finishing drugs—few companies in a few countries and places can invest in

them, and investments are efficiency-bound. That is, they do not include redundancies. While this might be efficient for the individual company, it is inefficient from a systemic perspective as it reduces robustness in the economy, especially in those countries where productive capabilities are lost.

A reduction in diffused productive capabilities across countries and places has occurred alongside reduction in inventories at the firm level. As pointed out by Gereffi (2020), globalization has encouraged the adoption of lean production and just-in-time (JIT) supply chains, hence reduction of inventories to lower operating costs and the amount of cash tied up in inventory. Streamlined global value chains and reductions in inventory are efficient business practices from a company perspective, until orders are steady. Over time, however, they can also make supply chains fragile and brittle in the event of a crisis. To prevent modern supply chains from snapping, redundancy rather than reshoring is recommended to bolster both the robustness and resiliency of supply chains (O’Leary, 2020; O’Neil, 2020). Diversification of supply chains and sources is also a way of reducing risks, while retaining scaled economies, reasonable costs and ramp-up opportunities. This strategy can have far-reaching ramifications. A few countries can become the main global sources of supply of key inputs used by health facilities for all other countries in the world (OECD, 2020). In case of either a symmetric or asymmetric shock affecting those production hubs, domestic markets and the entire global system become more fragile and vulnerable to shortages of essential equipment and drugs. These shortages tend to trickle down along the supply chain, further reducing robustness. Additional key sectoral value chains—such as the food industry—can be also disrupted via multiple channels.

Repurposing capabilities in strategic sectors and supply chain inputs can be leveraged to address these bottlenecks in key sectors. However, manufacturing repurposing is a complex process involving organizational flexibility, retrofitting capabilities and rapid scale-up of capabilities in addition to regulatory approval (Solomon et al., 2019). During the COVID-19 pandemic, this route was undertaken in many countries (see South Africa case in Section 3). For example, to combat a ventilator shortage in the United Kingdom, the so-called Ventilator Challenge initiative launched by the UK government encouraged companies to develop completely new design solutions. One group built on existing product architectures and proven design solutions. Many of those that pursued a "start-from-scratch" approach underestimated the fact that device safety is not simply a design property; rather, it depends on how the device is manufactured, quality management and appropriateness of product design innovation in meeting the clinical need (Andreoni and Hill, 2020).

While we have so far focused on the industrial capabilities that confer robustness (or lack thereof), industry robustness is not sufficient if public health facilities dedicated to prevention, testing, containment and care provision are not able to absorb such supply. Here, the presence of redundancies (such as in ICUs), agility in repurposing and public-sector coordination across government are critical to providing a robust response. Some developing and emerging economies have experimented with several measures at the aftermath of the pandemic. In some cases these measures have built on existing schemes introduced to address previous pandemics, while other countries have leveraged their existing social insurance and health provision networks and repurposed some of the instruments traditionally used to support the most vulnerable and provide social welfare and health services. Digital infrastructures have been leveraged to streamline the emergency transfers and payments and link, in a more targeted fashion, poor citizens to various public programmes (Rutkowski et al., 2020). For example, Chile relied on its national ID-linked basic account to provide more than 2 million low-income individuals a one-time grant. India also has sent money to Jan Dhan accounts linked to the Adhaar ID system, which was created to promote financial inclusion among the poor.

2.2.4 Readiness to change: Which government and industry capabilities matter?

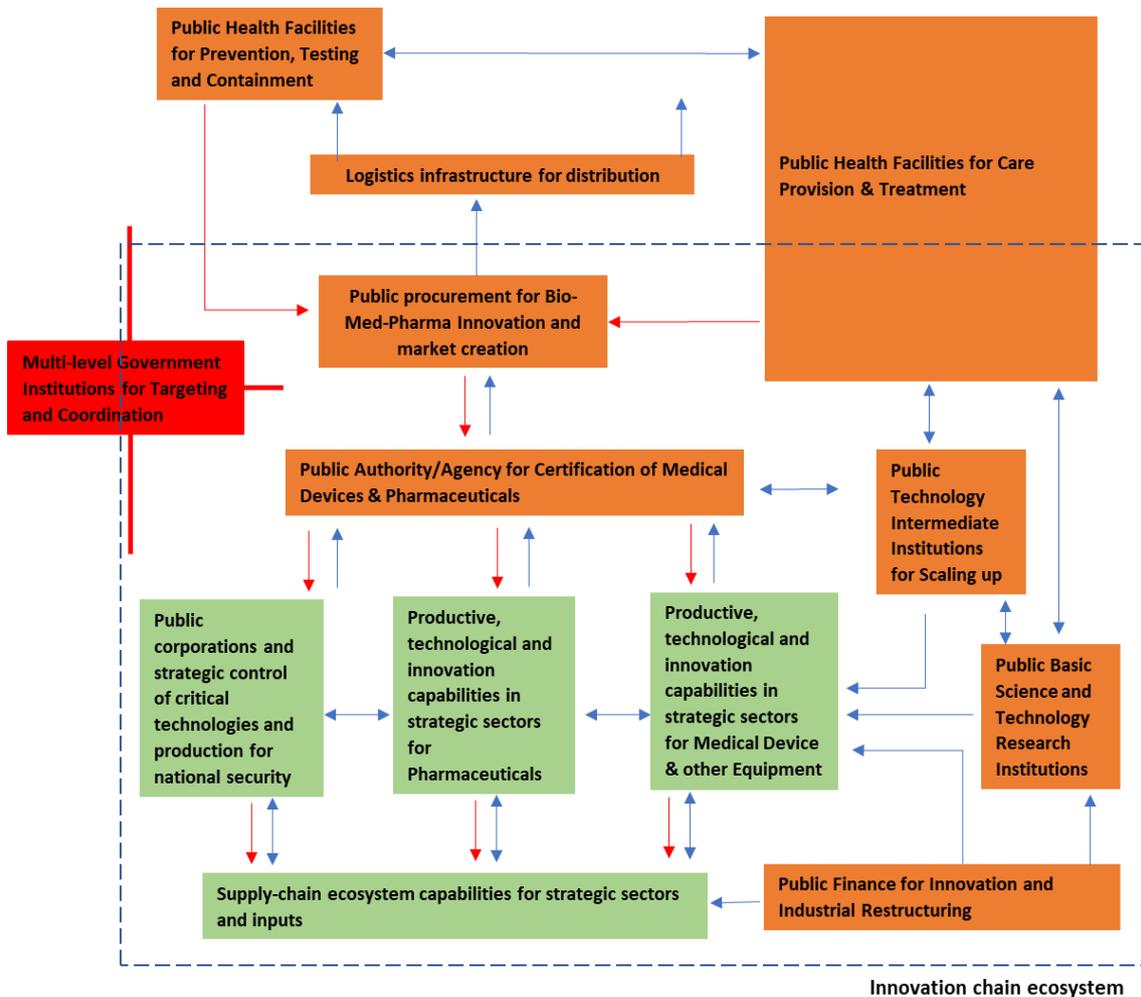
Table 2 identifies seven clusters of government capabilities as well as four clusters of industry capabilities that are critical enablers for developing a readiness to change in the face of a crisis like a pandemic. A set of qualifying features for each capability is also listed to highlight properties that have proven to be particularly important in driving speed and effectiveness of a country's pandemic response. Figure 3 provides a schematic showing the interdependencies between these different capabilities and the importance of filling capability gaps and nurturing capability alignment. Given their high degree of complementarity, bottlenecks can disrupt overall readiness to change, even in the presence of some pockets of government and/or industry capabilities. A functioning system also presents several feedback mechanisms (indicated in the figure by red arrows) that facilitate system agility to transform and recover.

Readiness to change as depicted in Figure 3 can depend on several pockets of capabilities across the sectors. However, capabilities, organizations and institutions cannot achieve change in isolation. If robustness to shock relied mainly on the capability of the government to coordinate sufficient supply, procurement and distribution to health facilities, readiness to change calls for an ecosystem reconfiguration and integrated packages of policy interventions. Moreover, the same institutional mechanisms can be used to performed different functions (Andreoni and Chang, 2019; Chang and Andreoni, 2020). For example, while public procurement remains relevant in matching existing and new demands of products effectively, it can also be used to

create new markets and drive innovation (see Section 4) and be integrated with forms of long-term finance support innovation as well as restructuring of supply chains. Public authorities and agencies for certifying medical devices and pharmaceuticals can also play a proactive market-shaping role in setting regulations, standards, etc.

Readiness to change is also highly dependent on capabilities distributed along the innovation chain ecosystem. As shown in Figure 3, this ecosystem involves a variety of government and industry players. In addition to universities and other public scientific research institutions, innovations in the medical device and biopharma domains rely heavily on public hospitals where the therapeutic appropriateness and scalability of new products is piloted and tested. Living labs and intermediate technology institutes are other key players in the scale-up of new medical devices and equipment (Rosenberg, 2009; Andreoni, 2018).

Figure 3: Readiness capability: Government and industry complementarity and alignment



Source: Author elaboration.

The pandemic has driven significant innovation in those countries and places with rich innovation chain ecosystems (Andreoni and Hill, 2020). At the outset of the pandemic in February 2020, the United Kingdom’s National Health Service (NHS) had only 8,000 ventilators, with epidemiologist models suggesting the need for 30,000 in a matter of weeks. In response, the UK government launched the Ventilator Challenge UK Consortium on 14 March. The consortium included leading industrial, technology and engineering businesses from across the aerospace, automotive and medical sectors. Companies in these sectors rely on similar technology platforms, flexible supply chains and coherent design capabilities for all product systems. In effect, they work with ecosystems—as much as products—comprising thousands of highly specialized and interdependent components whose design and production depends on the orchestration of long chains of specialized contractors. The High Value Manufacturing Catapult—a UK intermediate technology institution operating across public institutions and private sectors—took a coordinating role, particularly in investigating a range of design options and specifications for a Rapidly Manufactured Ventilator System, which was developed by clinicians and the Medicines and Healthcare products Regulatory Agency. Despite several challenges and false starts, the consortium managed to increase the combined capacity of Penlon and Smiths from 50-60 ventilators per week, to 100-200 per day. Work by the consortium concluded 5 July after delivering 13,347 ventilators to the NHS.

Similarly, in Italy, in late March 2020, an alternative design response to the shortage of ventilators originated from the bottom-up. The director of the Anesthesia and Intensive Care Unit at the Policlinico Sant’Orsola in Bologna seized an opportunity to double existing stock of ventilators by designing a circuit through which one device could be used to ventilate two people at the same time.³ This would have remained simply an idea if the industrial ecosystem in the Emilia Romagna Region had not been able to produce in only three days a functioning prototype of this “double ventilator”. Intersurgical, the company that made this product design possible, is one of Europe’s leading designers and manufacturers of medical devices and is located in the Mirandola biomedical district. The district is known for developing design capabilities in medical instrumentation, ranging from production capabilities for disposables to complex haemodialysis machines. From a design perspective, these devices are critical for product systems, such as flow and fluidic systems, sensors and controls, valves and filtration systems. Given their complex architecture system, integration capabilities and product design modularization are critical.

³ For more details on the development of the design, see: <https://www.unibo.it/en/notice-board/a-circuit-doubling-up-on-lung-ventilators>.

Italy's ventilator shortage also led to innovative design solutions along different therapeutic lines—such as the increasing use of Continuous Positive Airway Pressure (CPAP) devices. In contrast to ventilators, CPAP machines deliver oxygen via a mask and do not require intubation. They can be effectively used with patients who display relatively minor respiratory symptoms, thus saving ventilators for the most seriously ill patients. This example, along with others in China, were used by a team at University College London (UCL) to launch the UCL Ventura breathing aids in March 2020 (Singer et al., 2020). Working in collaboration with industry partners Mercedes-AMG High Performance Powertrains and relying on direct access to clinicians at the UCL Hospital, the Ventura initiative led to the production of 10,000 breathing aids in just one month and over 1,900 open licenses across 105 countries (alongside training materials). The design built on an existing device WhisperFlow invented by Medic-Aid in 1992, which was a purely mechanical device controlled simply by rotary valves to alter oxygen concentration and flow rate. While the product was much simpler than a ventilator, the UCL team would have not been able to scale up the CPAP without an industrial partner. The reverse engineering process relied on computer-aided design (CAD) and computational fluid mechanics simulators, which are more commonly used for Formula 1 automobile engine design. Design improvements were constrained by the availability of consumables, which later manufactured by Intersurgical. Although the product design effort also faced an implementation challenge, due to the limited supply of oxygen in British hospitals, the team used the UCL hospital to model oxygen flows to each floor and bed area; in short, an integrated product-system-therapy solution.

For many PPEs with simple product designs, like disposable surgical masks, design capabilities were required mainly to develop robust and highly automated production technologies and processes that could deliver high-volume production over long periods. In Italy, for example, the mask shortage was addressed by a leading packaging machinery company, IMA spa. Responding to a call from the Italian government, the company designed a streamlined and highly flexible production line—IMA Face 400—capable of producing and packaging 200-400 masks per minute. The design of 25 machines able to satisfy national demand was led by an agile task force leveraging internal design and organizational capabilities, as well as a network of specialized contractors that provided components despite lockdown restrictions in one of the most COVID-19 affected regions (Andreoni et al., 2017). The existence of a resilient and robust supply chain was critical in finding the most appropriate process and product system design solution.

As documented in the examination of South Africa’s pandemic response in Section 3, we have witnessed several cases of low- and middle-income countries relying on *frugal innovation*, initially triggered by repurpose, reuse and rapid deployment of existing technologies. Frugal innovation provides affordable opportunities to expand access to care and to ensure that the care is good enough under the current circumstances. However, reverse-engineering and technology adaptation to context-specific health facility and therapeutic practices are important avenues for indigenous innovation in medical device technologies.

Examining the industry as a whole, innovation and new solutions for a new context rely on productive technological and innovation capabilities distributed across strategic sectors in medical devices and equipment as well as pharmaceuticals. Governments can be directly involved in this process by retaining control of public corporations; supporting and de-risking business enterprises with public-purpose, challenge-oriented conditional finance; and exercising strategic control of critical technologies and production for national security. When governments provide support to private companies—either in emergencies or to subsidize investments—the relationship is too often designed to deliver private value for the corporation and not public value to society. It is common for risks to be socialized and rewards privatized when the public sector enables new value creation in the private sector. When the public takes risk and funds or protects private companies—via patents, for example—governments should ensure that the resulting outcomes for the public reflect the support provided by governments. If value is not retained and redistributed across value creators, the economy is doomed to lose its value-creation capabilities. Conditionalities are therefore needed, especially in those countries where financialization and “rentieristic” practices have weakened the economy. Far from a punitive and dirigiste attempt to put strings on the economy, attaching conditionalities to bailouts is a way to steer the economy and promote its productive forces towards more inclusivity, sustainability and innovation. When conditionalities are done well, they align corporate behaviour with the needs of a productive society (Mazzucato and Andreoni, 2020).

2.3 Industrial resilience development pathways

The Resilience Capability Framework presented in Tables 1 and 2 points to different stages of a crisis (early response phase and recovery phase) and different sector capabilities (government and industry) operating at both the country and ecosystem levels. Figures 2 and 3 identified key nodes and relationships among different pockets of capabilities nested in government and public-sector institutions, as well as in industry (and their productive organizations). Each of these nodes and relationships can play a different and complementary role in responding to a crisis like a pandemic and can be used to leverage a coordinated response if mechanisms linking pockets of capabilities, or lack thereof, are highlighted (see Appendix 1 for a combined theory of change).

Countries can develop and navigate different pathways out of a crisis. As discussed earlier in this paper, countries with LOW government capabilities and LOW industry capabilities, according to the framework, run the risk of being trapped and experiencing a vicious cycle in which one crisis leads to another. More commonly, however, different pathways may emerge given a country's baseline. Table 3 provides a stylized set of pathways and three main pathways are highlighted below. The in-depth country investigations in Section 3 provide a detailed discussion of the path-dependent formation of pockets of capabilities in government and industry as well as their deployment in response to the COVID-19 pandemic.

- **Pathway 1: Leverage government capabilities to develop industry robustness capabilities and readiness**

Countries can leverage government capabilities—its institutions, infrastructure, financing and procurement—to mobilize and coordinate public and private resources and players to rapidly improve industry robustness. This process is in itself critical to continue developing increasingly more sophisticated government capabilities in action, via experimentation and learning by doing. It is also critical to preparing industry transformation and recovery. While some advanced economies have found themselves with higher degrees of industry readiness than robustness, in most cases robustness is a precondition for industry readiness.

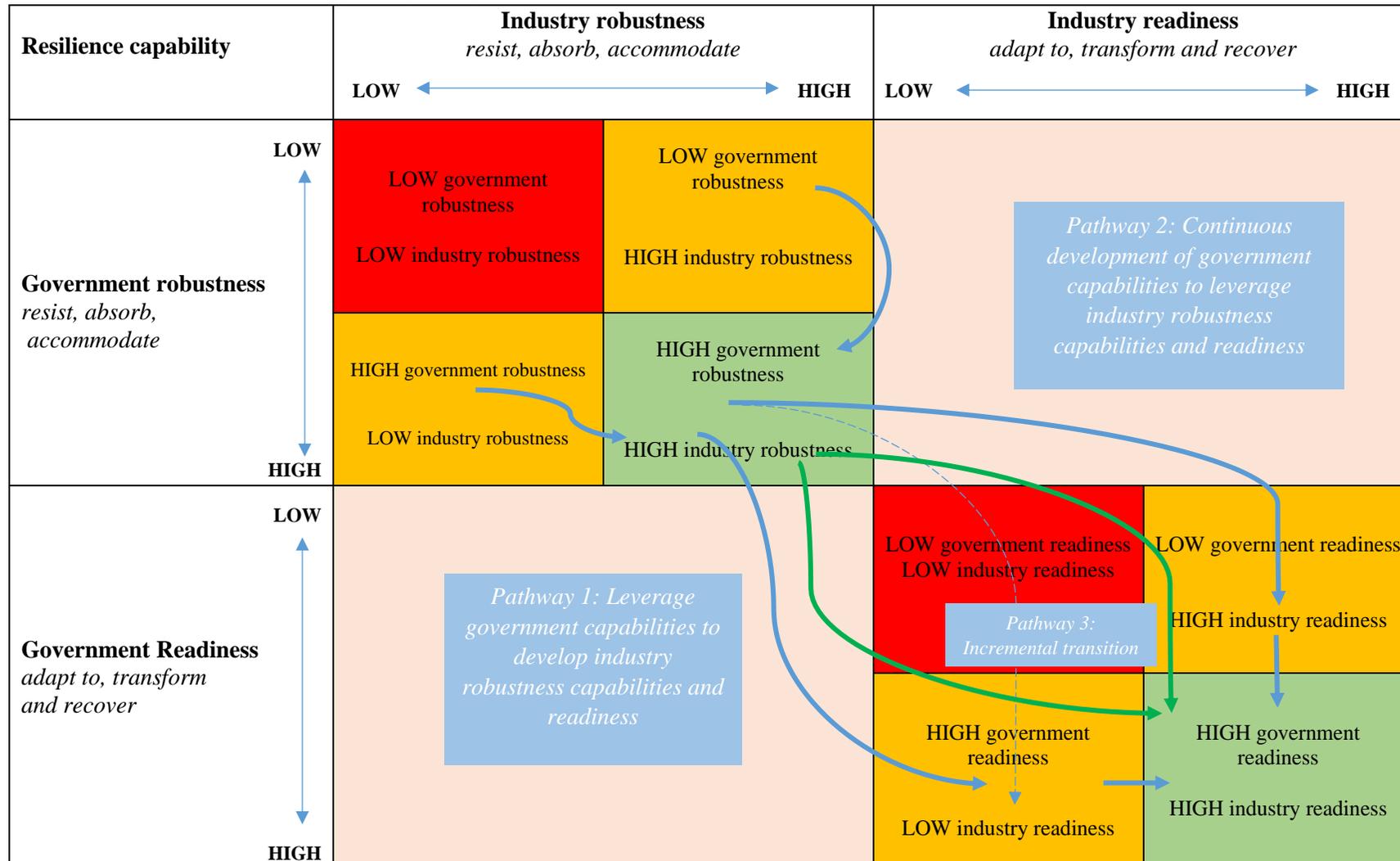
- **Pathway 2: Continuous development of government capabilities to leverage industry robustness capabilities and readiness**

Even countries starting with a low level of government robust capabilities can develop public institution and sector response by connecting its nodes to industry sectors. Partnerships can be used to transfer technologies and develop public-private collaborative arrangements in the early and later stages of the crisis. Cases in which government capabilities have become more robust to shock and ready to change are, however, those where the government has not given up on its functions. By outsourcing public functions, the government loses an opportunity to learn and develop key capabilities such procurement, testing, prevention and logistics.

- **Pathway 3: Incremental transition towards recovery**

Countries with both HIGH government capabilities and HIGH industry capabilities, per the framework, at early stages of a crisis—such as a robust socioeconomic system—are better positioned to face later stages of the crisis. However, the transition from a robust response to an adaptation, transformation and recovery phase of the socioeconomic system should not be taken for granted. As shown by comparing Figures 2 and 3, readiness to change depends on a much broader set of capabilities and complementary relationships. Threshold capabilities in terms of financing or basic research also matter in areas such discovering and manufacturing a new vaccine.

Table 3: Industrial resilience development pathways



Source: Author elaboration.

3. Learning from pandemics: Why, how, and when industrial and government capabilities matter

The case studies in this section provide in-depth examinations of the experiences of three countries during the COVID-19 pandemic. Building on the framework developed in Tables 2 and 3 (see also Annex 1) and focusing on specific dimensions of resilience and their underlying capabilities at different stages of the crisis, we analyse each country's overall performance and pathway out of the crisis, to offer actionable lessons for other countries.

First, we highlight how Viet Nam's robustness to shocks during the COVID-19 pandemic is the outcome of a long and continuous process of development of government capabilities, which has also made it possible for the county to leverage necessary industry capabilities over time (Pathway 2, Table 3). This case shows how government can develop capabilities and robustness to shocks by learning from previous pandemics (the case of the Republic of Korea mentioned earlier is another case in point among advanced countries). Beyond that, it also demonstrates how government learning is deeply rooted in the process of state formation and institution-building over several decades, and how this process is sustained by and co-developed alongside industry capability accumulation over time.

Second, we focus on Brazil to assess the role that intermediate institutions can play in integrating the entire innovation value chain for pharmaceutical products and how this is an important example of public-private strategic engagement. Earlier in this paper, Figure 3 highlighted the complexities associated with scaling up health solutions at early as well as more advanced stages in a pandemic. Furthermore, we have already emphasized how bottlenecks along innovation and industrial value chains and how misalignment between industry and government responses undermine country's resilience. In the Brazilian case we focus on the resilience capabilities and role played by Fiocruz as a key intermediate institution. Fiocruz leveraged several technological, innovation and organizational capabilities described in Table 2 at the interface of government and industry. As a result, Brazil has experienced a process of incremental transition (Pathway 3, Table 3) in the specific case of drug development capabilities.

Third, we turn to South Africa to illustrate how government can play an important coordinating role. By leveraging its own public-sector capabilities, the government can support private companies in developing capabilities that are critical for robustness to shocks and offer venues for future change (Pathway 1, Table 3). Specifically, we look at the ways in which the introduction of a government challenge-initiative allowed firms to scale up production of critical medical devices—in this case, ventilators—during the pandemic. This experience is important in a country with historically limited investments in the public-health sector, dramatic disparity in access and

other widespread health vulnerabilities, notably HIV. The fact that technological capabilities were redeployed to design and produce medical devices rapidly and effectively opens potential diversification pathways in the future for South Africa and the region.

Overall, these three cases are not exhaustive of the variety of possible government-industry configurations, capabilities and pathways highlighted in Tables 2 and 3. However, they are representative of both country-wide success stories and pockets of successes within countries recorded during the pandemic among developing countries. As such they point to lessons for a creating a more resilient post-pandemic economy and society.

3.1 Viet Nam: Robustness to shocks and deep roots in public-private co-development and government experimentation

Very few developing countries have managed to deliver a systemic and successful response to the COVID-19 crisis, yet Viet Nam is perhaps the most strikingly successful case. As of 31 December 2020, Viet Nam had reported 1,465 laboratory confirmed cases of COVID-19 and 35 deaths. The pandemic is projected to cost Viet Nam nearly 200,000 billion dong (\$9.4 billion) in revenue, according to Prime Minister Nguyen Xuan Phuc, with significant losses in the tourism and fruit-export sectors. However, GDP growth figures bounced back rapidly after five months of decline, with the manufacturing sector growing again already by June 2020 (Leung and Wu, 2020). During the pandemic, Viet Nam was a major exporter of PPE, with hundreds of millions of cloth masks exported to France and 4.5 million made-in-Viet Nam PPE suits sold in the United States. More advanced manufacturing value chains highly connected with the Republic of Korea and China have resumed their operations, also thanks to re-opening of flight routes.

Viet Nam's robustness to pandemic shock has been attributed to several structural and contingent factors, including a well-developed public health system, a decisive central government, and a proactive containment strategy based on comprehensive testing, tracing and quarantining (La et al., 2020; Pollack et al., 2021). The deployment of its testing, tracing and quarantining strategy has been particularly successful in containing the spread of the virus. The success of Viet Nam is comparable only to the case of the Republic of Korea discussed in Section 2, and is in striking contrast to the major challenges faced by advanced economies in containing COVID-19 infections.

The development of government resilience capabilities that allowed Viet Nam such robustness to shocks is the outcome of two decades of continuous learning and investments in dealing with pandemics. Among several other countries in the region, in the early 2000s Viet Nam faced its first pandemic stress test with the Severe Acute Respiratory Syndrome (SARS) outbreak. In 2003

Viet Nam was the first country recognized by the World Health Organization (WHO) to be SARS-free. Not only did Viet Nam manage the SARS emergency successfully; it also implemented several lessons learned to build a resilient, responsive and ready health and industrial ecosystem. Indeed, several measures experimented with under SARS were redeployed under COVID-19. Throughout the last decade, Viet Nam increased investments in its public health infrastructure, including developing a national public health emergency operations centre in 2013—and four regional centres in 2016—and a national public-health surveillance system. This network has become the country’s main response unit against outbreaks, and it has managed preparedness and response efforts related to measles, Ebola, MERS (Middle East Respiratory Syndrome), and Zika.

Since 2009, the responsiveness of this decentralized network of centres has been enhanced by the development of a nearly real-time, web-based system to collect and aggregate data from public-health entities. Since 2016, for example, hospitals have been required to report notifiable diseases within 24 hours to a central database, ensuring that the Ministry of Health can track epidemiological developments across the country in real time. “Event-based” surveillance programmes have been piloted since 2016 and were scaled up nationally in 2018 based on positive results. These schemes empower members of the public—including teachers, pharmacists, religious leaders, community leaders and even traditional medicine healers—to report public-health events.

Against this track record, it is not surprising that after Viet Nam reported its first case of COVID-19 on 2020 January 23, it then reported just over 300 cases and 0 deaths over the following four months. Government capabilities and state capacity were not only able to leverage existing processes and structures; they also built new ones to secure the response to the crisis.

By February 2020, public institutions released at least three locally made COVID-19 tests in collaboration with industries. These public-private collaborations included: (1) Institute of Military Medicine (IMM) and the biotech company Viet A; (2) Hanoi University of Science and Technology (HUST), the biotech company Innogenex and the pharmaceutical company Sunstar; and (3) Vietnam Academy of Science and Technology (VAST). Both HUST and IMM initiated their efforts to develop a test in late December 2019 in response to a “strange lung disease in China” in anticipation of a required response. Researchers in these public institutions quickly leveraged their existing resources and networks with local industries and small businesses to start prototyping and assessing the feasibility and manufacturability of the new tests (Kingler-Vidra et al., 2021).

Collaboration with private-sector partners proved crucial in the certification and commercialization phases of test kits in Viet Nam and in foreign markets. For the HUST-initiated test kit, for example, collaboration with two private entities, Innogenex and Sunstar, gave scientists access to essential funding, clinical validation and production capacity. Commercialization of IMM's kit was done by a private company, Viet A. These public-private sector collaborations in developing testing capability, which fit the specific Vietnamese context, leveraged and developed dynamic capabilities further. For example, two of the test kits referenced WHO and the American Centers of Disease Control (CDC) test kits but were adapted to make the test faster and more affordable. The one-step testing protocol developed in Viet Nam brings crucial time and cost savings, with test results available in just over one hour.

In developing different testing kits, the Vietnamese government also adopted a multi-pronged approach aimed at increasing chances of success. First, two public-private teams were offered financial support: VAST could spend state money on its own test kit even though IMM had already been developing theirs with funding from the Ministry of Science and Technology. A third team from HUST–Sunstar–Innogenex received non-financial support from the Ministry of Health. This team organized a committee of leading medical experts from the National Institute of Hygiene And Epidemiology (NIHE) and the National Institute for Control of Vaccine and Biologicals to assess their prototype kit (Klinger-Vidra et al., 2021).

Second, thanks to these efforts in producing testing kits, testing capacity was then ramped up quickly and the immediate over-capacity was re-deployed to identify potential clusters and prevent infections. As of 22 October, 2020 137 laboratories were capable of testing by RT-PCR, with a maximum daily capacity of 51,000 tests. The government has also pushed for including use of GeneXpert machines within the lung hospital system. Of these laboratories, 62 are designated as screening laboratories and 75 as confirmatory laboratories that conduct analysis and provide test results. They have adopted customized versions of WHO protocols. At early stages of the crisis, rapid testing of the population led by public-sector institutions was also critical for private-sector advancement of testing kits. Companies like Viet A, for example, had access to samples for validating kit effectiveness.

Third, when community transmission was detected (even just one case), the government reacted quickly with contact tracing, commune-level lockdowns and widespread local testing to ensure no cases were missed. International travelers were also tested, and when tested positive were sent to quarantine centres. In fact, Viet Nam has performed more tests per confirmed case than any other country in the world, even though testing per capita remains relatively low. Moreover, focusing on the epidemiological risk of infection more than the presence of symptoms seems to

have delivered more effective results. Targeting and preventing has been key to effective lockdowns.

Fourth, effective contact tracing was made possible by the launch of a dedicated app co-developed by the Ministry of Health and a number of telecom companies (Pollack et al., 2021). The NCOVI app helps citizens put in place a “neighborhood watch system” that complements official contact tracing efforts. In mid-April, Vietnamese cyber security firm Bkav launched Bluezone, a Bluetooth-enabled mobile app that notifies users if they have been within approximately 6 feet (2 meters) of a confirmed case within 14 days.

Finally, the government’s clear messaging and coordination contributed to the prevention of infections in larger urban centres as well as within the healthcare facilities. In February 2020, the Ministry of Health issued the national Guidelines for Infection Prevention and Control for COVID-19 Acute Respiratory Disease in Healthcare Establishments. This document provides comprehensive guidance to hospitals on: screening, admission and isolation of confirmed or suspected COVID-19 cases; establishment of isolation areas in hospitals; use of personal protective equipment; cleaning and disinfection of environmental surfaces; waste management; collection, preservation, packing and transport of patient samples; prevention of laboratory-acquired infection of COVID-19; handling of remains of confirmed or suspected COVID-19 cases; and guidance for COVID-19 prevention for family members and visitors.

Table 4 summaries key capabilities at the interface of government and industry which made the testing, tracing and quarantining strategy so effective in containing the spread of the virus. While many of these capabilities are sector- and institution-specific, their development is rooted deeply in Viet Nam’s dramatic structural transformation over the last four decades. As the response to the COVID-19 crisis has shown, these capabilities have co-developed in a cumulative process of change within—and, more critically, across—both public and private sectors.

Table 4: Viet Nam’s robustness to shock capabilities

Resilience capability	Industry robustness <i>resist, absorb, accommodate</i>	
Government robustness <i>resist, absorb, accommodate</i>	<ul style="list-style-type: none"> ✓ Public procurement for medical devices and pharmaceuticals (testing kits) ✓ Public-health facilities for prevention, testing and containment ✓ Public-health facilities for care provision and treatment ✓ Logistics infrastructure for distribution ✓ Multi-level government institutions for targeting and coordination ✓ Public authority/agency for certification of medical devices and pharmaceuticals 	<ul style="list-style-type: none"> ✓ Productive capabilities in strategic sectors for medical device and other equipment ✓ Repurposing capabilities in strategic sectors and supply chain inputs

Source: Author elaboration.

Viet Nam became independent in 1945 and reached its reunification only in 1975, with the end of the Viet Nam war, under the leadership of the Vietnamese Communist Party (VCP). At the time, Viet Nam was one of the poorest countries in the world, facing severe social and economic challenges, including food scarcity and macro-structural constraints. The country was also divided into two markedly different economic systems in the North and South and was largely isolated from the global market economy. After significant challenges and limited results during the first years of post-unification, starting with the Third Five Year Plan (1981-1985) the government embraced a more gradualist approach and initiated a number of policy experiments, especially at the local level—so called “fence breaking”. These policy initiatives included the promotion of the “family economy” (rather than “collectives”) and intensive cultivation and specialization in the agricultural sector, as well as the promotion of small-scale industries with a focus on the domestic market and, in some cases, exports (Gray, 2018).

With the adoption of the Doi Moi renovation programme in 1986, Viet Nam took the first steps on an impressive industrialization journey and almost three decades of sustained economic growth (Ohno, 2013). Between 1986 and 2016 industrial value added grew at around 8 percent per year on average, and there was a dramatic shift of the population away from the agricultural sector.

From exporting rice, oil and food—the three commodities accounted for more than half of Viet Nam’s exports until the late 1990s—since 2000, and increasingly over the last decade, Viet Nam has managed to diversify its exports by integrating with multiple high-tech global value chains (GVCs), especially in ICT and the garment sector. In addition, the country has been successful in attracting FDIs, culminating with Intel’s opening in 2010 of its biggest chip-making plant outside the United States. That same year, Viet Nam transitioned from a low-income to a lower-middle-income country.

Since the establishment of Doi Moi in 1986, the Vietnamese government has played a key role in restructuring its legal and regulatory system, managing its accession to the World Trade Organization (WTO) in 2007 and its strategic engagement with foreign investors, and managing the role of state-owned enterprises (SOEs) and their relationships with the indigenous private sector (Ohno, 2013; Gray, 2018). In particular, the government has developed a differentiated system of incentives and compulsions for FDIs, SOEs and private indigenous businesses. It also managed to implement industrial policies in a highly decentralized manner, thus experimenting in ways to better achieve coordination and policy coherence. For instance, a system of decentralized fiscal and non-fiscal incentives was introduced as part of an ambitious process of overall fiscal decentralization begun after Doi Moi. From 1992 to 2002, subnational government shares of total expenditures nearly doubled, from 26 per cent to 48 per cent, with the national government focusing mostly on large and country-level investments. Provincial and local governments were also given the freedom to establish off-budget financing mechanisms for capital projects, and to tailor fiscal and non-fiscal policies, including land allocation, to attract FDIs. These off-budget sources of finance were investment institutions such as the Social Security Fund, the Enterprise Restructuring Fund and the Export Support Fund which were kept out of official budget records (Gray, 2018).

This process of fiscal decentralization was not only beneficial in targeting industrial policies; it also involved several actors in the budgeting process, with the Ministry of Finance controlling the Current Budget, the Ministry of Planning and Investment managing the Capital Budget and lower levels focusing on the Public Investment Programme. Budgeting structures are critical in the governance of industrial policy as they provide an institutionalized process through which different groups exercise their influence and potential coalitions of productive interests consolidate. In this respect, the distribution of power in Viet Nam within the local levels of the ruling coalition played a very important role. Further, it also helped to build state fiscal capacity. Fiscal decentralization went hand in hand with an increase in on-budget revenues and

expenditures. Some of these revenues were invested in the healthcare system, with public health expenditures per capita increasing an average of 9.0 percent per year between 2000 and 2016.⁴

The co-development of the private and public sector in Viet Nam over several decades was made possible by the government's continuous experimentation with and learning from alternative solutions. This learning and accumulation of capabilities is what is behind 20 years of successful responses to pandemics in Viet Nam. Indeed, pandemics have been a major learning ground for the Vietnamese government in terms of embedding learning lessons within institutions. More recently, the country's rapid industrialization has also opened the way for more innovation-driven collaborations, such as those that were instrumental in the co-development of COVID-19 testing kits.

3.2 Brazil: Leveraging health institutions for vaccine manufacturing

The COVID-19 pandemic reached Latin America later than other continents. However, its evolution there has been increasingly dramatic, with a rapid acceleration in the first months of 2021, especially in Brazil, the region's largest and most heterogeneous country. The first case recorded in Brazil was on 25 February 2020. Over the first six months after WHO officially declared the COVID-19 pandemic on 11 March, Brazil recorded more than 5 million cases and more than 150,000 deaths. During this period large cities such as São Paulo and Rio de Janeiro became the main hotspots. The pandemic spread especially among the most disadvantaged groups—more than 13 million people living in favelas where physical distancing and hygiene recommendations were nearly impossible to follow (Linder, 2020). The impact of the crisis on the most socially disadvantaged groups was already evident in September 2020. By then, 107 million people in Brazil had applied for emergency aid from the federal government and more than 65 million had received the benefit.

Early concerns that the pandemic would move inland into smaller cities and among indigenous communities with inadequate provisions of intensive care beds and ventilators were soon confirmed. Across the country, in all states and Federal Districts, the number of cases and deaths per 100,000 inhabitants (incidence and mortality rates) followed a very heterogeneous pattern. This reflects a combination of factors, such as socioeconomic development level, robustness of public institutions in terms of disease diagnosis conditions (including tests) and assistance to

⁴ These investments have paid off with rapidly improving health indicators. Between 1990 and 2015, life expectancy rose from 71 years to 75 years, infant mortality fell from 36.9 deaths per 1,000 live births in 1990 to 16.5 deaths in 2018.5, and maternal mortality ratio plummeted from 139 deaths per 100,000 live births to 54 deaths. The 2018 immunization rate for measles in children ages 12 to 23 months is over 97 percent.

symptomatic patients, as well as the overall capabilities to prevent and control virus transmission and disease through a set of non-pharmacological measures. During the first phase of the pandemic, capacity for treating critically-ill COVID-19 patients revealed stark inequalities across regions and revealed structural weaknesses. First, the difference between the amount of available ICU beds to support the 75 per cent of Brazilian citizens dependent on the Unified Health System (Sistema Único de Saúde, SUS) and the 25 per cent with private insurance plans was striking. Second, challenges in coordinating the response, mitigating inequalities and optimizing processes for purchasing necessary PPEs and supplies led several states and municipalities to implement their own solutions that often competed for resources. Third, mistakes were made in investing heavily in temporary structures rather than the SUS' durable permanent structures.

In the second half of the pandemic, beginning in November 2020 the number of cases and deaths increased steadily in Brazil, reaching a peak number of deaths in April 2021. By May 2021, cumulative cases reached over 15 million and deaths over 400, 000, making Brazil one of the hardest-hit countries in the world. Despite this bleak scenario, which has dominated reporting on the country, Brazil has also shown some key pockets of resilience—in terms of both robustness to shock and readiness of its health-industrial system. The response of Fiocruz (Oswaldo Cruz Foundation), one of its most prominent healthcare institutions, is an important case study in this respect, as it highlights the importance of healthcare institutions accumulating capabilities to increase overall structural resilience to crises.

For 120 years, Fiocruz has integrated biomedical and pharmacological science research, alongside health technological innovation; drug production; health surveillance; and healthcare provision, education, information and communication. Throughout its history Fiocruz has developed a successful track record in healthcare research, vaccination and drug manufacturing, both nationally and internationally—including, for example, world-leading and ground-breaking research on Zika. Fiocruz's mission is to “produce, disseminate and share knowledge and technologies aimed at the strengthening and consolidation of the Unified Health System (SUS) and contribute to the promotion of health and quality of life of the population.” This translates into a concrete vision: “to be a public and strategic institution of health recognized by Brazilian society and other countries for its ability to *place science, technology, innovation, education and technological production of services and strategic inputs for the promotion of population health, reducing inequalities and social inequalities, the consolidation and strengthening of the Unified Health System (SUS), the formulation and improvement of public health policies*” (Italics added).⁵ Based in Rio de Janeiro, Fiocruz pursues its mission and vision through a network of

⁵ For more about Fiocruz, see: <https://portal.fiocruz.br/en/institutional-profile>.

research and production units spread across 10 states in the Northeast, North, South-East and Southern regions of Brazil (as well as from an office in Mozambique where its work in Africa is coordinated). Altogether, the organization has 16 scientific and technical units focused on teaching, research, innovation, assistance and technological development and extension in healthcare. Four technical and administrative units are dedicated to the physical management of the foundation, its trade operations and economic and financial management.

Throughout the pandemic Fiocruz has leveraged its wide range of capabilities and institutes to provide an integrated response to the pandemic. By February 2020, the Laboratory of Respiratory Viruses and Measles of the Oswaldo Cruz Institute (IOC/Fiocruz) began promoting training courses on diagnostic methods for laboratories in Brazil and throughout Latin America. WHO made this laboratory the flagship lab for COVID-19 in the Americas, and involved Fiocruz in the Global Research and Innovation Forum, which pushed forward several studies on the virus' genetic characteristics and effects (Fiocruz, 2020a). Leveraging its capabilities in diagnostics, in March 2020, the Immunobiological Technology Institute (Bio-Manguinhos/Fiocruz) began diagnostic test production, while a number of partnerships –such as the CoVida network—were established throughout the country to promote monitoring of and information about the crisis. The Institute of Scientific and Technological Communication and Information in Health (Icict/Fiocruz) played an important coordinating role in this respect and within the COVID-19 Observatory initiative, as well as in validating communication materials about the virus (for example, information campaign “Se liga no corona!” - “Watch out for the Corona!”). Moreover, as part of the Evandro Chagas National Institute of Infectious Diseases (INI/ Fiocruz), Fiocruz built a dedicated Hospital Center for COVID-19 focused on the treatment of severe cases. Through INI and the new centre, Fiocruz was able to coordinate the implementation of the WHO Solidarity clinical trial, aimed at studying repurposed drugs for the disease. The Hospital Center received its first patients in May 2020.

Beginning June 2020, Fiocruz also became an anchor institution in Latin America in the race towards the development, including clinical trials, of a vaccine. At the end of June 2020, the Ministry of Health announced an agreement with biopharmaceutical company AstraZeneca for the production, by Bio-Manguinhos, of the vaccine that was being developed by the University of Oxford. At that stage the Oxford-AstraZeneca vaccine still presented elements of technological risks, as the clinical trials were not yet completed. Through this technology transfer agreement from AstraZeneca to Fiocruz, Fiocruz became even more central to Brazil's pandemic response, in terms of producing and distributing a safe vaccine through the SUS, as well as in starting innovative experiments towards developing a domestic vaccine. The Technological Order

Agreement signed by Fiocruz was disclosed on 26 October. As reported by the Vice-President for Production and Innovation in Health of Fiocruz “the agreement with AstraZeneca guarantees not only access to an expressive volume of one of the most promising vaccines undergoing phase 3 of the clinical trial; it also ensures full transference of technology to Bio-Manguinhos/Fiocruz. The agreement also guarantees the inexistence of profit margin obtainment for AstraZeneca or for Fiocruz until July 1st, 2021. [...] At the price of US\$ 3.16 per dose, this is considered one of the cheapest ones, when compared to other ongoing negotiations in the world. This value, including the transference of technology that will result in national autonomy starting in 2021, is the direct result of a differentiated action made possible by the existing production and technological capacity” (Fiocruz, 2020b).

The agreement was signed to help Fiocruz sustain a phase of technology absorption until July 2021 which would enable the company to address national needs of vaccines, their production at scale and potential future export. The agreement was initially limited to 100.4 million doses scheduled to be delivered to the Ministry of Health and the SUS, but an additional 100 million doses were planned for the second half of 2021 after final incorporation of the technology. Fiocruz was able to enter this critical partnership with AstraZeneca thanks to its previous investments in capabilities and infrastructure development. In particular, Bio-Manguinhos—the Fiocruz unit responsible for manufacturing the immunizer and supplying vaccines, biodrugs, pharmaceutical drugs and diagnostic kits—was an essential infrastructure to absorb vaccine technology and ramp up vaccine manufacturing.

In December 2020, Bio-Manguinhos switched gear by signing a land deed with the Government of the State of Rio de Janeiro to build the largest vaccine manufacturing facility in all of Latin America. Based in the Industrial District of Santa Cruz, the Industrial Complex of Biotechnology in Health (Cibs) was launched to strengthening the National Immunization Program (PNI) and increase overall pandemic resilience in the country. Thanks to this investment, Fiocruz will be able to increase up to four times the production capacity of vaccines and biopharmaceuticals to meet primarily the demands of the SUS, through the National Immunization Program (PNI) and the Specialized Component of Pharmaceutical Assistance (Ceaf). The investment is of approximately BRL3.4 billion (\$660 million) and provides for the creation of 5,000 direct construction jobs and 1,500 jobs to operate the facility (Pereira, 2020). The final deed of the land (totalling 580,000m²) transfers the property from Codin to Fiocruz and guarantees security for raising private capital, in the BTS (built to suit) financing model, a modality that will be used to finalize the construction of the project. Under this model, financing will be private, paid in the form of the lease with reversion over the 15-year term. The complex will include an integrated

manufacturing facility for vaccine formulation, filling, freeze-drying and review; packaging activities; storage of raw material; finished product storage; quality control and guarantee; utilities in general; waste and effluent treatment plants; and administration. It will also integrate cutting-edge Advanced Aseptic Processing (AAP) technologies, which will make it easier to obtain certifications from regulatory agencies and international bodies. High-level automation will increase operational safety at a lower cost without compromising quality of final processing steps. Production capacity is estimated at 120 million vials of vaccines and biopharmaceuticals per year and may be expanded by relying on flexible and adaptable platforms. For example, it would enable production of new vaccines such as the bivalent vaccine (used to treat measles and rubella), clinical studies of which were recently concluded by Bio-Manguinhos; meningococcal C, which is in an advanced stage of study phases II/III; and new vaccines from Fiocruz portfolios. Table 5 summarizes Brazil's readiness to change capabilities that were evident during the COVID-19 pandemic.

Table 5: Brazil's readiness to change capabilities

Resilience capability	Industry readiness <i>adapt to, transform and recover</i>	
Government readiness <i>adapt to, transform and recover</i>	<ul style="list-style-type: none"> ✓ Public basic science and technology research institutions ✓ Public technology intermediate institutions for scaling up ✓ Public procurement for bio-med-pharma innovation and market creation ✓ Public authority/agency for certification of medical devices and pharmaceuticals ✓ Multi-level government institutions for experimentation and coordination 	<ul style="list-style-type: none"> ✓ Productive, technological and innovation capabilities in strategic sectors for medical device and other equipment ✓ Productive, technological and innovation capabilities in strategic sectors for pharmaceuticals ✓ Supply-chain ecosystem capabilities for strategic sectors and inputs

Source: Author elaboration.

In January 2021, the Brazilian Health Regulatory Agency (Anvisa) authorized two vaccines for emergency use: the Oxford-AstraZeneca produced by Fiocruz and the Coronavac of the Butantan Institute. On 29 January, Fiocruz submitted an application to register the Oxford-AstraZeneca vaccine, concluding the journey begun in June 2020 when the agreement was signed. After just six months from the Technology Order Agreement, Fiocruz had already started production of a COVID-19 vaccine. Production capacity was expanded in March 2021 with the introduction of a second production line to reach around 1 million doses per day (the first line in operation has a capacity of 300,000 doses per day) (Lang, 2020). Thus, technology absorption has developed alongside an expansion of production capacity, as well as innovative research into vaccine platform technologies and new immunizers against COVID-19. By April 2021, Fiocruz was involved in developing six additional vaccines with various national and foreign partners (Valverde, 2021). Bio-Manguinhos has two internal vaccine projects based on 100 per cent national technology: one relying on synthetic peptides based on the S protein sequence and another using a recombinant protein. Bio-Manguinhos has also developed two partnerships for new vaccine development platforms: one involving a company from Oxford University focusing on cellular response and another with the University of Washington in Seattle, the American company HDT and Senai Cimatec from Bahia focusing on new-generation RNA vaccines. Other projects are the result of partnerships with Universidade Federal de Rio de Janeiro (UFRJ) and Universidade de Sao Paulo (USP) as well as with UFMG that has the support of the Ministry of Science and Technology.

3.3 South Africa: Indigenous and adaptive innovation for affordable medical devices

On the African continent, the first wave of the pandemic peaked in July 2020 and progressed more slowly than the rest of the world. However, Africa's second wave of the pandemic began in December 2020 and witnessed more cases, more aggressive variants of the virus, and a reported 30 per cent increase in both weekly incidence and mean daily new cases when comparing the peak of the first wave to epidemiological week 53. As of 31 December, 2020, African countries had reported 2,763,421 COVID-19 cases and 65,602 deaths—although these accounted for only 3.4 per cent of cases and 3.6 per cent of deaths reported globally. Nine of the 55 countries on the continent accounted for more than 82.6% of reported cases: South Africa (38.3 per cent), Morocco (15.9 per cent), Tunisia (5.1 per cent), Egypt (5.0 per cent), Ethiopia (4.5 per cent), Libya (3.6 per cent), Algeria (3.6 per cent), Kenya (3.5 per cent) and Nigeria (3.2 per cent). In addition, those 65,602 deaths mentioned above were reported from 54 (96 per cent) African Union Member States, with most (77 per cent) coming from just five countries: South Africa, Egypt, Morocco, Tunisia and Algeria (Salyer et al., 2021).

These results, however, were impacted by the availability of testing facilities and the capacity to sustain testing efforts over time. At the beginning of the global pandemic in February 2020, only three countries in the continent had COVID-19 diagnostic capacity. And although by July all countries had developed this capacity, many countries still struggled to maintain adequate testing volumes during peak outbreak periods. This partially explains why South Africa figures prominently. On 5 March 2020, the first COVID-19 patient was confirmed in South Africa, and the country entered into a strict national lockdown from 27 March, including the complete closure of childcare, primary and higher education institutions, and all public leisure activities; severe physical distancing rules; and an estimated 70 per cent reduction in shopping, 85 per cent of the on-site work force, and 90 per cent in other activities (Schroder et al. 2021). Such drastic lockdowns announced when South Africa had just 402 known infections and no deaths is considered an important factor in limiting the initial outbreak of the pandemic and delaying the transmission. During these first weeks, testing capacity was ramped up, with the introduction of mass community screening and testing. Community health workers (CHWs) were deployed for home visits throughout the country. By April 2020, 28,000 CHWs screened 900,000 people and referred 11,000 for testing. The National Health Laboratory reached a capacity of over 50,000 tests per day, using 67 mobile laboratories and 325 GeneXpert machines available at 166 facilities (Wadvalla, 2020).

At the outbreak, and throughout the two main waves of the pandemic, South Africa faced many of the challenges highlighted earlier in this paper that are common among low- and middle-income countries. While relative to other African countries South Africa has a smaller fraction of the work force at lower-income levels or in informal sectors, 13 per cent of the population lives in crowded informal settlements that have poor access to running water and sanitation. Moreover, the country's health situation is complicated by high risk of COVID-19 co-infections in patients with HIV/AIDS or forms of tuberculosis (TBC). According to WHO, in 2019, South Africa ranked 4th globally in the number of TBC infections per capita (around 320,000 people) and 3rd for those co-infected with TBC and HIV. As of 2018, 7.7 million people (13 per cent of the South African population) are infected with HIV; and 2.5 million of them were not being treated with antiretrovirals. These weaknesses make the management of a large-scale outbreak particularly challenging, as patients can rapidly deteriorate and already limited ICU beds become quickly unavailable. While South Africa has the most robust healthcare system on the continent, the system is highly unequal. Just 16 per cent of South Africa's 59 million people can afford medical insurance through access to the best healthcare in the private sector. The rest of the population relies on public health facilities. A proxy of the different equipment available in the public sector

in comparison to the private sector is the number of ICUs: 1,500 ICU beds in the public sector vs. at least 3,500 in the private sector.

Due to this scenario, during the first wave of the crisis, one of the South African government's main immediate priorities was to increase its capacity among the public sector. ICUs are very expensive, and partly because ventilators were not produced domestically and were scarce globally, they quickly became inaccessible and unaffordable. Similar to other countries, the South African government launched an initiative to mobilize domestic production and technological capabilities to address ventilator scarcity (see Section 2.2). However, unlike other advanced economies, South Africa needed ventilators and other therapeutic solutions that were affordable and appropriate for the country's healthcare system. For example, ventilators are not only complex technologies; they also require adequate supply of oxygen. These constraints, however, were turned rapidly into an opportunity to deploy domestic capabilities distributed across the ecosystem of private organizations and public institutions.

In April 2020 the Department of Trade, Industry and Competition (DTIC), with the support of the Department of Science and Innovation (DSI), established the National Ventilator Project (NVP) to develop ventilators for use on COVID-19 patients. The NVP called for proposals for a non-invasive (pre-intubation) ventilator to identify role players in the industry able to assist the DTIC to meet anticipated demand⁶. A team of experts from Denel, Armscor, Eskom, the state-owned Council for Scientific and Industrial Research (CSIR) and other entities was formed to investigate designs and produce a prototype of a locally produced medical ventilator. The South African Radio Astronomy Observatory (SARAO), which employs a number of engineers who are working on the Square Kilometer Array (SKA) project, was mandated to manage the national effort to design, develop and produce the respiratory ventilators because of the experience its engineers gained in the development of complex systems for the MeerKAT radio telescope system in the Karoo, which was the precursor to the SKA.

Based on advice from clinicians and experiences from other countries (see Andreoni and Hill, 2020), the project—'CSIR L.I.F.E.' (Lung Inspiratory Flow Enabler)—focused on the production of Continuous Positive Airway Pressure (CPAP) ventilators, which were identified as most appropriate to support COVID-19 patients⁷. The CSIR solution is a CPAP device that provides a

⁶ A non-invasive ventilator is usually a smaller medical device than a mechanical ventilator and with less sophistication. Specifically, mechanical ventilators are able to sense the breathing needs of an individual and give appropriate pressures to inflate the lungs, hence substituting normal breathing function of the patient

⁷ The CSIR started also working on a Bi-level Positive Airway Pressure ventilator with a local partner to develop a solution for patients with more severe symptoms. These units assist with both inhalation and

mild level of oxygenated air pressure to keep airways open and, thus, assist with breathing. The units are non-invasive and can be deployed and applied easily—even outside of hospitals. The system uses standard, hospital-grade oxygen supply and features easy-to-use, on-device flow gages to adjust Fraction of Inspired Oxygen in steps of 10 per cent oxygenation. (CSIR, 2020). By June 2020, the necessary R&D had been completed and the CPAP system was tested at UCT’s Medical Devices Laboratory, which houses specialized apparatuses to evaluate such products. This led to regulatory approval and licensing obtained from the SAHPRA.

The project attracted several public entities and companies based in South Africa, from automotive component manufacturers to specialist contractors. In some cases, companies had to mobilize their own supply chain or develop new ones to produce critical components. For example, Acacia Medical developed a new partnership with a local machine shop that makes vital “peep valves” which help control pressure in the device, allowing the patient to exhale.

Production began in late July 2020 and the final units were completed during the month of November 2020. Of the 20,000 units produced, 18,000 Venturi-type CPAP devices were manufactured through a contract with the CSIR and 2,000 blender-type CPAP devices were manufactured by SAVE-P. The CSIR ventilator systems were assembled and packaged by Akacia Medical in the Western Cape. Individual components for the CPAP ventilator were manufactured by a consortium of industry partners in Gauteng, KwaZulu-Natal and the Eastern Cape, including the Central University of Technology and firms such as Black Capital Systems, Andani Futuretech Manufacturing, UV Tooling, Sola Medical, Gabler Medical and Pitchline Engineering. All manufacturing was done for the CSIR. Siemens provided software support for the digital design and product lifecycle management, as well as rapid production scale-up. This included components for systems engineering processes, CAD tools and manufacturing execution tools, as well as quality management solutions. A digital product lifecycle design methodology also ensured that the product could be manufactured at multiple factories and in large volumes (Science Business, 2020).

The NVP was funded by the Solidarity Fund via three main grants for a total financial commitment of 260.7 million rand. The Solidarity Fund was established in March 2020 with a clear mandate: to support the national health response, contribute to humanitarian relief efforts and mobilize South Africans to drive a united response to the COVID-19. The fund’s health response is executed in collaboration with the National Department of Health (NDoH) and

exhalation, either in fixed pressure modes or by sensing the oxygen supply required by a patient and adjusting the pressure accordingly.

Business for South Africa (B4SA), with its established capability to procure PPE, including the validation of local suppliers and accessing of products from international markets.

On 24 August 2020, the Solidarity Fund handed over the first ventilator units to the Charlotte Maxeke Johannesburg Academic Hospital. By September, several hospitals across the country managed to receive much-needed ventilators to assist their COVID-19 patients.

While the case of South Africa highlights several context-specific vulnerabilities, the ventilator challenge initiative and its outcome point to the presence of latent capabilities that can be activated to give more robustness to shocks to the country in the face of pandemics. Table 6 summarizes these capabilities.

Table 6: South Africa’s robustness to shock capabilities

Resilience capability	Industry robustness <i>resist, absorb, accommodate</i>	
Government robustness <i>resist, absorb, accommodate</i>	<ul style="list-style-type: none"> ✓ Public procurement for medical devices and pharmaceuticals ✓ Public authority/agency for certification of medical devices and pharmaceuticals 	<ul style="list-style-type: none"> ✓ Productive capabilities in strategic sectors for medical device and other equipment ✓ Repurposing capabilities in strategic sectors and supply chain inputs ✓ Productive capabilities in other strategic sectors

Source: Author elaboration.

4. Industrial policy and public procurement for resilience: Opportunities and multiplier effects from industrial-health ecosystem development

Several of the country cases mentioned earlier in this paper—especially the studies of Viet Nam, Brazil and South Africa—have pointed out how resilience is a key *structural property* of entire industrial ecosystems, made up of public and private actors, and their technical, innovative and organizational capabilities, as well as the relationships among them. As an outcome of these complex, context-specific and continuously evolving interactions, as highlighted in Section 2 and Annex 1, resilience must be also understood as a *dynamic efficiency property*. Markets alone are not sufficiently equipped to deliver the inter-temporal investment coordination function that is

needed to build resilience across the economy and society. Industrial policy and planning that focuses on resilience has a major role to play.

However, paving the way to industrial policy and planning for resilience requires rethinking the role of the state in the economy. Moving away from an idea of the state as the “lender of last resort” and towards an idea of the state as “investor of first resort” is a critical step in building resilience in socioeconomic systems. Being an investor of first resort means creating and shaping the development of those sectors that are of strategic relevance in the context of extreme events. The health-industrial ecosystem, spanning from the chemical to the biopharma and medical device sectors, is critical for resilience, but it is also a key cluster of production activities that have potentially high multiplier effects. Multiplier effects are traditionally associated with employment dynamics triggered by some specific investments. However, as shown in the country case studies in Section 3, multiplier effects can also encompass technology spillovers and opportunities for indigenous innovations. The development of test kits in Viet Nam, pharmaceutical products in Brazil and medical ventilation devices in South Africa are prime examples.

Furthermore, disruptive changes in the length, location and governance structure of GVCs following the recent COVID-19 crisis give rise to not only additional structural transformation challenges, but also to new opportunities to pursue more inclusive and sustainable pathways of development and catch-up. In particular, reduced opportunities for export- and FDI-led industrialization due to reshoring of production and new trade regimes suggest the importance of imagining alternative industrialization models whereby countries can diversify their production base by leveraging existing domestic markets and creating new ones through forward and backward integration.

4.1 Medical device and equipment as a new industry multiplier

While opportunities for sectoral and cross-sectoral developments are country-specific, the pandemic has highlighted the strategic importance of the medical device sector—specifically the provision of essential devices and equipment to address a global pandemic. Based on the WHO’s Covid 19 Essential Supplies Forecasting Tool as of 9 April 2020, and with a focus on five African countries (South Africa, Ethiopia, Kenya, Senegal and Ghana), it was estimated that the short-term demand for essential medical equipment alone would be above \$3 billion (up to \$1.7 billion just in South Africa). These estimates have proven relatively conservative given the unfolding of the pandemic on the continent. The list of priority medical devices and equipment includes a wide range of medical devices, each of them presenting different levels of technological complexity. Building on the classification developed by Bamber and Gereffi (2013) we can distinguish four

major medical device product groups (See Annex 2 for a full description of products and product categories):

1) **Disposables**, which are the least complex products in the medical device industry, consist mostly of hospital supplies, such as bandages, surgical gloves, plastic syringes, masks and first-aid kits. They can also include plastic disposables for basic intravenous diagnostic and therapeutic use (such as tubes and micro-tubes for haemodialysis). These products are subject to fewer regulatory requirements than others due to the relative simplicity of their construction and the limited potential harm caused to the patient. In the United States these are Class 1 medical devices. While these products are relatively simple, the automated production technologies to manufacture them at scale, speed and reliability can be extremely complex (see, for example, the discussion on mask production ramp-up in Section 2.2). The primary backward-linked industries for the final product are the chemical, rubber and textile/garment sectors, while production technologies can come from the machine tool, electronics and automation sectors.

2) **Surgical and medical instruments** are medical devices used in various procedures ranging from cosmetic and endoscopic procedures to open-heart surgeries and organ transplants. Examples include forceps, scissors and dental drills. In the United States these are Class 1 medical devices. These devices often require sterilization equipment due to their frequent use on multiple patients and are made of advanced and specialized materials with specific properties and functionalities. The primary backward-linked industries are the chemical, rubber and metal and advanced materials sectors. The rise in surgical robots is transforming this device segment, making it more advanced and helping it to fuse with the more complex therapeutic and diagnostic segments.

3) **Therapeutics** are a broad category of devices that assist patients with various maladies. Some can be implanted directly into the body; examples include hearing aids, prosthetics and pacemakers (devices that regulate irregular heartbeats). Others such as ventilators and infusion pumps are non-implantable. This device category also includes intravenous diagnostic kits. In the United States therapeutics are considered Class 2 and 3 medical devices.

4) **Diagnostic equipment** helps in the diagnosis of various conditions ranging from fractured limbs to cancer. These devices include capital equipment such as computed tomography (CT) scanners and magnetic resonance imaging (MRI) devices, which can

cost hundreds of thousands of dollars. This category includes the most technologically sophisticated medical devices (Class 3). Innovation, technological and manufacturing scale-up of diagnostic equipment as critical product systems are comparable to the most complex manufacturing products such as airplanes. However, their supply chain can allow for relatively smaller suppliers and customized solutions.

Medical device and equipment production depends on a broad range of scientific fields, industries and technologies. The close relationship between these different fields of science, technology, innovation and production are well highlighted by Rosenberg (2009, pp. 234-35):

“medical innovations have depended heavily on breaking down barriers [...] some of the biggest breakthroughs for the Life Sciences have come from the realm of the Physical Sciences; [...] the introduction of diagnostic technologies that have drastically transformed numerous sectors of medical care; [...] Note also that the great achievements in medical research instrumentation have been powerfully complemented by the impacts of other innovations that have taken place well outside the medical world: information, computer and communication technologies that have, in turn, transformed the nature of research itself in the past quarter century. Instrumentation and techniques have moved from one scientific discipline to another in ways that have been full of consequences for the progress of science.”

The need for a broad range of capabilities makes medical devices and equipment challenging and at the same time highly appealing as an industry multiplier with several potential linkages and pull-and-push dynamics for local production system development (Andreoni, 2018). This is a truly cross-sectoral ecosystem comprising both medical device and bio-pharma industries, as well as several public institutions providing healthcare services including hospitals, laboratories and testing facilities. And the ecosystem is highly dynamic, benefitting from co-location, local customization and indigenous innovation. Furthermore, high-technology platforms underpinning this complex industrial ecosystem, opportunities for technological innovation and multiple technology linkages and spillover make it a potential driver for structural transformation. To a certain extent, medical devices and equipment can offer what automotive and electronics provided the late and late-late industrializing economies.

Traditionally, given their R&D intensity and high technology and safety standards, the medical device and equipment sectors have been dominated by a few countries and blocs (United States, European Union and Japan) and companies (Medtronic, GE Healthcare, Johnson & Johnson, Abbott, Philips, Siemens Healthiness, Fresenius, Roche and Baxter). Moreover, companies tend to operate surrounded by their suppliers, given the importance of retaining a close link between

research, development, living labs, hospitals and manufacturing. Examples of bio-medical clusters can be found in Massachusetts in the United States, Emilia Romagna in Italy, and the west of Ireland, thus in many of the most advanced manufacturing regions in the world. Not coincidentally, these are also the countries and companies that lead in areas like artificial organ bio-engineering, regenerative medicine, precision medicine, nano-biotechnology and e-health.

Lessons from developing and emerging countries that managed to enter in and develop these industries over the last few decades can support other countries as they build back better and healthier post-pandemic. Costa Rica is a case in point (UNIDO, 2020). Costa Rica has emerged as a global medical device centre of more than 70 specialist companies, including some leading multinationals such as Baxter and Medtronic. The country's medical device industry has expanded, diversified and upgraded substantially, from focusing on Class I medical devices such as disposables to Class III medical devices such as surgical instruments, therapeutic devices, infusion and drug delivery systems, implantables, and diagnostic equipment. These medical devices are used in the most critical fields, such as for the treatment of cardiovascular, neuro-endovascular and neuro-modulation conditions. In many of these areas, digitalization is the new technology platform—and to be competitive the digital capability threshold of firms must be high.

Costa Rica has managed to overcome this threshold and move from a low-tech manufacturing hub for multinationals to an R&D and advanced manufacturing ecosystem. Between 2007 and 2018, medical device exports tripled to become Costa Rica's largest export (valued at just under \$3 billion, almost 30 per cent of total export value). Although a small country, Costa Rica is the second-largest exporter in Latin America after Mexico. Industrial policy has played an important role in shaping this sector and Costa Rica's overall industrialization trajectory. Since the late 1980s, the government has targeted FDI and invested in the skills and infrastructure needed to upgrade along the value chain. Large medical equipment firm Baxter set up a plant in Costa Rica in 1987 and Intel selected Costa Rica, China and Malaysia as the three locations outside the United States to manufacture microprocessors. When it first began a policy of attracting FDI, the government realized that high-tech sectors must be targeted to increase value domestically and spur innovation. The government, along with the investment promotion agency (CINDE), planned to move away from electronics, given the volatility of the industry and the potential for low margins for assemblers. The medical device industry was targeted and building on the experience with Baxter and Intel, the government developed an incentive policy and combined this with targeted investments in the development of capabilities. Over the years, the government's continued emphasis on investing in technology upgrades has established the country as a research centre. Hence when Intel relocated its microprocessor plants to Asia, Intel's Global Services

Centre as well as the company's Engineering and Design Centre remained in Costa Rica. The country's medical device sector currently has around 30 research institutions and almost 7,000 specialized researchers.

Costa Rica's example could inspire further developments across regions where demand for medical device has steadily increased. According to the World Bank, between 2005 and 2012, Africa acquired 70,000 new hospital beds, 16,000 doctors and 60,000 nurses, bringing continental totals to 1,050,000 beds, 498,370 doctors and 1,250,000 nurses. New demand for medical devices and equipment, combined with the need for developing a domestic base for pharmaceuticals, is creating a unique opportunity for Africa to leverage pockets of industrial capabilities and develop new ones along different backward (pull) and forward value chains (push). The recent development of regional authorities such as the African Medicines Agencies also offers an opportunity for regional value chain development. As in the case of Costa Rica, however, public procurement in addition to supply-side industrial policy is needed to foster the development of a local production system around medical devices and equipment.

4.2 Pharmaceutical and vaccine manufacturing: models, challenges and opportunities

The COVID-19 pandemic has revealed the vulnerabilities that all countries—but especially developing countries—face in accessing vaccines and other pharmaceutical products affordably and at scale. The pharmaceutical industry accounts for turnovers on the order of hundreds of billions globally. In 2018, total spending in pharmaceutical products accounted for 8.5 per cent of the GDP in Europe, 16.9 per cent in the United States and 10.9 per cent in Japan. North America alone accounts for half of the world pharmaceutical market, while developing and emerging economies in Asia, Africa and Latin America account for less than 25 per cent of the global market (EPFIA, 2020).

While the industry is global, it is dominated by only a few major players. For example, the vaccine market before the pandemic accounted for around €30 billion. Four multinational companies (GSK, Pfizer, Merck and Sanofi) account for 80 per cent to 90 per cent of the global supply of vaccines. They control this market either directly or indirectly via orchestrating complex supply chains and production establishments via licencing and contract development and manufacturing organizations (CDMOs). Smaller companies do exist and tend to spin off from universities and other public research facilities. However, given the huge costs associated with clinical trials (especially Phase III) and drug manufacturing, smaller firms' product pipelines tend to be absorbed within larger global players via acquisition or several forms of licencing.

Vaccine development is typically very time- and capital-intensive and involves several risks. The average time to bring a candidate vaccine to market is more than 10 years. Capital investments for manufacturing vaccines are on the order of \$70 to \$500 million and involve a commitment to resources in highly specialized assets such as stainless-steel bioreactors. Therefore, vaccines are normally delayed until completion of Phase III trials—once there is evidence that the vaccine is effective. A company wishing to take a vaccine from the lab to the market can expect a success rate of around 6 per cent.

Even when a trial has been successful and the vaccine formulation optimized, manufacturing readiness for production at scale must be built at the plant and supply-chain levels. Vaccines contain several components, including active and added ingredients, and their volumes must match production at scale. Operating with large-scale volumes of ingredients affects the behaviour of the microorganisms used to produce active components of the vaccine, the biochemical and physiological interactions between components, and, ultimately, the amount of vaccine produced. Throughout this process several tests are needed to make sure that the final product is as effective as the one developed through lab-scale experiments. Not only are these processes and steps complex, some of them are also highly specific to the vaccine platform used.

Given these features, it is not surprising that COVID-19 vaccine manufacturing has been largely concentrated in advanced economies, except for a few countries, such as India, with highly developed pharmaceutical industries. Messenger RNA technologies underpinning the Biontech/Pfizer vaccines are more innovative and demanding from a technological and manufacturing perspectives, hence they are less widespread than vaccines based on viral vector platforms (e.g. Oxford-AstraZeneca). On the other hand, they are more flexible, especially with respect to addressing variants of the COVID-19 virus. It is striking to note from the figure the extent to which the Africa lacks manufacturing capabilities. This exposes African countries to extreme vulnerabilities and, potentially, a very slow vaccination process.

Section 3.2 discussed Brazil's experience developing and scaling up vaccine manufacturing. However, the Brazilian case was made possible because of the country's rich health-industrial ecosystem, which is uncommon among developing and emerging economies. Large, centralized, bespoke facilities have been the manufacturing model more often used in vaccine manufacturing, as it was in the case of Brazil. At the cost of flexibility, this model allows countries to benefit from economies of scale; yet, it also requires robust supply chains for ingredients such as enzymes and lipids, as well as distribution "cold chains" to work. This model has been developed with conditions in advanced economies in mind.

Smaller and less developed countries than Brazil have experimented with more flexible models which might better fit context specificities and allow these countries to overcome some of the complexities associated with vaccine manufacturing highlighted earlier. One of these emerging models is inspired by “ultra-scale down” approaches (VaxHub, 2020). These approaches reduce materials and overheads costs, while enabling scientists to optimize manufacturing processes and adapt them to different contexts. For these same reasons, the “ultra-scale down” approach is very useful for application during disease outbreaks, where saving time is essential.

Other scholars have advanced other models leveraging modularity in processes and technologies and the opportunity of “scaling-up by copying exactly.” For example, Portable Miniature Modular Continuous production is a manufacturing approach widely used by pharmaceutical firms, including Pfizer, to scale up production within establishments. In a sector with similar scale barriers and complex processing, the “copy exactly” approach has also been in, for example chip manufacturing by companies like Intel. The reproducibility of the ingredients for vaccines is another factor in moving towards more distributed vaccine manufacturing capabilities and scale-up. Vaccines built on the mRNA technology platform rely on a synthetic molecule made in cell-free systems and based on a linearized DNA template that is “made to order”. Finally, there are other opportunities for expanding production by pivoting bulk vaccine production that does not involve large retooling.

Encouraging signs that these approaches have been explored and are viable come from Africa. BionTech has estimated that transferring mRNA in Senegal and South Africa could take five years. The adoption of alternative manufacturing models could, however, reduce this duration and increase regional readiness to future pandemics. However, as in the case of Brazil (as discussed in Section 3.2), the development of pharmaceutical industry capability needs government intervention via industrial policy.

4.3 Public procurement: an underused industrial policy for resilience

Governments tend to focus their attention on supply-side industrial policy interventions such as tax credits and subsidies, even when the additionality of these measures and the extent to which these types of incentives are sufficient to drive change remain unclear. Demand-side measures—especially procurement policies—can play a central role in building the health-industrial ecosystem and, in doing so, enhance broader country resilience. This is especially the case given the important role that government institutions play in health service provision and health system management, especially medical and pharma supply procurement.

Governments can engage this public procurement function in either a passive way—simply as a buyer interested in cost-benefit static considerations—or in a strategically active way. As for the latter, the government can use public procurement to set a clear direction by creating demand and shaping industry development, make the initial high-risk bold investments that crowd-in private actors later on, and reward those that are willing to invest and innovate in product and service delivery. The fact that the medical device and pharmaceutical sectors present several opportunities for industrial innovation and potential multiplier effects—as outlined earlier—reinforces the rationale for an industrial policy for the health-industrial ecosystem in developing countries.

Public procurement can be used to perform different functions. First, public procurement can create or increase the demand for products—goods and services—as well as emerging technologies. This is particularly important in areas where markets tend to under-invest or scale economies, or where infrastructural investments must be overcome to make the use of certain technologies viable. Second, if markets do not exist, public procurement can be used to artificially create demand and the conditions for competitive processes whereby new firms emerge, and old ones are encouraged to diversify into new technology areas and markets (in some cases shifting away from their old core business). This was highlighted in the case of South Africa’s ventilator development (see Section 3.3).

Third, public procurement can set the standards and regulatory requirements (in, for example efficacy, performance targets and affordability) under which the products and technologies are both produced and deployed. Standard-setting is of central importance, not simply because it can be used to shape the emerging markets and industry. It is also critical for coordination across innovation and technology investments, shifting competition away from areas where industry coordination delivers relatively better payoffs. The development of a major pharma facility in Brazil highlights this point, including the possibility of coordinating both supply-side and demand-side industrial policy.

Fourth, public procurement can be used to promote the development of a portfolio of competing products, experiment with them at different levels and in different places, and scale up those that best fit different energy systems and country contexts. The development of competing solution is a key learning and experimentation strategy. It also reduces risks associated with mono-solutions and allows to crowd-in multiple stakeholders beyond incumbents. This dynamic was highlighted in the case of Viet Nam’s testing kit development (see Section 3.1).

Public procurement can be designed based on different approaches, some more traditionally anchored around products (*product procurement*) and others organized more experimentally around problems and solutions (*functional procurement*, Edquist and Zabala-Iturriagoitia, 2020). In more traditional product procurement, the government sets the terms of the solution to a problem *ex ante* and implicitly, and looks for firms that can deliver the best identified product for a certain need. As for functional procurement—which has already codified in several national and supranational legislations such as in the EU—the government sets a process through which social (including health) and environmental needs are identified. The way in which these needs are addressed is left open; competing solutions to the problem are elicited and those responding functionally to the expressed needs are rewarded.

Despite its potential, in many developing countries public procurement has not delivered such envisioned outcomes. In these contexts, it is challenged by coordination and governance issues. Fragmentation in procurement among different government departments and public-sector institutions creates inconsistencies and reduces government capacity to provide directionality to the sector. Given the large scale of resources involved in procurement of drugs and medical devices, risks in resource misallocation and rent capture are also significant. Across developing countries, various procurement models have been introduced to counterbalance these risks. However, more experimentation and design innovation would be needed if public procurement were to be used as a strategically active industrial policy for resilience.

5. Conclusions

In this paper, we developed a Resilience Capability Framework focusing on the specific ways in which industrial capabilities contribute to countries' overall economic resilience, and how governments (and their capabilities) are central for leveraging, coordinating and deploying industrial capabilities to respond effectively and innovatively to a systemic crisis like a global pandemic.

We presented three in-depth investigations of three countries' experiences during the COVID-19 pandemic. Building on the framework, and focusing on specific dimensions of resilience and different stages of the crisis, we analysed each countries' overall performance and pathway out of the crisis, in an effort to provide lessons for other countries. Specifically, we looked at the unique process of co-development of industrial and government-institutional capabilities in the case of Viet Nam. We then focused on the Brazil to assess the role that intermediate institutions can play in integrating the entire innovation value chain for pharmaceutical products and how this could be an important area for public-private strategic engagement. Finally, we turned to South

Africa to show how technological capabilities can be redeployed to develop medical devices, and how past experiences in managing the HIV crisis are important but not sufficient if investments in state capacity remain limited.

Industrial strategies, which are seeing a revival around the world since the pandemic, should be directing economies towards solving grand challenges and missions like those aimed at developing resilient health industrial ecosystems. Policies targeting large societal challenges require confronting the direction of growth—growth that is, for example, more inclusive and sustainable. But this is very challenging within the traditional framework that sees policy as simply fixing market failures and, at best, as facilitating or enabling value creation. Challenge-led growth requires a new toolkit, one based more on market shaping and market co-creating.

The government is the only actor able to steer such large-scale recovery and industrial policy plans and has an advantage in committing resources in uncertain times. However, governments have a responsibility to assure that this unprecedented effort has a renewed public purpose. While all these policy instruments are welcome, their impact on the recovery from the pandemic depends on the extent to which they seize emerging opportunities and are aligned and coordinated in a systemic way with clear directionality. Policy targeting, alignment, coordination and directionality are key to achieving maximum additionality and exploiting the full spectrum of functions that existing industrial policy instruments and institutions can deploy.

We focused our attention on two industry areas—medical devices and equipment, and pharmaceuticals. In the face of the COVID-19 pandemic and current shifts in global value chains and technologies, these two industries provide opportunities for industrial development (such as industry multipliers) and increasing resilience (as, for example, a domestic base for industrial-health ecosystems). In relation to the development of these two sectors, public procurement is a key and often underused industrial policy instrument.

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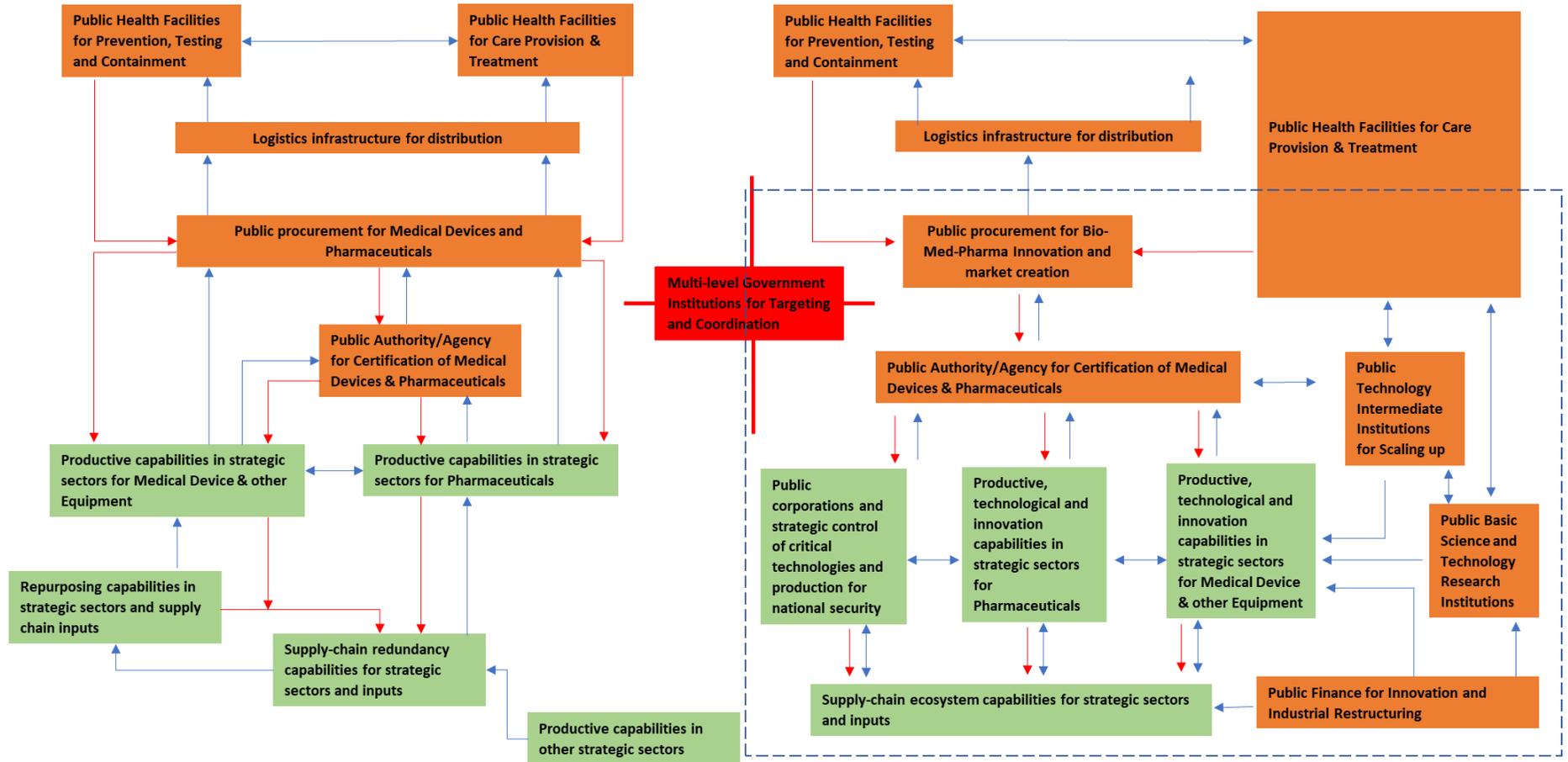
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Annex 1: Resilience-integrated framework theory of change

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Source: Author elaboration.

Annex 2: Medical devices by HTS description and product category

HS	Product Description	Category
9019	Mech-Ther, Massage, Psych Test, Ozone App Etc, Pts	Therapeutic
901890	Instr & Appl F Medical Surgical Dental Vet, Nesoi	Surgical Instruments
3005	Bandages Etc Coated Etc Or In Retail Medic Etc Fm	Disposables
901839	Med Needles. Nesoi, Catherers Etc And Parts Etc	Disposables
300630	Opacifying Preparations For X-Ray Examinations Etc	Diagnostic
901831	Syringes, With Or Without Needles; Pts & Access Surgical	Instruments
901812	Ultrasonic Scanning Apparatus	Diagnostic
8713	Carriages For Disabled Persons, Motorized Or Not	Other
901819	Electro-Diagnostic Apparatus Nesoi, And Parts Etc.	Diagnostic
901813	Magnetic Resonance Imaging Apparatus	Diagnostic
902212	Computed Tomography Apparatus	Diagnostic
902110	Orthopedic Or Fractre Appliances, Parts & Accessor	Therapeutic
902140	Hearing Aids	Therapeutic
401519	Gloves, Except Surgical Etc, Vulcan Rubber, Nesoi	Disposables
871420	Parts & Accsories Of Carriages For Disables Persons	Parts
401511	Surgical & Med Glove, Vulcanize Rubber	Disposables
902190	Oth Artificial Pts Of The Body & Pts & Accessories	Therapeutic
902121	Artificial Teeth And Parts And Accessories	Therapeutic
902214	Appts Base On X-Ray, Medical, Surgical, Vetnry, Nesoi	Diagnostic
901849	Inst & Appln For Dental Science, & Pts & Acc, Nesoi	Surgical Instruments
901832	Tubular Metal Needles & Needles For Sutures & Parts	Disposables
3822	Composite Diagnostic/Lab Reagents, Exc Pharmaceut	Intravenous Diagnostics
300650	First-Aid Boxes And Kits	Disposables
902131	Artificial Joints And Parts And Accessories Therof	Therapeutic
901850	Other Ophthalmic Instruments & Appliances & Parts	Surgical Instruments
841920	Medical, Surgical Or Laboratory Sterilizers	Surgical Instruments
900140	Spectacle Lenses Of Glass	Surgical Instruments
901811	Electrocardiographs, And Parts And Accessories	Diagnostic
902139	Artificial Joints & Parts & Accessories Therof, Nes	Therapeutic
902230	X-Ray Tubes	Diagnostic
901841	Dental Drill Engines And Parts And Accessories	Therapeutic
901814	Scintigraphic Apparatus	Diagnostic
902129	Dental Fittings And Parts And Accessories	Therapeutic
300640	Dental Cements And Other Dental Fillings Etc	Therapeutic
901820	Ultraviolet Or Infrared Ray Apparatus, & Pts & Acc	Diagnostic
3821	Prepared Culture Media For Development Of Microorganisms	Intravenous Diagnostics
300691	Appliances Identifiable For Ostomy Use	Therapeutic
900130	Contact Lenses	Therapeutic
611510	Graduated Compression Hosiery	Disposables
902221	Appts Base On Alpha, Beta, Etc Radiation, Medical, Etc	Diagnostic
902213	Appts Base On X-Ray For Dental, Uses, Nesoi	Parts
902150	Pacemakers For Stimulating Heart Muscles	Therapeutic

Source: UN Comtrade



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