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Institutional variety and sustainable industrial policy

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Institutional variety and sustainable industrial policy

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Abstract

Many industrializing economies have multiple institutions for learning, building technological capabilities, and for coordinating manufacturing and services. The governance of institutional variety, and the related design of industrial policy, underpins not only how we think of “development” in the industrial transformation process, but also defines the practical scope for the ability of countries to adapt, recover and prepare for shocks. COVID-19 has illustrated the disproportionate call to healthcare-focused technological capabilities, including pharmaceuticals, diagnostics, devices and vaccines. Industrial reorganization and technological advance require a framework of analysis and detailed industrial cases which are more relevant to diverse industrial development paths.

1 Introduction

Industrializing economies have multiple institutions for learning, building their technological capabilities, and for coordinating manufacturing and services. The governance of this *institutional variety* and the related design of industrial policy underpin not only how we think of “development” in the industrial transformation process, but also define the practical scope for countries to adapt, recover and prepare for shocks (see Srinivas 2012, 2020b, 2021a) for discussions and connections to prior economic development and industrial policy literature).

As the COVID-19 pandemic has shown, a wide set of strategies have defined national responses, and demonstrated attributes and commitments to narrow or wider technological learning. One particular commitment worth documenting includes the ability of governments to recognize and govern the co-existence of multiple knowledge systems that impinge on industrial structure. In some instances, such technological learning may be occurring in organizations but only outside the scope of formal policy identification and supports. In others, it may be outside the formal industrial systems of research and development (R&D) and manufacturing scale-up in micro-firms or in family-led or ‘informal’ apprenticed systems. And, finally, in yet others such learning may be occurring in parallel and isolated from more sustainable systems of full-cycle design and manufacturing.

The industrial governance and institutional design of such co-existing systems has both conceptual and practical implications for building technological capabilities in economic development. This background paper focuses on the practical side, with a lens into sustainable and inclusive manufacturing, using three qualitative case examples. Each case has been chosen to highlight different degrees of institutional variety and the context of cross-country and within country examples. In the discussion that follows the emphasis is on moving to long-term industrial development potential.

The structure of this paper is as follows: Section 2 discusses institutional variety (IV) and its theoretical implications for the practical domain of industrial development.

Section 3 addresses three industrial development cases. All are health-directed, but diverge in how they are framed and addressed by industrial policies: (1) Ayurveda, (2) Covid-19 diagnostic test production, and (3) oxygen production and delivery. These cases have important multi-industry and sub-sector challenges that may affect inclusion and sustainability concerns. They exemplify IV and underscore the challenge of industrial governance and the *Industrial Development Report* goals of inclusion and sustainability. The higher the IV, the more explicit

that policy and planning considerations matter within national (and sometimes sub-national) contexts.

Section 4, Conclusions, underscores why IV matters to how post-COVID-19 industrial development can be directed. It makes policy and planning recommendations for industrial governance to explicitly address variety. This section also discusses the implications of IV for industrial policy design, “big P” (policy as legislation and goal) versus “little p” policy, planning and public administration in industrial governance systems. Finally, the consequences for specific industrial policy instruments is discussed, as is the opportunity for UNIDO and the role of multilateralism itself.

1.1 Current context

The global impact of COVID-19, as of October 2021, is illustrated in Table 1, which lists pandemic deaths per 100,000 population for a variety of countries. Despite accepted errors in national counting, this is a broad comparative gauge of COVID-19’s health impact. There is little correlation by per capita income. On the contrary, the industrialized economies of North America and Europe have suffered heavily, raising questions of how we consider shock, effect, impact and adaptation. Deaths or hospitalization per capita will not end this contrast. However, factors such as job growth, technological advancement and industrial exports can provide additional measures for analysis.

Among countries sorted by deaths per 100,000 population, few African or Asian countries rank in the first 55. Almost all countries listed are located in North or South American regions and include much wealthier, industrialized, European countries. As the virus becomes better understood and more open debate emerges on case load, testing, death certificates, reporting and classification norms, other measures will be needed to assess “true” incidence or impact. The complete absence of China in the statistics and mystery surrounding the disease’s origins is of concern.

Table 1: COVID-19 deaths per 100K people, as of 11 October 2021 (Pettersson et al. 2021a)

Rank	Country	Deaths per 100K	Number of Covid-19 deaths reported
1	Peru	614	199,703
2	Bosnia–Herzegovina	332	10,965
3	North Macedonia	329	6,849
4	Montenegro	320	1,992
5	Bulgaria	313	21,813
6	Hungary	310	30,320
7	Gibraltar	288	97
8	Czech Republic	286	30,512
9	Brazil	285	601,213
10	San Marino	269	91
11	Moldova	265	7,048
12	Argentina	257	115,491
13	Colombia	252	126,655
14	Georgia	250	9,306
15	Slovakia	233	12,735
16	Paraguay	230	16,207
17	French Polynesia	225	629
18	Belgium	224	25,695
19	Slovenia	221	4,618
20	Mexico	221	282,227
21	United States	218	714,064
22	Italy	218	131,335
23	Croatia	216	8,778
24	Tunisia	214	25,039
25	United Kingdom	206	137,763
26	Romania	205	39,629
27	Poland	200	75,918
28	Chile	198	37,571
29	Guadeloupe	196	785
30	Lithuania	190	5,282
31	Armenia	190	5,618
32	Ecuador	189	32,848
33	Spain	184	86,827

Rank	Country	Deaths per 100K	Number of Covid-19 deaths reported
34	Portugal	176	18,048
35	Uruguay	175	6,064
36	Martinique	172	645
37	Panama	171	7,271
38	France	171	114,808
39	Sint Maarten	169	69
40	Andorra	169	130
41	Suriname	167	968
42	Kosovo	166	2,972
43	Grenada	163	183
44	Bolivia	163	18,803
45	Aruba	160	170
46	Liechtenstein	158	60
47	South Africa	151	88,346
48	Bahamas	151	590
49	Russia	149	214,476
50	Iran	148	122,868
51	Latvia	147	2,806
52	Sweden	145	14,905
53	Saint Martin	145	55
54	Ukraine	142	62,921
55	Greece	142	15,177

Source: Pettersson et al. (2021a), reporting country data compiled by Johns Hopkins University.

Note: Data comes from individual reporting countries and compiled by Johns Hopkins University Centre for Systems Science and Engineering.

Despite all these gaps however, the high deaths per population in wealthier countries in Europe, as well as in the United Kingdom and the United States, will still need to be understood in terms of their industrial capabilities and assumed health governance superiority in, for example, investments in healthcare, staff training, including health education, and types of facilities.

Similarly, while much has been said about industrialized (richer) countries hoarding vaccines, more needs to be studied about supplier countries (other than their per capita income), as well as about countries with large enough populations to boost procurement and bargaining in shaping their ability to move ahead.

As Table 2 shows, some smaller or wealthier countries have managed vaccine disbursement well. Cuba's capabilities in healthcare are well recognized. Yet, democracy and COVID-19 management raises questions for managing industrial transformation and job loss.

Table 2: Vaccination doses administered per 100 people, as of 2 July 2021¹

Location	Doses administered per 100 people	Days since first dose	Total doses
Gibraltar	237	275	79,927
United Arab Emirates	205	285	20,479,211
Cuba	202	155	22,875,849
Pitcairn Islands	200	147	94
Uruguay	184	225	6,404,740
Israel	178	297	15,647,667
Chile	174	292	33,398,155
Singapore	164	286	9,670,942
Malta	163	289	840,675
Cayman Islands	163	277	108,614
Qatar	163	293	4,767,210
Iceland	163	287	558,483
Portugal	158	289	16,042,424
Jersey	157	303	159,090
Faroe Islands	154	286	75,519
China	154	301	2,222,666,000
Bahrain	153	299	2,669,575
Guernsey	152	299	102,157
Isle of Man	152	281	129,494
Spain	152	289	70,822,813

Source: Pettersson et al. (2021b), reporting country data compiled by Johns Hopkins University.

¹ Data as of 2 July 2021, days after India overtook the United States in number of vaccine doses administered, and amidst a continued low vaccine rollout in high-income countries such as Australia, New Zealand and Canada.

However, those countries that have dominated vaccine administration at scale include countries that manufacture vaccines themselves or had sufficient industrial capacity—including personnel, trials and testing, procurement, cold chain, and vaccine logistics. China, India, Brazil, Turkey, Mexico and Indonesia, which dominate the per-capita industrial capacity to manage this scale of rollout—can move the discussion towards a need for a different framework other than per-capita purchasing capacity. If we catalogue doses versus days and geographic spread (such as the number of vaccine centres and personnel per vaccine centre), the list could change and India and China, both supplier countries with large community health infrastructure and major rural areas with poor coverage, could dominate vaccine administration capabilities. However, the lack of reliable, third-party scrutinized Chinese data remains. In its absence and with several large supplier countries still relevant, national industrial case studies prove useful.

The next section discusses institutional explanations that can improve upon the current comparative conceptual framework for industrial development in use during the COVID-19 pandemic. These explanations can help situate UNIDO's future strategy and narrow the list of policy instruments which may be helpful to a long-term sustainable plan.

Table 3: Total vaccine doses administered, as of 12 October 2021

Country	Total doses	Doses administered per 100 people	Days since first dose
China	2,222,666,000	154	301
India	954,908,095	69	269
United States	401,819,240	119	302
Brazil	249,340,259	117	268
Japan	175,700,765	139	237
Indonesia	157,929,575	57	272
Turkey	112,666,626	132	272
Germany	109,141,510	130	290
Mexico	107,381,477	82	292
France	96,292,913	143	289
Russia	94,671,192	65	311
United Kingdom	94,376,101	138	308
Pakistan	92,597,193	41	252
Italy	86,449,863	143	289
Spain	70,822,813	152	289
Republic of Korea	69,161,152	135	228
Thailand	59,539,624	85	226
Iran	57,676,540	68	245
Canada	57,071,632	150	302
Bangladesh	54,798,986	33	247

Source: Adapted from Pettersson et al. (2021b), reporting country data compiled by Johns Hopkins University.

2 Institutional variety: Theoretical basis and differences in microeconomic assumptions

2.1 Why institutional variety?

A society has many ways of doing things, and, historically, countries have evolved in different ways. Analysing industrial development for every country can provide us with an institutional and organizational structure in which specific technological capabilities are developed by firms or at other organizational sites. Institutional variety represents different norms, customs, regulations and guidelines, but also their different organizational strategies. Technological capabilities and the epistemic context of how new knowledge is sourced and converted to productive capabilities will consequently have different industrial development implications depending on how and where these capabilities are defined and developed.²

Industrialized economies—as they are currently understood—tend to have common technology sourcing and management features despite their distinct histories. These features may include patent offices, technical training institutes and formal apprenticing systems, investment and industry councils and capital-intensive supply chains, among others. This institutional and organizational structure’s rewards may be more or less globally linked, and in each country privilege certain types of investment and learning.

The COVID-19 pandemic has arguably demonstrated a shock to the existing industrialized structures caused by unexpected economic pressures: a drop in demand for most goods; trade curbs, from export bans to import restrictions; supply-chain bottlenecks (ranging across oxygen cylinders to toilet paper); unexpected need for new products and services (sanitizers, PPEs and telemedicine, for instance) and loss of old ones (restaurants, air travel). This shock-driven shift in industrial dynamics demands attention to why some countries and sub-national regions have been able to manage better during the pandemic, and which countries and regions may have different industrial priorities that need support.

² See Srinivas (2012; 2020a; 2020b).

2.2 How does institutional variety develop?

Institutional Variety is useful to demonstrate variety across different types of industrializing economies, but also variety within them. The development consequences of the co-existence of different norms and rules can offer important lessons for sustainable and inclusive manufacturing systems. Pressures on industrial growth and revenue have made a shift in investment in healthcare toward the more profitable segments. Industrial response during COVID-19 can be examined here using qualitative data to develop hypotheses about which institutional variety builds reliable technological capabilities that can transform into industrial resilience. With greater variety among industrializing economies, challenges emerge for planning and government administration of the variety of the ecosystem. At least in the first waves of the pandemic, several industrializing countries appear to have managed their constrained settings with greater agility than countries with more resources, despite lacking many of the attributes of formal institutions that are widely considered essential to “development.” Related process issues concern the pressures on “formal” institutions and organizations of industrial economies, such as larger industry associations, arbitration councils, labour unions and others that may have been too inflexible to respond quickly. This section focuses on the practical industrial phenomena on what types of adaptations were underway in the early waves of the pandemic. Implications and consequences for policy and planning are then discussed.

2.3 Novelty and COVID-19

Industrializing economies have multiple institutions for learning, building technological capabilities, and for coordinating manufacturing and services. The governance of institutional variety, and the related design of industrial policy, underpins not only how we think of “development” in the industrial transformation process, but also defines the practical scope of countries to adapt, recover and prepare for shocks. COVID-19 has illustrated the disproportionate call to healthcare-focused technological capabilities, including pharmaceuticals, diagnostics, devices and vaccines.

Countries and industries may face not only exogenous shocks, but also discover new or less documented ways of “doing business.” This institutional variety includes the norms, customs, rules, standards and laws through which an industrial system is able to manage the shocks and turbulence of change. Resilient systems emerge from a familiar yet pronounced ability to handle problems of lower scale. In normal times, a network of institutions and organizations in each country provides a relational framework for production decisions, which may include technical and market considerations of global harmonization, technology transfer or routine import considerations for firms. At both national and sub-national levels, especially in larger countries,

there may be differences across sub-national regions and cross-jurisdictional and cross-border regions. Similarly, firms must also deal with hyper-local challenges, from hurdles for electricity and water supply to local tax payments or public permissions for land acquisition or leasing.

Supply-chain considerations cut across levels (whether national, sub-nation, or local) and include the people available and their skills. If firms are to learn and adapt, theory proves limiting in describing a generic firm because the scales matter at which markets work or are regulated. For example, an equipment manufacturer uses local materials and sells to the domestic market. It will need different production standards and considerations from one that uses local materials but focuses on exports. In contrast, firms that hope to export may need to invest disproportionately to meet global harmonization standards whether for intellectual property, safety or quality. The institutional ecosystem for industrializing countries in particular has ambiguous relational boundaries and information barriers to local, regional or international markets, and effective actors and policies. This ambiguity is compounded by the fact that many industrializing economies have multiple, culturally embedded, institutions for learning, building technological capabilities, and for coordinating manufacturing and services. Micro and small firms may further face growth caps to receive subsidies or exemptions, creating disincentives for growth or making it more difficult to use innovative materials or skills.

2.4 Practical theory-policy design issues

Theoretically, therefore, institutional variety provides detail to a too-simple directional arc of industrial development, moving the debate from cross-national convergence indicators to more complex questions on the very nature of variety. The governance of institutional variety (see Srinivas 2020b, 2021a for definitions and discussions) and more effective industrial policy design underpins not only how we think of “development” in the industrial transformation process, but also defines the practical scope for the ability of countries to adapt, recover and prepare for shocks. In current thinking, especially from a neo-Schumpeterian perspective, firms are sites of searching and learning. A firm has people and other assets; and it must have some ability to convert its assets into proprietary or additional value-added classes of assets. Industrial firms—those with technological capabilities of interest—must also have assets that enhance learning within the firm in order to develop better products and services or to provide learning and new capabilities to their networks of partners and clients.

To do this, firms must be able to work within an uncertain environment and situate their products and services to advance the cause, strategically employing industrial policies to participate in markets of choice. Some firms—those in niche markets—may not know if they are textbook price-takers or price-setters since the market itself is evolving and multiple markets may potentially be a good match. Other firms that have not yet entered a market because of this uncertainty may choose to stay out or remain stunted. This “market menagerie” (Srinivas 2012) is potentially a problem for both firms and policymakers because the regulations required to manage the population of firms and advance their capabilities may require agility of policy design, programme administration, planning and foresight, or other public and private capabilities for coordination, that some theorists have argued are beyond most states.

The cases discussed in the following section have therefore broadly been selected through the filter of a qualitative heuristic that queries co-evolution of institutional domains and co-existence of knowledge systems (Srinivas 2012). Separate analyses have discussed the challenge of thinking of microeconomics and production sets or industrial policy as a selection device when an evolutionary perspective is applied (Srinivas 2021a and 2021b; Srinivas 2020a and 2021b).

3 Cases and industrial consequences

High institutional variety (IV) may render a clear learning trajectory risky and unclear. This has consequences for individuals, organizations and for the design of a reliable planning and public administration process as well as outcome-tracking policies. Where learning is risky, industrial policy must pay special attention to IV to keep costs low for generating new knowledge and optimizing existing learning. On the one hand, the more that variety exists, the greater the chance that innovation may thrive; on the other hand, certainty and reliability may falter. The relationships between the norms, customs, regulations and laws must be clarified when variety is high, when many things are changing at once, or when all paths are, in principle open. The question is: “which way is better?”

This section focuses on practical case examples of institutional variety and why IV matters, from the standpoint of “preparedness”, “response” and “recovery”, for the technological capabilities of countries and regions.

- Ayurveda (IV from cross-system knowledge and co-existing industries)
- COVID-19 diagnostic tests (cross-country IV)
- Oxygen production, conversion and delivery (cross-product, sub-sector IV)

These cases were selected to demonstrate different types of resilience and industrial potential.. With Ayurveda, resilience has been a problem with variable production sustainability within its specialized supply chain, and also source material sustainability. This pre-dates the pandemic, although it has induced some surge in consumer demand. However, the industry and Ayurveda practitioners and patients have suffered from considerable policy uncertainty—for example, the choice between allopathic or Ayurvedic or both.

Ayurveda is not unusual in these respects. Policy ambivalence and regulatory gaps regarding supply chain commitments are visible across conflicting industrial systems for healthcare. These have been especially pronounced during this pandemic. For example, the increase in diagnostic kits may be a commendable production spurt in response to the pandemic, but there are questions about long-term diversification within the diagnostics investment base, agility during and post-Covid business models, and how production and availability of test kits connect to medicine and vaccines usage (Fransen et al. 2021). Similarly, oxygen production and delivery represents cross-industry potential and displays varying degrees of IV within the supply chain and across countries. These three cases also refer to the critical importance of sub-national industrial policies whose last-mile governance and planning cannot be collapsed, especially in larger countries, into “national” industrial policies.

While all three cases are linked to the healthcare industry, as Table 4 indicates, each has features and opportunities that go beyond a single industry.

Table 4: Diversification benefits from the three cases

Case	Industry type	IV and other technology, engineering and industries involved (indicative list only)
Ayurveda	“Traditional”, “Alternative”	Food, packaging, agriculture, biodiversity, logistics, chemicals and pharmaceuticals, tourism, cosmetics, digital and other ‘wellness’
COVID-19 diagnostic kits	Biotechnology	Moulding and injection, reagents, microscopes, swabs, sanitizers, equipment and materials design and prototyping, clean room facilities, pathology and digital services, packaging and home delivery, dry specimen logistics, miniaturization and equipment design and prototyping, automation, visual displays and other electronics, algorithm platforms and software
Oxygen production and delivery	Industrial	Steel, construction, railways, trucking, small freight (autos, taxis), robotics, storage and warehousing, device design, tubing, repair and servicing

Source: Author’s elaboration.

Any country or region that can undertake advancements in these industries stands to benefit in other industries as well. This means administrators and other stakeholders must be able to reconcile the IV with sound arguments about the goals and processes for industrial deepening in any of these sectors.

The three cases involve aspects of sustainable manufacturing—some used more urgently during the COVID-19 pandemic, and some that have become urgent but are age-old systems of manufacturing, such as Ayurveda. All require sustainability, not simply in the use of resources and quality manufacturing. They require clear, responsive governing norms and rules which address essential elements of production such as standardization protocols and verification, procurement organization and decentralized audits, stocking, clean room-equivalents, and laboratory systems that produce reliable and certification-grade assembly operations. However, the cases differ in important ways that matter for future industrial sustainability. The scientific, epistemic base of knowledge and the industrial organization of firms is different, neither neatly oppositional nor monolithic; and in each instance, traditional industrial economic features such as competition, proprietary knowledge and standards-setting face different levels of difficulty, post-pandemic.

The three examples here are chosen based on the following industrial criteria:

1. Some are COVID-19 specific, others have pre COVID-19 significance.
2. Organizations described (including firms) are established in an environment of considerable institutional variety and associated ambiguity, including the policy ambiguity and the co-existence of multiple potential knowledge systems and markets.
3. Sectors are those in which attempts have been made to reach wide audiences, especially for low-income or vulnerable groups: improved access considerations, including resource supplies, pricing and affordability, or design customization for wide use.

3.1 Case 1: Ayurveda source materials and manufacturing³

Essential industries such as food, furniture, clothing, housing, transport, etc. have supply chains dependent on natural resources and fossil fuels that are intensively mined, nature-depleting, and have intra-industry effects on input and product markets that impinge on human and animal health. The pandemic has underscored these relationships. Simultaneous industrial challenges

³ Ayurveda refers to a complex and well-researched arena across several disciplines. Only a small subset of materials is referenced here for the sake of argument.

result: logging and loss of habitat, questions about wet meat and dairy as unsustainable and potential zoonoses generation, human and animal disease mitigation and treatment, climate changes and falling biodiversity. Pre-pandemic estimates indicate that sustainability concerns of manufacturing are growing. While many industrializing countries have seen gains in their manufacturing capabilities, they need to demonstrate a sustainable resource extraction, processing and employment model.

In this context, Ayurveda and other older health-knowledge systems have both current and future promise. Ayurveda as well as Traditional Chinese Medicine offer a global market beyond domestic consumption and an expanding policy goal to increase the number of users.⁴ In 2021, India's Ministry of AYUSH built expansion plans for global outreach (Chawla 2021; CII 2021; Madhavan and Gaudiliere 2020).⁵ The several "traditional" (non-allopathy) health fields overseen by the Ministry of AYUSH include Ayurveda, Unani, Siddha and Homeopathy. Each has diverse systems of knowledge—some such as Homeopathy are more contested than others, and Ayurveda is widely considered the largest and oldest indigenous system of medicine, with industry impact on food, cosmetics and tourism, and specialized areas such as perfumes, supplements, etc.

Ayurveda (Life + Science/Knowledge in Sanskrit/ Samskṛta) is an Indic/Indian/Hindu science of health treatment and prevention, within which herbal medicines may be used, driven by a science and philosophy of living and ecological embedding. It is made up of multiple traditions, some much more locally situated, and in contemporary times has adopted some features of standardized pharmacology. It is thus far from monolithic; it reflects several sub-traditions and norms for diagnosis and treatment combined with availability and application of formulations. Despite some commonalities, the practice of Ayurvedic medicine is complex and customized by geography with regard to, for example, plants and dietary differences, both in its application to patient care and also in the sourcing of products.⁶ Because climate change and biodiversity loss are closely linked and tied to human and animal health, any sustainable industrial system for Ayurveda will have to embrace such interlinkages and clarify how it enhances the human and animal health in a context where the climate change and biodiversity loss—driven by human choice, including use of

⁴ No strict comparison between the two is suggested but their demand and potential global use is worth further study.

⁵ See Chawla (2021): "The Ministry of AYUSH has signed Country to Country MoUs with 18 countries for cooperation in Traditional Medicine and Homeopathy, MoUs for collaborative research/academic collaboration, and MoUs for establishing AYUSH Academic Chairs in international universities to promote AYUSH systems around the world. Then there are the AYUSH Information Cells located in approximately 28 countries that disseminate information about AYUSH systems." CII (2021) puts the global market potential at \$9 billion by 2022. See also Harilal (2009).

⁶ Much of this discussion is derived from Upadhyaya (2011); Pant et al. (2021); Dejouhanet (2014).

animals—are transforming the planet.⁷ Precisely because of the need for such interlinkages, Ayurveda has been only narrowly addressed by policymakers. While Ayurveda has its own science, its requirement to adhere to a different epistemic system makes it less effective and undermines its own unique industrial structure and requirements of specialized institutions to govern its knowledge and material sources.

‘Ayurveda is the science of life aimed at promotion of health, prevention of diseases as well as the eradication of the diseases 1. All these three mottos can be achieved mainly through a dravya or drug which includes both food and medicine 2. The age old practice of Ayurveda has sustained on the basis of self-regulated quality standards and the controlled and well planned life style practices followed by our ancient cultures. But the uncontrolled and ill-planned lifestyle practices employed by contemporary societies and big vacuum created by the generation gap in the healing tradition has severely compromised the quality standards of the drugs and there by reduced the reliability in the safety and efficacy of the treatments explained in Ayurveda. This has posed as a major hurdle for Ayurveda to qualify the dual standards of repeatability and consistency to compete with western scientific paradigm.’
(Upadhyaya 2011, p.1.)

Healthcare manufacturing includes tablets, capsules, ointments and creams, especially those generic medicines for conditions and procedures where Ayurveda is well known to be effective, from blood purification to immunity, blood pressure to diabetes. Consumer good segments manufacture and market heavily “from Ayurveda” using the labelling loosely in the food and cosmetics domains where regulation is less stringent and profit margins more predictable. Both branded and unbranded segments exist for medicines, and at the higher value-added supplier end of manufacturing, some build their reputation for manufacturing by World Health Organization (WHO) and Good Manufacturing Process (GMP) certified facilities and Drugs Controller General of India (DCGI) approved drugs. Many claim 100% natural products, clean supply chains and wide networks of distributors. Certain families or houses well known for Ayurveda are from Kerala and other parts of the south of India as well as Uttarakhand, Uttar Pradesh and other states. In 2018, the Ayurveda market size (all segments) was estimated at \$4.4 billion, 75% of which in

⁷ See WHO (2003) and Dejouhanet (2014).

Ayurveda products and 25% in services. Pre-pandemic, the estimated 2025 size of the Indian market was \$13 billion.⁸

The importance of Traditional or Alternative Medicines are recognized by the WHO as a central piece of health seeking behaviours. The WHO (2002) estimates that about 90% of the population in Ethiopia and 70% of the population in Canada uses “traditional”, “complementary and alternative” medicines either regularly, or “at least once” in the case of Canadians. Use in Benin, India and Rwanda are at 70% of the population, and Tanzania and Uganda at 60%, while France, Australia and the United States range from 49% to 42% (WHO 2002).

Ayurveda requires a unique and long-term industrial development strategy that, at the same time, can be highly sustainable. It has the potential for different types of affordability, employment and long-term health. “One Health”, however popular today, has been mostly silent on industrial development and its policy landscape for the future. As a determinant of health, industrial policy is a critical foundation for enacting sustainable change (Mackintosh et al. 2016; Srinivas 2016).⁹ At a time when healthcare burdens are increasing, investment in health-related industries is skewed toward more profitable sub-segments and treatment costs are rising, Ayurveda has important industrial development lessons and opportunities for countries committed to expanding biodiverse and preventative strategies for healthcare, food and alternate patterns of urbanization and resource use. Currently, “sustainable healthcare” if viewed through revenue alone, may turn out to be health-depleting rather than health-generating. From an income standpoint, greater health burdens are borne by lower-income groups; and the higher out of pocket payments and catastrophic expenditure may not be mitigated by insurance strategies alone.

Indian Ayurveda is a vibrant and, in some parts, growing tradition of medicine and healthcare; it is neither “traditional” nor ‘alternative’ to ‘industrial’ streamlining. The labelling may in fact undermine the very industrial policies needed to boost authentic (not diluted) Ayurveda and to strengthen and expand its complex knowledge base.¹⁰ Furthermore, understanding the overlaps and tensions between Ayurveda’s several knowledge systems, its production supply chains, and

⁸ See Hindu Business Line (2018) citing a 2018 CII report.

⁹ The reason industrial policy is so critical rests on how problem-solving occurs in industrial organizations.

¹⁰ As system of practice, Ayurveda has many “schools” but may also combine with the sister system yoga, which is also from India, and consists of situated daily physical and mental practices requiring Dharmic/Hindu socio-spiritual norms (for example, Ashtanga, the eight-limbed yoga of Patanjali). These practices affect mind and body, and combine with the Ayurveda *doshas* and local explanations (geographic, diurnal, annual) of human beings as ecological/nature entities. In the contemporary global economy, Ayurveda and Yoga are a large growth front, even when “diluted.” They provide several transformative medical, lifestyle and business services. Both focus heavily on individual choice and transformation, and every patient and regimen is standardized, but in ways different from Western medicine.. Practitioner reputation is paramount.

generic and on-patent pharmaceuticals is essential to its future. The fact that these coexisting systems may converge only in some respects—and that pharmaceuticals, food and cosmetics may be sometimes low-entry, but highly profitable segments—makes it essential to clarify what aspects of industrial development Ayurveda genuinely requires. It has distinctive and fundamentally different requirements to input quality, personnel expertise, and whole-system links to biodiversity and climate change. Yet, it offers the potential of extensive, affordable and prevention-oriented medicine.

During the COVID-19 pandemic, several controversies regarding Ayurveda versus allopathy/Western medicine have surfaced, with the political aspects of industry profits, the notion of one type of medicine, effectiveness and authenticity pitted against each other. However, the Ministry of AYUSH and the Indian population appear to have continued to use Ayurveda, especially for immune-boosting functions alongside or, in some cases, in lieu of, “modern” medicine.¹¹ There has clearly been mixed policy-signalling and clarity about how to address different systems of medicine even when demand is growing.

Ayurveda also interacts with manufacturing and industrial supply-chain bases that are crucial to a sustainable and inclusive industrial system in which health knowledge has efficacy and demonstrates growing demand, but struggles with the challenge of consistently applied quality and standards. This occurs because of increasing pressures of production incentives and regulatory design which focus on profitable and globally integrated pharmaceuticals, biotechnology, which are systems of science with different epistemic and ontological traditions and measurement. Prior to the COVID-19 pandemic, and during the virus’s progression, many generic pharmaceuticals and on-patent drugs claimed to extract many drugs, cosmetics, and nutritional supplements from Ayurveda. But Ayurveda itself, as well as TCM, have long been in high demand for their ancient techniques and holistic practices as much as medicinal products, as data from WHO confirms (Mittal 2020; TimesNowNews 2021).

“Traditional” medicines like Ayurveda illustrate a viable but currently non-resilient industrial system, arguably because there is little clarity on what industrial policy should provide Ayurveda. There has been (from author’s exchanges with specialists), very little systematic attention paid by policymakers to its underlying principles and biodiversity complexity. This is because of its existence both as a complete system of long-term healthcare in its own right with its own industrial

¹¹ See: <https://www.ayush.gov.in/>, from the Ministry of Ayush for several suggestions for preventative remedies and amelioration strategies (last accessed 4 June 2021). The Confederation of Indian Industry also has an Ayurveda group. See also CII (2021).

needs, but also due to its increasingly subservient relationship as ‘stripped’ inputs and patents to a more profitable and opportunistic and agile pharmaceutical industry.

“The quality control methods modeled on those applied to western medicines and phytochemical industry is incompatible and meaningless to ASU industry. Further the present policy has adopted a post-mortem approach, with an intention to reject the products in the event the finished product does not meet the standards laid down in official pharmacopeia.” (Upadhyaya 2011, p.254).

High-profile, high-profit stakes and medical controversies are still being played out in India—as well as dissatisfaction among frequent Ayurveda users about available treatment choices or lack of insurance coverage. There is also a burgeoning collection of clinical literature on case-based medicine and protocols for Ayurveda specialists, clinical phasing as diseases develop (The Week 2021; Kamath 2021), as well as randomized placebo-controlled pilot clinical trials that have yielded positive outcomes (Devpura et al. 2021; Girija and Sivan 2020; Rastogi, et al. 2020.). The mixed business-clinical model comprising the two types of treatment—Ayurveda alongside allopathic medicine—can be seen as a practice-driven, expert mechanism to bridge complex, long-standing institutional practices that some have argued are epistemic and methodologically irreconcilable systems of medicine. However, the urgency of treatment needs for severe cases and the immense scale of COVID-19 patient numbers, as well as unclear policy guidelines, has left Ayurveda use in clinical settings with high institutional ambiguity.

There continues to appear high demand for use of Ayurveda for mild and moderate cases, and those interested in boosting immunity as a prophylactic. However, suppliers of Ayurveda formulations have found it impossible to treat COVID-19 routinely except by individual patient consent and only outside formal clinical settings. Some hospitals have used Ayurveda mainly with strategic use of allopathy where needed, or in mild to moderate COVID-19 cases, to claims of positive outcomes (Mishra 2021). Nevertheless, with high-profile disputes and controversies about the relevance of standardized, controlled trials, there are several unresolved institutional norms and rules of “dilution”, whether perceived to have occurred within the existing separate “authentic” systems, or that rest on claims—in both systems of medicine —of no known and accepted treatment regimen for COVID-19.¹² Patients have often chosen to rely on local Ayurveda experts (who are not subject to standard regulation) on quality of formulations or methods of evaluation of efficacy (Economic Times 2021c). A clinical case repository of treatments and

¹² In later waves of Covid-19, the AYUSH Ministry has put out self-care protocols including for Ayurveda and Yoga.

outcomes was recently launched by the Ministry of AYUSH, making it more likely that some professional norms of mutual acceptance or mixed treatment strategies will be bridged in the future.¹³ Yet, during a pandemic when routine treatment from diabetes to high blood pressure needs attention and is severely sidelined, Ayurveda could have played a wider role beyond COVID-19.¹⁴

It can be argued that adulteration as an Ayurveda challenge is a symptom of an industrial system that is increasingly shifting away from a just-in-demand, authentic older system focused on prevention and high quality, with small batch manufacturers and institutional norms of expertise (including name of specialist, family, region or brand) to a system struggling to meet high demand, where lowered quality continues to reap profits, and offer a sub-standard response to a mass manufacture industrial system largely focused on “Western” standardized products and tertiary care. Here, “dilution” of authentic Ayurveda is used loosely (and profitably) in nutritional supplements, hair oil, shampoo or face creams, and tourism-driven spas, also adding to the cross-industry challenges for certification and authenticity.

However, because Ayurveda and Traditional and Alternative Medicines continue to be important in health-seeking behaviour, they provide a critical missing element of inclusive patterns of health consumption and industrial demand. Ayurveda, when guided by experts who recognize its complexity and epistemic bases, can act as a powerful new model of industrial development combining high levels of authenticity and local certification with growing demand for affordable and sustainable healthcare in some areas.

Broadly, Ayurveda treats individuals as ecological beings in terms of their food, lifestyle and consumption patterns; uses exercise and breath and pulse to judge quality of life; and emphasizes making ongoing ecological adjustments, including exposure to sunlight and other elements, as well as seasonal changes. Ayurveda is also highly customized to an individual’s health status, and there are few side effects when diagnosed and prescribed by an expert. Further, dispensing of medicine and treatment regimen evolve and adapts with close patient monitoring and patient feedback.

¹³ See Kaul (2021): “The Ayush Clinical Repository (ACCR) portal (<https://accr.ayush.gov.in/>) will serve as a platform to support both Ayush practitioners and general public. This portal aims to aggregate information about clinical outcomes achieved by Ayush practitioners on a large scale. It will facilitate not just dissemination of information but also further analysis and research. It is expected to document the strengths of Ayush systems for treatment of various disease conditions,” said Ayush ministry in a statement.”

¹⁴ May be positive outcome but patient-solicited decision to rely on specific system of medicine. See, for example, Shirkhande and Shirkhande (2021).

In summary, Ayurveda is focused on different forms of prevention as well as some cures; it offers alternative methods for assessing complex diseases such as cancer, diabetes and cardiovascular diseases. However, its toolkit of locally significant and therapeutically treasured plant sources is shrinking. Ayurveda and TM (including Chinese TM) have epistemic differences with “Western” allopathy; but Ayurveda is itself highly varied. Ayurveda and TM are more effective with long-term and preventative care rather than emergency care. Treatments are customized to the individual patient and combine physiology, mental states and other attributes. In contrast, “Western” medicine is strongest as standardized, large-population care, with little adjustment for the individual. Ayurveda and TM are best used to address root causes over longer timelines. Technologically, allopathy has gone much further, devising complex tests, treatments and surgeries, while Ayurveda and TM may be better addressed toward long-term strengthening of physiology, especially when patients adhere to lifestyle and ecological changes. “Western” medicine may also be better suited to addressing cures using standardized treatments, often asking little lifestyle change from the patient. In contrast, Ayurveda and TM are much less expensive but also requires customised monitoring and regulation by highly-qualified practitioners.

However, despite this highly customised and supervised Ayurveda approach, it is still an “industrial” system with deep supply-chain fissures and changing norms of pharmacology, effectiveness and representation. Table 5 lists the fundamental differences required of the diverse supply chains of Ayurveda and TM.

Table 5: Institutional Variety in Ayurveda manufacturing

Manufacturing institution	“Modern” manufacturing firms	Farms and nurseries	Cooperatives	Other organizations	Family-linked production, including by TM practitioners
Resource source	Traditional supply chain network	Planting	Planting and harvesting	mSMEs and lead suppliers and distributors often known in the area	Regional specialization, close to source materials?
Quality control and standardization	Strong but variable	Highly ecologically variable	Highly ecologically variable	Unbranded and dependent on others	Very strong and by family/practitioner reputation or associated retailers

Source: Author’s elaboration.

Note: TM = traditional medicine; mSME = micro and small and medium-sized industries.

A fundamental challenge for Ayurveda is to develop strong policy guidelines that enshrine its own standardization system, “Dravya Sampath”.

Standardization is not a new concept in Ayurveda but is inbuilt in the system itself under the name *Dravya Sampath*. This *Dravya Sampath* is in fact influenced by place of origin, time of collection and administration quality, method of storage and potency enhancements, by virtue of which the drug is capable of producing desired results” (Upadhyaya 2011; note that Sanskrit/Samskrta terms have been removed).

Thus, unlike the traditional view of industrial production, where a “raw material” is seen as a simple, unprocessed commodity, the input into Ayurveda is the plant and even biome of the individual in an ecosystem which is a complex and systemic entity unto itself (Upadhyaya 2011).

The lack of a consistent industrial perspective on Ayurveda is pronounced in both national and global health policy design. The institutional norms of standardization and quality control of such resources, seen as an essential part of the system of Ayurveda, have been compromised over time for several reasons. Reliable sources of knowledge and resources continue to exist but struggle to stay alive, as they have been—as some have argued—force-fitted into alien knowledge and industrial systems. WHO’s TM strategy (2002-2005) frames the issue primarily as one of already existing industrial products that have to be certified, regulated, bought and used; industrial challenges of Ayurveda sourcing and manufacturing critical to its future, are absent (WHO 2003).

While WHO has developed technical guidelines, in the collection of standardized agricultural norms for example, the industrial, IP, geographical indication or other system of attribution remains underdeveloped, unlike for other agricultural or food product in higher-value segments.¹⁵

¹⁵ See WHO (2003), p. 1: According to the Secretariat of the Convention on Biological Diversity, global sales of herbal products totalled an estimated \$60,000 million in 2000. As a consequence, the safety and quality of herbal medicines have become increasingly important concerns for health authorities and the public alike(1).Some reported adverse events following the use of certain herbal medicines have been associated with a variety of possible explanations, including the inadvertent use of the wrong plant species, adulteration with undeclared other medicines and/or potent substances, contamination with undeclared toxic and/or hazardous substances, over dosage, inappropriate use by health-care providers or consumers, and interaction with other medicines, resulting in an adverse drug interaction. Among those attributable to the poor quality of finished products, some clearly result from the use of raw medicinal plant materials that are not of a sufficiently high-quality standard. The safety and quality of raw medicinal plant materials and finished products depend on factors that may be classified as intrinsic (genetic) or extrinsic (environment, collection methods, cultivation, harvest, post-harvest processing, transport and storage practices). Inadvertent contamination by microbial or chemical agents during any of the production stages can also lead to deterioration in safety and quality. Medicinal plants collected from the wild population may be contaminated by other species or plant parts through misidentification, accidental contamination or intentional adulteration, all of which may have unsafe consequences.”

Table 6. Ayurveda and generic pharmaceuticals: Standardization and stakeholders

Type of Medicine	Source of knowledge	Evaluation of quality	Manufacturing process	Raw material	Largest regulatory difference
Generic pharmaceuticals	Chemical materials (raw and chemists and engineers)	Well-established (but gap with customized treatment, results in standardized products)	Well-established	Chemicals and chemical industry	Global and national regulators with clear signalling for most standardized products
Ayurveda formulations	Botanical materials (raw and Ayurvedic doctors, increasingly with chemists, engineers and biologists)	Lack of standardization protocols in modern industrial systems to evaluate medicinal plants (strength with authentic products is a highly customized treatment efficacy)	Patchy	Medicinal plants and plant nurseries	Difficulty in large number of and fragmented institutions in standardizing/Dravya Sampath ¹⁶

Source: Author's elaboration.

¹⁶ Upadhyaya (2011, p.4) specifically lists “1. Lack of control over collection and trade of medicinal plant raw materials. 2. Presence of multiple authorities like Forest Department, Bio Diversity Board, Medicinal Plant Board and Drug Control Agencies of Central and State Governments. 3. Lack of institutionalized regulatory mechanism to regulate medicinal plant trade. 4. The absence of clear cut law to enforce regulation on medicinal plant raw materials trade. 5. Shortage of infrastructure and expertise to achieve the purpose of standardization and quality control of medicinal plant raw materials.” In addition, WHO's regulatory guidelines for TM (WHO 2002) have an ongoing gap between biodiversity and standard World Trade Organization (WTO) conventions.

Thus, high levels of institutional variety (IV) of the norms, customs, guidelines, regulation, and other laws lead to considerable ambiguity in Ayurveda, for biological inputs to quality and certification standards, all affecting its manufacturing systems and goals.

Furthermore, while there may be demand for products, there appears to be changing consumption behaviour in rural populations, compounded by uneven product quality disbursed by inexperienced practitioners. At the same time, medical Ayurvedic practitioners may be “diluting” knowledge sources and genuine scientific inquiry, based on hypotheses and experiential results, with allopathic clinical process by offering attractive “one-shot” solutions (such as injections or tablets) that pander to “standardization” customs instead of responding to an individual’s symptoms and response. There is anecdotal evidence from specialists demonstrating that, in order to mimic or compete with allopathy, Ayurveda practitioners may have to compete by offering higher dosages or easily available but poorer quality formulations to secure desired health outcomes. There are also pipeline problems, such as skills challenges and uneven quality of medical personnel (although some specialists contacted for this study indicate that after a period of decay, things are now improving with many capable students finding Ayurveda a viable professional option and healing vocation).

In some respects, prospects are already better. Interest in and controversies about Ayurveda during the COVID-19 pandemic are symptomatic of existing and growing cultural preferences for immune-boosting remedies and lifestyle health transformations—but also of uncertainty and unease with chronic ill health that many believe Western medicine can treat only partially, generating many side effects, or best used in emergency contexts alone. COVID-19 has revived ongoing concerns of fragmented WM strategies to deal with disease; a seeming lack of clarity on what works for a virus such as COVID-19, even in emergency conditions; and societal worries about vaccines, real or perceived.

Ayurveda’s approach to human well-being and transformation emphasizes ecologically sound lifestyles and diet and biodiverse and climate-sound healthcare. It should be pursued to offer a vibrant industrial development pathway in direct contrast to more routine strategies of scale and scope of other industries, such as consumer goods, extractive industries and industrial utilities, whose consequences for the planet can be discussed more closely. Many countries with rich natural resources can pursue policies and train people in Ayurveda, embed and expand an Ayurvedic knowledge base, and develop long-term strategies for health-enhancing individual and consumer behaviour. Explicit industrial policy attention is needed for several linked but solvable features of Ayurveda: the multiplicity of norms and regulations required for fragmented ‘Ayurveda’ branding and challenges of quality, sourcing and standardization at several stages of

production, prescription and retail. However, Ayurveda should be considered a highly promising and fundamentally transformative industrial domain, with long-term repercussions for national development and contributions to the health of individuals, communities, and the planet.

Although in some respects Case 1 and Case 2 can be discussed in tandem, they are treated separately in this paper.

3.2 Case 2: Industrial oxygen supply during COVID-19

Case 2 discusses the response of the United States and India to the challenges of sourcing industrial oxygen and offers a contrast between an industrialized economy struggling to provide oxygen during the COVID-19 wave of late 2020-2021 with an *industrializing* economy during the second ‘delta’ wave of 2021 (late 2021, currently subsiding). In addition to its medical uses, industrial oxygen is used in pharmaceuticals, chemicals, the automotive industry, iron and steel. Its use is driven by infrastructure expansion in urbanization investments, but also by rising demand in metal, glass, food processing sectors (including refrigeration and storage sub-sectors) and semiconductors.

The industrial resilience of oxygen production and delivery in response to severe shortages during COVID-19 has been notable. Many countries and sub-national regions offer examples of rapid production and diversification in industrial oxygen that can form a foundation of post-pandemic industrial development. Both the Indian and US industrial responses are discussed to showcase the speed and range of oxygen supply for medical use. In both cases, state-level government responses were crucial alongside national coordination. The example of industrial oxygen is premised on production meeting demand and delivery for primary users such as hospitals, state procurement agencies and end users, the patients who have been suffering.

The discussion that follows set the less-scrutinized and troubling US industrial oxygen supply context against the quite successful Indian response. The struggling US response has been far less publicized than the Indian response. Neither case has received the attention it deserves.

3.2.1 United States

Due to media reporting regulations and laws prohibiting journalists from reporting within hospitals as well as ethical guidelines prohibiting visuals of acute suffering, there has been relatively little global media attention of the US oxygen crisis. While it is well-known that the United States has had among the highest cases and deaths of any country worldwide, and among the highest per million, the oxygen crisis affecting individual states has received much less

attention. Three states—New York, California and Texas—experienced significant lack of oxygen and associated deaths and ill-effects (Toner 2021).

And with later surges in the United States, by the end of August 2021 even more Southern states (Florida, South Carolina and Louisiana) were running out of oxygen, hospital beds or both (Holmes, and Elaroussi 2021). Examining how a highly industrialized economy could experience severe oxygen shortages, and understanding its response to the shortage, are important for gauging the degree of resilience, robustness and recovery of industrializing countries. . Because for the most part, national rather than state-level responses have been reported outside the country, an investigation of the experiences of New York, California and Texas can offer a last-mile view of industrial response. It is important to note that in both countries, although oxygen was known to be a problem and flagged at policy levels, state and city governments acted at different rates (Murphy 2021).

The reason to look not at national industrial estimates but at local industrial challenges has to do with facility, infrastructure and industrial regulations. For example, extremely cold weather conditions in the United States have worked against safety regulations: placing oxygen outside the building has resulted in serious challenges for availability to patients, even when available on site. This is a different type of industrial problem from the Indian case, yet the outcomes are similar.

“The challenge is that high flow oxygen therapy uses roughly 5 to 10 times the amount of oxygen as a mechanical ventilator. The resulting high flow of oxygen through hospital oxygen systems is causing liquid oxygen vaporizers to freeze over. These vaporizers, which convert a hospital’s stored liquid oxygen to gas for the hospital’s oxygen systems, are located outside of the building next to tanks where bulk liquid oxygen is stored. Additionally, oxygen pipes in many older hospitals are not able to accommodate the increased flow demands due to design limitations. To reduce the draw on the wall oxygen in hospitals, portable oxygen is being used, especially in alternate treatment sites; however, the increased use of portable oxygen is contributing to a shortage of oxygen cylinders of all sizes. Timely oxygen delivery to hospitals has also been a problem, and oxygen flow regulators, which are needed for both wall oxygen and portable oxygen tanks, are in critically short supply.”

In early January 2021, California experienced significant oxygen shortages and had guidelines to clinicians to use oxygen sparingly (at or just above saturation levels of 90%). At the time, Los Angeles County, the country's most populous county warned that "[...] a person is being infected every six seconds in the county and one in five residents currently tested was infected with Covid-19." Given the shortage of oxygen tanks, the state deployed the U.S. Army Corps of Engineers and the California Emergency Medical Services Authority to refill and deliver the tanks (Patil 2021).

Box 1: California's oxygen crisis, as of 1 January 2021

- 4,374 people with COVID-19 died in the preceding two weeks in the United States
- California Department of Public Health on 1 January reported 585 deaths in a single day, the highest by then, more than 47,189 new confirmed COVID-19 cases, totalling 2.3 million cases, and nearly 26,000 deaths in California alone
- California was already facing an acute shortage of ICU beds (Leatherby et al. 2021)
- Los Angeles County (the country's largest county by population) estimated one in five residents were testing positive for COVID-19, one person dying of the virus every 10 minutes.
- Severe shortages of oxygen tanks and refilling capacity, including older medical centres in Los Angeles County experiencing difficulty maintaining oxygen pressure and non-availability of additional oxygen tanks for discharged patients
- Severe hospital bed shortage and patients lining up outside many hospitals, ambulances waiting as much as eight hours to transfer patients inside, and, in some cases, doctors having to treat patients in ambulances for lack of hospital beds
- Los Angeles County health authorities directed ambulance crews to not give transportation priority to cardiac arrest patients whose survival was unlikely (Sutton 2021); ("brutal directive from LA health authorities to overwhelmed ambulance drivers has revealed the terrifying truth about America's COVID battle"); ambulance crews were also told not to give supplemental oxygen to those whose saturation levels fell below 90%
- US Army Corps of Engineers asked by the California governor to assess and upgrade ageing infrastructure for oxygen delivery systems at six Los Angeles hospitals

Source: Weber 2021

The US case in brief laid out here serves as a reminder that industrialized economies have struggled during COVID-19 in all aspects, and we are served poorly by standard comparisons across higher and lower per-capita income countries or by industrial capabilities. Many European countries also suffered from lack of oxygen.

States suffered even worse when Texas experienced severe climate-induced major electricity failures and the industrial backbone of the state became paralyzed: "[...] the human toll is still being tallied. Dozens of Texans have filed lawsuits against ERCOT and local power companies. Some of the suits allege that medically fragile children and adults suffered permanent or severe injuries because they were unable to get electricity to power life-sustaining medical equipment.

Others have been filed by the surviving loved ones of older residents who died of hypothermia in their homes.”[...] ¹⁷

Other industrializing countries such as Indonesia and South Africa have also experienced serious problems with medical oxygen availability. In 2020’s first wave, South Africa—like many other countries including India and the United States—was able to manage its oxygen needs, even encouraging the use of in-hospital interventions such as high-flow nasal oxygen with proning rather than intubation (Cleary 2020). Similarly, by early 2021, its doctors, engineers and other innovators were coming up with bridge medical devices to manage within the fragile health system as well as in hospitals per se (African News Agency 2021). Despite the innovations, the standardization of more optimal clinical protocols was not governed by clear-cut industrial guidelines that were needed to augment supply.

3.2.2 The India case

India’s example of adapting industrial oxygen for medical use is a unique and encouraging case of industrial ramp-up and distribution of oxygen supplies in a country with a population larger than all other countries apart from China—and with many individual states larger than Brazil, most Western European countries, and even Indonesia, exhibiting uneven and under-industrialized capacity.

As the Director of INOX (India’s largest liquid oxygen manufacturer) remarked to an interviewer (Sharma 2021):

“Do you think India could not have anticipated this spike in Covid-19 cases and no preparation would have been enough?”

Absolutely... Why cases spike in this manner is beyond me. I don’t think any country would have been prepared for this kind of acceleration (in Covid-19 cases), which is currently the world’s highest.

All I can say is from an infrastructure perspective, we are scaling up. India has increased its oxygen manufacturing capacity by 30% within a month. This

¹⁷ See Hixenbaugh et al. (2021): “In an effort to reduce the strain on limited hospital resources during the pandemic, it’s become standard practice for hospitals to send most COVID-19 survivors home before their lungs have fully recovered, said Dr. Jamie McCarthy, chief physician executive for the Memorial Hermann Health System in Houston. Those patients often spend several days or weeks dependent on breathing equipment, such as oxygen concentrators or BiPAP machines, that require electricity.[...]With statewide COVID-19 hospitalizations peaking at more than 14,200 people in mid-January, medical experts say thousands of Texans like Marin had been sent home with plug-in breathing machines and portable oxygen tanks in the days and weeks before the electric grid failure.”

is unfathomable. I don't think it has happened globally. It's a world record in itself. The effort has been so enormous, however, increasing the capacity of manufacturing is not the same as getting it to the patient."

—Siddarth Jain, Director, INOX Air Products, the largest producer of liquid oxygen in India.

Gaseous and liquid oxygen are produced through many different industrial strategies. And it can be argued that IV is low in the industrial production of oxygen which is standardized, but high in supply chain segments that address the demand and delivery needs of patients. Countries and regions with rapid oxygen production ramp-up using existing infrastructure have managed the phase and scale of production, especially those quality and safety regulations governing technical standards and industrial regulations of facilities on storage, transfer, and disbursement and refilling operations. Closer to the patients' needs as end users, however, IV is significant, confusing, and, in some cases, in direct conflict with the most efficient way to get oxygen to a patient.¹⁸

During the COVID-19 pandemic, medical oxygen supply has proven critical, especially during surges of patients entering hospitals or in the number of those suffering at home. Patient surges and lack of oxygen supply occurred in the United States and other industrialized countries as they did elsewhere. Yet media coverage of suffering patients—especially in the United States, Europe and the United Kingdom—was less intense than in India, where minute-by-minute reporting persisted within emergency rooms and outside hospitals with patient's families, journalistic practices often prohibited in the home countries of these publications (Associated Press 2021; Moole 2021; Parker 2021; Saaliq 2021; Frayer and Parthak 2021). Yet, there was notably less monitoring or reporting of industrial successes. This COVID-19 “double standard” of reporting, especially in the absence of any other large country data sets (which were prohibited for different reasons in China or the United States), may have significantly affected the framing of countries' industrial responses, perceptions and policy priorities of multilateral agencies, global charities, and investors (Chellaney 2021). In terms of industrial development, this has led to assumptions

¹⁸ The topic of industrial regulation is too extensive to be discussed here. However, an example from secondary data on patterns of learning and conducive regulation for medical devices and diagnostics shows that serious attention is needed to address bottlenecks in the medical device and diagnostics sub-sector relative to regulations designed for pharmaceuticals and vaccines (Srinivas and Kale 2021). Large-scale manufacturing companies and, to some degree, SME commodity manufacturers influence outcomes. See also Watkins et al. (2015) and Papaioannou et al. (2016) on the importance of industry associations). Unsurprisingly, mSMEs and a fragmented Ayurveda manufacturing scenario have more entrenched regulatory challenges, driven not only by manufacturing firm market power but also by at least two different clinical and professional systems and their epistemic reasoning of health science.

that responses to COVID-19, however poor they may have been in industrialized economies, were worse in most low- and middle-income countries (LMICs), although no reliable measures appear to demonstrate this either in deaths per 100,000 population or by industrial response¹⁹. Yet, the oxygen production and end-user supply case demonstrate similar industrial and federal challenges, even in considerably different clinical practice settings. These include the foundational elements of industrial resilience through large industrial oxygen facilities as well as less visible but essential last-mile planning of sourcing and deployment of existing capabilities in storage, maintenance and repair, delivery, restocking and refilling. Both the India and United States cases demonstrate these challenges (Graham and Falade 2021). In India, many more last-mile innovations are visible. What this implies requires discussion.

Because western media reporting was especially focused on Delhi (and to some degree Mumbai) where most foreign correspondent and local bureau sourcing occurs, few reported the on-the-ground industrial response elsewhere. Delhi reporting also skewed many hypotheses about the importance of local oxygen supply chains, since this city had little oxygen of its own despite warnings from the Ministry Health to states during wave 1 of the pandemic that oxygen could prove a serious problem in wave 2.²⁰ There appears to be evidence that other states had either set up some oxygen production plants by wave 2 or developed the logistics to bring in and distribute liquid oxygen where needed. Because other states experienced COVID-19 cases spike after Delhi and Mumbai, they were also better prepared. However, technologically more advanced cities such as Bengaluru still faced shortages. Large industrial oxygen sites are often located far from cities, requiring tankers and trucking to respond to requests.

¹⁹ While the Indian media also covered the story in detail, many have pointed out that there was no shortage of oxygen in absolute quantity but rather in the availability at site and for patient needs.

²⁰ There have been reports in court documents that the Delhi government received funds after the first wave in 2020 for setting up eight oxygen production plants for the second wave in 2021, but Chief Minister Arvind Kejriwal had built only one. There were allegations that, although he had promised setting up as many as 44 plants during the crisis, the state lacked the logistics to receive much of what it was ordering and may have returned 100 metric tonnes of oxygen to producers during the second wave. There were also allegations of requests for sharp increases (133% by 20 April 2020 reporting) and a minimal dedicated administrative staff presence (just one nodal officer) with very high per-capita patient use estimates, which were reduced by the Delhi government, and that much large states of over a 100 million, such as Maharashtra (also with acute COVID-19) were requesting much lower amounts. Several news stories covered Delhi's highest per-capita usage of oxygen while other states were issuing guidelines about monitoring per-capita use and training on how to monitor and regulate oxygen at the bedside while rationing supplies to save more lives. See: New18 (2021), Times of India (2021a), Sarkar (2021), Press Trust of India (2021), Banka (2021) and Kumar Das (2021).



Source: Kumar Das (2021).

Between the critical periods of early to late May 2021, Indian Railways had delivered more than 20,000 million tonnes of emergency medical aid and 300 ‘Oxygen Expresses’ to 39 cities across 15 Indian states, an area larger than Brazil, Indonesia and Mexico, or France and Germany, and with difficult onward distribution to far-flung district headquarters, towns and villages. In addition to railway operations, oxygen storage and road transport road rose significantly.

Table 7: Regional distribution of medical oxygen from industrial sites in India

Region	Towns/cities/industrial plants	Delivery states
West	Hapa, Baroda, Mundra	Uttarakhand, Karnataka, Maharashtra, Madhya Pradesh, Andhra Pradesh, Rajasthan, Tamil Nadu, Haryana, Telangana, Punjab, Kerala, Delhi, Uttar Pradesh and Assam
East	Rourkela, Durgapur, Tatanagar, Angul	

Source: Author’s elaboration based on several Indian daily news sources.

Table 8: Distribution of Indian Railways' one-month 'Oxygen Expresses' liquid medical oxygen throughout India

State	Delivery cities
Punjab	Bhatinda and Phillaur
Tamil Nadu	Tiruvallur, Chennai, Tuticorin, Coimbatore and Madurai
Kerala	Ernakulum
Andhra Pradesh	Nellore, Guntur, Tadiparti and Visakhapatnam
Uttarakhand	Dehradun
Karnataka	Bengaluru
Rajasthan	Kota and Kanakpura
Delhi	Tuglakabad, Delhi Cantonment and Okhla
Haryana	Faridabad and Gurugram
Telangana	Hyderabad
Uttar Pradesh	Lucknow, Varanasi, Kanpur, Bareilly, Gorakhpur and Agra
Maharashtra	Nagpur, Nashik, Pune, Mumbai and Solapur
Madhya Pradesh	Sagar, Jabalpur, Katni and Bhopal
Assam	Kamrup
Jharkhand	Ranchi

Source: Author's elaboration based on news reports and government press statements.

By January 2021, before the second wave, India's central government appears to have met with oxygen producers, discussed capacity needs, and allocated funds across 32 states and union territories (Office of the Prime Minister of India 2021). As of early October, every state and union territory were given dedicated Pressure Swing Adsorption (PSA) oxygen facilities and 90% were judged operational.²¹

²¹ See New Statesman (2021): "All districts across the country will have now commissioned PSA Oxygen Plants with induction of these 35 PSA oxygen plants. A total of 1,224 PSA Oxygen Plants have been funded under the PM CARES across the country since the advent of the Covid-19 pandemic. Out of that more than 1,100 plants have been commissioned, providing an output of over 1,750 MT oxygen per day.[...] The project to commission a PSA oxygen plant in each district of the country was executed while dealing with complex challenges of hilly areas, islands and territories with difficult terrain. Around 7,000 personnel have been trained to monitor the operation and maintenance of these plants. These plants will be monitored with an embedded Internet of Things (IoT) device to check real-time functioning and performance through a consolidated web portal."

Table 9: Number of requested and allocated Pressure Swing Adsorption (PSA) medical oxygen generation plants, by Indian state or UT

Sl. No.	State/UT	Number of PSA plants
1.	Assam	6
2.	Mizoram	1
3.	Meghalaya	3
4.	Manipur	3
5.	Nagaland	3
6.	Sikkim	1
7.	Tripura	2
8.	Uttarakhand	7
9.	Himachal Pradesh	7
10.	Lakshadweep	2
11.	Chandigarh	3
12.	Puducherry	6
13.	Delhi	8
14.	Ladakh	3
15.	J&K	6
16.	Bihar	5
17.	Chhattisgarh	4
18.	Madhya Pradesh	8
19.	Maharashtra	10
20.	Odisha	7
21.	Uttar Pradesh	14
22.	West Bengal	5
23.	Andhra Pradesh	5
24.	Haryana	6

Sl. No.	State/UT	Number of PSA plants
25.	Goa	2
26.	Punjab	3
27.	Rajasthan	4
28.	Jharkhand	4
29.	Gujarat	8
30.	Telangana	5
31.	Kerala	5
32.	Karnataka	6
	TOTAL	162

Source: PM Cares allocation.²²

Delhi state, which requested 8 plants—all of which were eventually approved—had a much higher per-capita allocation than other states, but had no reliable standing oxygen capacity for the second COVID-19 wave. Conflicting reports and court submissions indicate a range of challenges: planning coordination, unfinished approvals for new regional investments in oxygen ramp-up, coordination challenges with the centre, delayed or standing oxygen tankers not reaching patients, and higher per capita clinical use compared to other states (Times of India 2021b). At the same time, industrial capacity and on-site response has not received as much attention, even though there is evidence that states with plans for building plants, the technological capability in running and expanding them, and the assured capacity to respond to clinical needs, also appear to have better experience in estimating demand, creating storage needs, managing procurement logistics, managing external contracts for trucking capacity and a range of other associated expertise.²³ Many states did construct oxygen plants between the first and second waves or focused on storage facilities. Some constructed or regenerated plants at high speed during the second wave and continued issuing incentives for restarting defunct industrial plants or investing in new ones, ramping up existing production capacities, and encouraging oxygen-producing SMEs (The Economic Times 2021a).

²² See <https://www.pmindia.gov.in>

²³ See Times of India (2021b): “While Mumbai has easier access to liquid medical oxygen, the city administration had also prepared for a possible second wave by creating large storage facilities, which helped hospitals in the financial capital during the last surge.”

For cities that had high oxygen needs, states that built capacity between wave 1 and 2 or that were lucky in avoiding large casualties in wave 2, have to be recognized.²⁴ And for cities that were especially hard hit, such as Delhi, there have been legal cases on mismanagement and political contention with the central government. Across all countries—not just India—oxygen procurement and at-site delivery plans required many state actors, including public-sector facilities, informal citizen groups, non-governmental organizations (NGOs) and private companies. In extended exchanges and media battles, both the Indian (especially Delhi) and US judiciaries and executive branches (such as in Texas, agency bureaucrats from several national and state level agencies) were often at odds in estimating and procuring, then delivering—onsite—the necessary oxygen.²⁵

However, we need to recognize the wider industrial context and the successes in meeting oxygen supply needs. States with high existing industrial oxygen production capacity either had manageable emergency COVID-19 cases or managed with state-level suppliers (for example, West Bengal). Some states listed in Table 9 are industrial oxygen supply states (such as Karnataka, which disbursed 1200 metric tonnes of liquid oxygen daily) but received oxygen because of increasing caseloads. By approximately 25 May 2021, Karnataka (with a population of over 61 million and Bengaluru/Bangalore as its capital city) was disbursing 1,200 metric tonnes of liquid oxygen across the state. Six in-state industrial producers provided 830 metric tonnes, 60 metric tonnes from mSME PSA plants that had been authorized by the central government, 240mt from Maharashtra, and 70mt from Orissa, There were also plans to increase district-level capacity to 20mt in order to buffer stock storage for emergency last-mile reach and raise the industrial investments across Bengaluru and the surrounding areas (Gunasekar 2021). Even less industrialized states with remote areas, such as Assam, had planned for and set up oxygen plants prior to the second wave.²⁶

Federal and shared commitments for health provision (traditionally a state-level issue) were essential to coordinated responses in both industrializing and industrialized countries for oxygen. While international aid of mobile oxygen generation plants and concentrators played a helpful

²⁴ States experienced different realities of supply depending on both production ramp-up as well as distribution capabilities. In addition, many states experienced black marketeering although the government did enact fiscal measures to control costs. See Reddy (2021) and Bikkina et al. (2021).

²⁵ See Gunasekar (2021): : “The Delhi High Court on Monday ordered oxygen firm Inox not to divert supplies marked for the Capital to other states after the Aam Aadmi Party government informed it about the acute shortage in the city amid rising coronavirus cases, reported NDTV....In a letter to Union minister Piyush Goyal, Kejriwal had also named Inox for not following the agreement with the Delhi government.” The firm appears to have disagreed with this assessment.

²⁶ See Assam Tribune (2021): “After the COVID crisis hit the state, the government has installed eight oxygen plants, producing 5.25 metric tonnes of oxygen per day, in five medical colleges of the state [..]”.

role in India, existing national industrial capacities shared between and within Indian states were essential and much larger. Rapid scale-up and deployment of defence forces formed the basis not only for airlifts and travel and stocking logistics, but also for the defence research establishment and commissioned health staff, emergency financial authority for ordering the services, and establishing oxygenated beds and facilities across the country.

Box 2: Mission Oxygen plan involving the public sector and the armed forces

- Airlifting of generators and other oxygen delivery.
- Army, Navy and Air Force personnel; budgets; and facilities, including new buildings, production plants, clinical sites and transportation.
- Field staff and field hospitals, including critical evacuation and quarantining facilities, in urban and remote areas.
- Navy production of oxygen at dedicated plants and diversion of operations at docklands, steel and shipbuilding. ‘Portable Multi-feed Oxygen Manifold’.
- Defence Research and Development Organisation (DRDO) SpO₂ (Blood Oxygen Saturation) supplementary Oxygen Delivery System.
- Oxygen enrichment units for on-site facilities (CSIR’s Indian Institute of Petroleum) delivering up to 500 litres of oxygen per minute.

Source: Shandilya 2021

The Indian central and state governments had to quickly identify and coordinate the core elements of the changing relationship between industrial oxygen and medical oxygen. This learning took place under urgent conditions and became concentrated and then dispersed in protocols across and within states. Data appears to reveal the increased speed at which Indian industrial oxygen production grew, as well as the exploration of on-site or close-to-site storage and delivery, including potential new future industrial rules for clinical sites of use. The fact that industrial oxygen production was diverted from industrial to medical use (as required by the Government of India) affected manufacturing operations in many industrial sectors: petrochemicals, chemical processing, steel, oil refineries, automotive and, increasingly, space research (Shandilya 2021; Jestin 2021; The Hindu Business Line 2021). Large industrial oxygen producers and multi-industry conglomerates such as Reliance, Adani and the Tatas all diverted supplies, often at the cost of lowered prices, free provision, and scaling down or stopping other industrial operations that used oxygen. It is perhaps one of the largest diversion of industrial resources in just one month in developing countries’ recent history, underscoring the importance of recognising and managing IV with flexibility under duress. The industrial oxygen case and its use in medical

treatment also offers alternate measures of industrial resilience and long-term diversification across industries that use shared resources.

The health industry and its reliance on oxygen production is increasingly linked to energy innovations. The technological capabilities and trends of operational changes—including those implemented at the conglomerates as well as by traditional medical oxygen producers—have coincided with the onset of shifts toward alternative sources of energy and interests in such investments, especially large-scale gasification plants and capabilities focused on intensifying the combustion process. These signal that there are COVID-19 driven opportunities for large-scale industrial investments and expansion of brownfield, greenfield and defunct sites to be regenerated. PSA and mobile facilities have emerged as efficient and cost-effective options to increase high-grade industrial oxygen, while also being relevant to increasing onsite and decentralized oxygen storage needs that may be needed to service flexible operations in agricultural processing and storage. “Onsite” and “on-demand” imply that high-pressure cylinders and the related downstream complications of filling stations, storage and delivery will be partly circumvented. In addition, air separation unit (ASU) production facilities are becoming more attractive in order to respond to infrastructure and manufacturing needs. With the rise of food processing and storage, just like in other sectors, new oxygen and gas-to-liquid requirements will only increase.

The global market for industrial oxygen, which is highly capital-intensive, is now heavily concentrated through mergers and acquisitions, driving consolidation of technology-specific regulation and standardization. This may not offer countries or companies much flexibility over the nature of emergency industrial and clinical response (especially in the metallurgy and healthcare sectors) when long-term, lower-risk service contracts and standardization costs are driving business arrangements.²⁷ For instance, Inox, which has dominated the liquid oxygen industrial response in India, announced a R 2,000 crore (approximately \$268 million)²⁸ greenfield investment in India’s industrial gas sector. Inox is already operating in 44 Indian locations and plans to increase oxygen production and anticipates high demand for nitrogen, argon and helium. Investments will include ASUs and other expansion in seven major industrial corridor states, beginning with Gujarat and including Uttar Pradesh, West Bengal, Tamil Nadu, Maharashtra and others (Mukul 2021). Industrial gases are a critical utility to sectors like healthcare, automotive,

²⁷ Storage and distribution sectors may be especially open to technical cooperation in upgrading and certification.

²⁸ 1 crore = INR 10 million, so INR 2000 crore = \$268 million.

iron and steel, metal, glass, pharmaceuticals, chemicals, food processing and semiconductors (OmmcomNews 2021).

India's industrial successes have been in rapid and widespread increase across states with populations the size of major G7 countries, and its attempts to enhance delivery of liquid medical oxygen (LMO) to hospitals is despite limitations of cryogenic trucking of industrial gases in a controlled, incubated environment. Railway use of the so-called Oxygen Expresses on dedicated corridors also established freight routes for hundreds of tankers and thus partially addressed the bottlenecks of moving LMO.

Table 10: Examples of increased oxygen supply capacity and onsite delivery in India

Industrial oxygen producers	% increase of LMO	Date	Also supplying
Steelmakers (including SAIL, RINL, Tata Steel Ltd, AMNS India, JSPL, Liquid Medical Oxygen) Indian steel plants and oil refineries supplying 66.5% of daily required oxygen allocation	Over 4,473mt per day, from 538 mt per day	1 April 2021	8,500 oxygenated hospital beds across the country, 100 PSA oxygen generator plants in hospitals across the country
IOCL, Haryana state BPC Limited Refinery, Bina, Madhya Pradesh Kochi Refinery, Kerala			15 mt per day of gaseous oxygen to 500-bed facility at Panipat 10 mt per day of gaseous oxygen to a 1,000-bed COVID-19 care facility Gaseous oxygen and drinking water to local COVID-19 care facility
Industrial imports from: Saudi Arabia, UAE, Singapore, Bahrain, Kuwait and Qatar	13,740 mt of liquid oxygen		

Source: Author's elaboration based on various sources, including company sites and press releases and petrochemicals minister twitter feed.²⁹

²⁹ See, for instance, The Economic Times (2021b; 2021d).

The example of India's response to industrial oxygen production, and onto demand and delivery challenges the standard 'rich vs poor' analysis and focuses on real-world industrial capabilities when evaluating COVID-19 global policy responses.

Box 3: Public and private coordination transforming India's oxygen supply from industrial use to medical use during COVID-19

- Required shutting down of all industrial use of oxygen to be diverted to medical use for the emergency period.
- Certification and quality checks of medical grade use from industrial facilities.
- Rapid demand and production estimates by railways along with Ministry of Health and Family Welfare and Industrial departments of states and other administrative entities.
- Indian Railways construction of unloading and mounting ramps for oxygen tankers in just 24 hours, commencing with a 15 April request from the Maharashtra government (at distance).
- Coordination with many regional governments, with regular meetings at the highest levels.
- Indian Railways coordinating, along with state-level and private-sector oxygen distributors, freight routes and dedicated trains. State governments provide the dedicated tankers to offload the medical oxygen and are cleared by police and other state officials for rapid delivery.
- Indian Railways covering the entire country and optimizing both pickup of oxygen from industrial sites across the country (both public and private sector) and delivery.
- Running average speeds of freight trains well above 55 kmph for long stretches and on high-priority, dedicated Green Corridors and with high safety protocols.
- 24-7 crew, repair and logistics teams coordinating with last-mile operations teams to provide oxygen to patients.
- Air freight where relevant, including coordinating Air Force and other dedicated flights for delivery, as well as deployment of all armed services where needed.
- Importation and coordination of aid of oxygen equipment from several countries and coordinating customs, transport and other assistance to speed delivery and use at sites of need.

Given the scale of industrial ramp-up of production, no industrial accidents for production scale shifts, although storage and delivery accidents have occurred at hospital administration levels.

Source: Adapted by author from reports in Economic Times (2021b) and Kumar Das (2021).

It demonstrates how local responses, public-private coordination, variety of state capacity in planning (drawing from legislators, technical experts, executive including bureaucracies, and a range of technical engineering companies), helped India develop last-mile plans and strategies to circumvent and innovate in emergency conditions with a much less-resourced industrial base, in contrast to the European, US and UK industrial oxygen experiences during the COVID-19 pandemic. It also showcases an effectively multi-country population response. In terms of scale and size, European country-sized populations—such as those of France, Germany, Brazil and Mexico are included within India.

Furthermore, it stresses the importance of existing large-capacity industrial oxygen production plants and supply-chain capabilities that include networks of private distributors servicing multiple industries, without which this transformation would not have been possible. As a backbone however, India's coordination and public-sector production capacity and freight rail, road, sea and air logistics have been critical.

The local administrative response to anticipating patient numbers, oxygen needs, and deployment capacity, alongside innovative technical training, has allowed many regions of the country to maintain low COVID-19 risk. The importance of last-mile administrative perspective and use of skilled personnel is demonstrated by the dramatic reduction in forecasted COVID-19 cases and their anticipated oxygen crisis.³⁰ Administrative success stories from across the country have been reported. In some cases, this was accomplished by a comprehensive and imaginative use of existing administrative autonomy; in others, by expanded plans and logistics.

Several states in India have indicated that all 50+ bed capacity hospitals will now be required to have their own industrial arrangements for oxygen storage and delivery. Finally, legal tightening of racketeering of cylinders and concentrators has also been swiftly accomplished, while much remains to be done.

3.2.3 Bottlenecks, future opportunities and ongoing investments

IV in oxygen production is more visible closer to the end user. No single designated regulatory authority, ranging from oversight and complex bureaucracies of ministry of health to food and drug administration, may exist at this 'end'. Exporters that go through importer country regulations may have industry association safety certifications or other approval paperwork which serve as proxies for domestic regulation.

It is evident that there is now considerable private- and public-sector capacity (including from the defence industry) in industrial oxygen and to facilitate innovations in reaching the end user. What remains to be seen is how much additional narrowing of IV-especially standardisation of storage, use, and service norms, will take place closer to intermediate and end users based on the existing norms and technical standards of the types of firms that are currently investing in the industrial oxygen sector.

³⁰ See Better India (2021) for an example: Dr Rajendra Bharud, an Indian Administrative Services officer of Nandurbar in Maharashtra, anticipated oxygen needs in simple but coordinated and highly efficient ways, using consultation and participation, and utilizing all resources officially at his disposal. The district of Nandurbar, with a population of 1,648,295 (15.45% urban), requires many rural logistics. The district's website shows details of what is available and how to access it: <https://nandurbar.gov.in/covid-19-updates/>.

Table 11: Projected public and private PSA plants in India, as of June 2021

Company	No. of PSA plants (states)
Tata Sons and DRDO (Defence)	500 (multiple)
Oil Public Sector companies	100 (multiple)
Tech Mahindra	50
Maruti Suzuki	22 (Haryana, Jammu and Kashmir, etc).
HCL	17 (Delhi)
Northern Coalfields	5 (Madhya Pradesh)
Powergrids Corporation	3 (Rajasthan)
DCMM Shriram	2 (Gujarat)
Western Coalfield	2 (Maharashtra)
IGL	1 (Delhi)

Source: Thadani (2021).

In oxygen production, IV is lower in manufacturing, which is more narrowly standardized and regulated. Yet, as COVID-19 has shown, considerable ambiguity and higher IV exists between lead purchasers and the end user. One can thus hypothesize that, where demand is high, there are more skills and innovations in a context of unclear institutional rules on medical devices and business models to service this population. In countries such as India, this has resulted in a rapid response to delivery models, whereas one sees less of this innovation in the United States, which also experienced severe oxygen crises but where IV is lower (and regulation stricter) in the supply chain.

In summary, the successes of industrial oxygen ramp-up in India include:

1. The long-term industrial implications of successful oxygen production switching and delivery in India are several, but are supported across other countries to a lesser extent based on *existing* capabilities, as well as many new ones that combine uncertainty with industrial protocols. COVID-19 diagnostic kit production is similar (See Case 3).
2. The industrial development learning curve is rooted in the relationship between the three vertices of the ‘institutional triad’ of production (which has successfully ramped up), demand and delivery, which have been much weaker and more difficult to sustain because of their complexity across sites and facilities, at distance, and with weak end-infrastructure (including often ramshackle hospital facilities in rural areas).
3. There has been a sharp learning curve across industries about how to estimate and procure, at state-level, required medical-grade oxygen and other essential commodities needed to save lives.

4. While first wave plans had anticipated the need for oxygen, especially based on the experience of California and other geographies, many state governments in India, where health is an issue for the state constitution, had not fully rolled out second-wave oxygen logistics. Worse, in some cases, states had stood down existing facilities for hospital beds, oxygen production, etc.
5. Industrial accidents in the enormous ramp-up have been surprisingly absent, although accidents (especially fires) at individual hospital sites have occurred. This implies that industrial site management for logistics is perhaps more robust, and hospitals in industrializing countries may need to be treated as industrial sites going forward with their required checks and standards, including technical standards for building codes, construction standards and layout of urban and fire code specifications.
6. Public-sector investments in the two COVID-19 diagnostic kits (see Case 3) and oxygen production cases indicate the importance of public R&D, manufacturing and logistics, even while coordination with private companies has been beneficial.
7. In addition to mSME and larger firm personnel, well-trained administrative staff in government bureaucracies and strong state governance (from planning to procurement and disaster management) have been critical to turning around oxygen-use capacity and ramping up production of diagnostic kits and their deployment, as well as iterative streamlining of regulations and specificity of test guidelines.

Some of this narrowing of IV will depend on global oxygen markets. By 2019, and thus before COVID-19, industrial oxygen (mostly produced by cryogenic air separation techniques) was already expected to rise at a compound annual growth rate (CAGR) of 6% until 2029, in response to the heightened steel production needs of large infrastructure products in East Asia, and half of revenue shares were from North America and East Asia, which showed significant investment capacity in industrial oxygen manufacturing (Future Market Insights 2019). In addition, the growth of chemicals, petrochemicals, food and beverage, health products and services, especially pharmaceuticals and biotechnology, have all generated demand for production of oxygen. The sizable rising demand (pre-pandemic) in North America, Europe, South Asia and East Asia is of medical-grade oxygen driven by both ageing populations, increased non-communicable diseases, and life-saving ICU and pediatric care—and assisted by many governments permitting 100% FDI in this sector (especially in products like oxygen concentrators, portable kits, and small and medium oxygen plant generation on-site). Globally, Linde PIC, formed in October of 2018 from the \$90 billion merger of Linde A.G. and Praxair Inc., is the dominant private firm in the oxygen gas market.

The COVID-19 experiences and clinical contexts and healthcare systems of India and the United States are vastly different, and further industrial scrutiny is encouraged. Table 12 compares and contrasts the industrial capabilities of these two very different countries in the context of the industrial production features of oxygen. The table illustrates how both countries have managed on several industrial and technical planning and policy fronts, including where they faced shared struggles.

Norms, customs, and laws around healthcare delivery and care, and industrial production, were being rapidly drawn and re-drawn in many countries and locations, as the Delhi, New York City and Texas X cases discussed earlier in this paper have shown—perhaps too often for any organization except strongly established firms to act with certainty. This did provide opportunities for local corruption or other global oxygen market profiteering.³¹ Yet, other states Indian, either those that had built up capacity between waves 1 and 2 or already possessed existing industrial capacity, seemed to have moved ahead more successfully, regardless³². Industrial plans for oxygen worked to fruition for many states before and even during the deadly second wave, and the national coordination capacity was essential for building long-term logistics, industrial switching protocols, and tackling huge freight and geographic challenges. Smaller adjustments, such as oxygen audits and guidelines for nozzle-monitoring, saved huge amounts of critical oxygen, pointing to improvements in canisters, flow mechanics and the potential for other industrial process improvements. No countries, nor WHO, were necessarily coordinating these industrial-side findings nor implications.³³

³¹ More analysis is required in the coming months to expand the sources of data. This is necessary to understand what is occurring in Indonesia currently or to extend the US and India comparisons. US COVID-19 surges in late 2021 indicate how badly hospitals have experienced patient surge and oxygen availability. Parts of Europe, such as Italy, have experienced the same industrial lack of capacity or pressures on industrial regulations of oxygen during COVID-19. See Keohane and Miller (2020).

³² See, for example, CNA (2021). In Indonesia, similarly, while existing industrial oxygen producers exist, sharp increases in patients needing oxygen may need alternate strategies. See also Antara News (2021): “The ministry informed that oxygen manufacturing industries were mandated to convert their products to meet medical requirements. Consequently, 1,700 tons of medical oxygen per day will be available. Some 1,400 out of the 1,700 tons of medical oxygen are used to meet the demands in Java, according to Pandjaitan.”

³³ See, for example, Times of India (2021c): South Africa and other country specialists had been advising on high-flow nasal oxygen (HFNO). In India, “Stop the use of HFNO machines until further notice.”

Table 12: Industrial oxygen production features common to India and the United States during COVID-19

Industrial product feature	Notable Indian use	Notable US use	Where both countries struggled
Oxygen-related equipment and last-mile instruments such as tanks, regulators and liquid oxygen delivery trucks	Extensive use of Indian Railways to transport dedicated LMO storage tankers	Existing road use with plant-level storage	Cylinders and piping
Policies, regulation, personnel	Rapid use of centralized government ministries, acts, regulations and decentralized stakeholder participation to ramp up production; use of public sector, defence forces, national rail and road, Army Core of Engineers, Defence Production Act or other central government procurement	More decentralized governance, except for invocation of Defense Production Act	
Storage and delivery at hospital sites and beds	Limited oxygenated ICU beds New guidelines for hospital self-reliance	Assumed oxygenated bed but serious mishaps with grid collapse	Tubing for multiple patient beds Home patients and oxygen supply
Clinician guidelines of per-capita use and conservation	Audits and nozzle-flow monitoring provide some gains		Countrywide operational guidance for technical staff to monitor and lower oxygen over hours to reduce per-capita usage (good practice exists in both as well)
Home-based guidelines and access	Several innovations to be studied: providing oxygen cylinders to those ill or recovering at home, including oxygen concentrators, with new business models, purchase, rent, 'Uber-like' sharing, etc. ¹	Oxygen saturation measurement and simple diagnostics to ensure at-risk patients are admitted where possible	Countrywide home monitoring, quotas or rationing

Source: Author's elaboration.

Note: LMO = liquid medical oxygen; ICU = intensive care unit. 1. See for instance, Nitnaware 2021 and Muthkumar 2021.

The industrial oxygen supply and the medical-grade oxygen needed for responding to COVID-19 are closely linked. Oxygen supply goes beyond resilience, expanding into other aspects of industrial development—in particular, the deep-rooted agility challenges of heavy industry and associated prospects for long-term industrial development in several associated sectors that require last-mile effectiveness and coordination with public administration and with public benefits. And since oxygen supply requires several associated industries to work together at different coordination and technology scales, it is a useful measure of industrial depth and stakeholder involvement outside a single industry or region. Countries, companies, sub-national regions and many industries are needed. Those entities that can jointly supply oxygen and ramp up production of oxygen at short notice show good prospects for long-term industrial development post-pandemic and should be tracked, especially as there is an expected fall in demand of medical oxygen once the crisis is passed. India's proposed PSA fiscal disbursement and commission will push authorities to manage the skills required to set up, manage and repair PSA facilities and judge, through operational experience, the clinical flow pressure requirements for patients at PSA versus traditional facilities (Chitlangia 2021; Barnagarwala 2021).

COVID-19 oxygen supply has demonstrated that health policy cannot remain divorced from industrial supply chains. Equally, the health industry cannot be thought of as focused on R&D and manufacturing of medicines, vaccines or diagnostic kits. As discussed in the next section, COVID-19 diagnostic kit production demonstrates its own IV within and across countries.

3.3 COVID-19 diagnostic kit production

As Cases 1 and 2 have shown, institutional variety (IV) provides a window into specific types of adaptation challenges in industrial organization. It is a means to reveal how essential industrial development features can provide both a theoretical and practical context for viewing how societies may transform over time. Some of this transformation may be induced by external shocks, a tradition of inquiry quite well known in economics. But transformation may also be emergent and hidden, evolving in an iterative adaptation to its context. Such an endogenous view of change—more evident in neo-Schumpeterian and institutional, evolutionary analyses—lends itself quite well to understanding the technological capabilities required. Traditional literature on late industrial development would have foreseen a small sub-set of countries, among highly industrialized and industrializing economies, to manage to boost the production of diagnostic kits. What the early evidence from the pandemic—a natural experiment with imports prevented in most countries—indicates is that some unexpected capabilities do exist and alternative institutional norms about regulation, investment, shared facilities, sped-up quality checks, or

simplified prototype designs all played a role in ensuring some of what was locally needed to ‘test, test, test’.³⁴

The unexpected ways in which institutional change occurred during the first wave, second wave and the onset of third waves in several places provides useful evidence to catalogue new industrializing data to see how anticipation, resilience and adaptation can be represented by a comparative national analysis. The analysis used in this section was based on secondary data and two hypotheses: first, that only industrial supplier countries could implement the WHO’s testing strategy; second, the individual tests production and the testing strategy will require informed decision-making based on test results. In the absence of an ability to carry out the practical consequences of test-based decision-making, only a small subset of supplier countries can respond to enhance diagnostic kit production.

Box 4: Seven types of uncertainties in industrial diagnostic kit production

- Multiple clinical uncertainties about testing and its use
- COVID-19 testing and clinical effectiveness are not independent of the effects of other co-circulating pathogens or results or treatment
- National scale varies because of variation in size of asymptomatic populations
- Practical industrial contexts matter when it comes to testing technology, technical personnel and turnaround time
- High-stigma, low-privacy tests versus a desire to know outcomes compete, leading to unclear demand models
- Countries with multiple chronic health challenges are unwilling or unable to respond to single-disease test strategy
- Health specialists-clinicians, epidemiologists and virologists respond to uncertainties differently, influencing the industrial uncertainty that follows about production of COVID-19 test kits

Source: Adapted from Srinivas et al (2020)

The seven industrial uncertainties listed in Box 4 can be addressed only when economic and public health considerations are jointly viewed and addressed. The paper cited in Box 4 used a qualitative heuristic to address production, consumption and delivery of diagnostic kits. COVID-19 has emphasized that the traditional order of countries as “advanced” because of their

³⁴ “The WHO’s exhortation to “Test, Test, Test!” has led to an unprecedented global effort to increase testing capacity for SARS-CoV-2 infection. Notably, however, a debate about national customization of the industrial context to enable the roll-out of testing is missing. Furthermore, countries often demonstrate idiosyncratic priorities, difficult industrial policy choices and organizational features. Their COVID-19 testing strategies will therefore be unique. Without this foundational industrial context in which firms—public or private—must invest in technological capabilities, even if to import, manage or deliver testing, the WHO advisory risks a formidable coordination challenge between global health goals and domestic realities for present and future pandemic response.” See Srinivas et al. (2020).

technological capabilities, based on industrial indices that measure such advances, has somewhat been turned upside down. For instance, the highly industrialized (according to “optimally” socially organized assumptions) Nordic countries, the United States, United Kingdom and Australia have all experienced different conditions of COVID-19 and struggled with managing the pandemic. During the first wave, this contrasted starkly with the experience of “developing” countries. The industrial elements of their response however, received relatively little attention for some time. There is a need to categorize in diverse ways the efforts to distinguish industrial capabilities within and beyond national context. This separation is necessary for reasons having to do with the differing assumptions behind the microeconomics of uncertainty and the political economy of the traditional ways industrial manufacturing has been organized.

While there can be additional IV and advanced capacity in demand and delivery, the categories reflect ways of viewing and assessing different types of diagnostic kit production capabilities. Applying this qualitative heuristic during the early, March-October 2020 allows us to organize countries by degree of production capacity.³⁵ The initial findings demonstrate that, even under stringent import bans or limited local capability, there have been surprising national attempts in country groups where LMICs responded more quickly and in some cases, ingeniously, to local problems. From a co-evolutionary standpoint, there are many solutions to the IV problem, including managing without domestic production from the outset, relying instead on domestic capabilities in demand or delivery as long as possible until import bans were withdrawn or global strategies were devised. For example, Japan, India, Viet Nam, Ghana (whose test kit production came later) and South Africa adopted notably different strategies. Both Japan and the Republic of Korea could have produced diagnostic kits as a major first strategy, yet they diverged on multiple fronts.

A series of import-restriction studies during the pandemic have pointed to the need for deep agility and capability for manufacturers and service models, and therefore regulators. First- and second-wave data across Africa also show no single pattern of either industrial oxygen response or COVID-19 diagnostics production and deployment. Distributed manufacturing capacity and last-mile problems have also emerged (Salzer et al. 2021). Similarly, distributed manufacturing challenges, regional market consolidation, and prototyping and currency supports are all issues that require more local attention and customized regional policy strategies (Fransen et al. 2021). Even industrialized economies have had to find new ways of import substitution through unusual global knowledge networks and cross-border R&D and prototyping challenges. This has had

³⁵ The degree of production capability versus demand and delivery are estimated for select periods of ramp-up in a table by country in Srinivas et al. (2020).

implications not only for ‘Open Virtual Labs’, but also for new bilateral and multilateral knowledge systems. At the same time, there is no substitute for government signals and new national initiatives for priority investments.³⁶

Finally, new classification systems across countries are urgently needed. COVID-19 has raised several questions of why industrialized countries have struggled so much and why many industrializing countries managed better than imagined despite dire shortages. Heuristics analysis permits a sorting and re-sorting based on the evidence as it becomes available. A heuristic will help this sorting without claiming a final answer. It will serve as a guide to generating hypotheses from this inductive exercise through which successive specialization in a single domain of health industry evolution can be tracked. COVID-19 responses during the first waves, specifically under the repeated “test, test, test” guidance of the WHO, encouraged nations to develop a pandemic response with the existing resources within their borders.

The final section of this section provides some conclusions across the three cases then discusses policy implications.

4 Conclusions

This section focuses on the implications of IV for industrial policy design: “big P” (policy as legislation and goal) versus “little p” (policy, planning, public administration and industrial governance systems).

The examples of Ayurveda and industrial oxygen production both point to significant regional development gains for industrial development, where many more stakeholders are essential to full use and feedback of manufacturing and service models. While COVID-19 diagnostic kit production also requires sub-national development and local logistics, those aspects were not discussed here. Instead, the case was used to illustrate the importance of diagnostic kits in the context of considerable IV in which other COVID-19 strategies also played a role. All three cases thus point to a contextual institutional background where policy design and existing technological standards and regulations have a selection effect on firms.

The cases presented in this paper focus on manufacturing in context, including the co-existing systems of knowledge, uneven production capabilities, certification and standardization arrangements and procurement for firms. They show how industrial policy capability and governance play a crucial role in detailing plans and governance. This focus on industrial policy instruments such as standardization and procurement highlights some wider problem-solving and

³⁶ See, Business Today (2021) for an example of a major new initiative on industrial oxygen.

devolution planning as well as rapid manufacturing of essential commodities, including distributed networks of warehousing, clean rooms, and small batch manufacturing and materials re-use. The consequences for sustainable manufacturing are important and have implications for what “industrial governance” and the “resilience” framework really means.

At the heart of industrial development are individuals and their institutional frameworks. Industrial development pathways of industrialized countries are broadly similar but not identical. Calls for homogenous rules on, for example, patent-free medicines or equal access to healthcare are ideal-type propositions of policy design. And the goals of inclusion and sustainability are value-driven claims to future industrial development that may be at odds with actual industrial organization—its rules and laws—embodied in the knowledge and skills of individuals and their organizational context of technological capabilities as well as their daily practice.

Box 5: Local and sub-national skills and regulatory capacity

The three cases discussed here—Ayurveda, COVID-19 diagnostic kits and the ramped-up production of industrial oxygen and its diversion to medical use—are examples where the skills base exemplifies high IV, with no clear, shared regulatory understanding or policy and planning process for improvement. A simple example suffices: In Ayurveda, a supplier of robust facilities for the manufacture of known Ayurvedic formulations may be competent but has little or no incentive—fiscal, certification or monetary—to switch to an expanded base of biodiverse and high-quality ingredients because of immense uncertainties associated with gains to operational investment. Younger workers, investors, owners, brokers, clinicians or procurers are all facing similar disincentives to innovate or source more widely or sustainably. The systemic convergence and cohesive evolutionary strands driven by policy design are at odds in several respects. Both Ayurveda and Chinese Traditional Medicine have features of cohesion disruption that should be investigated further.

From the perspective that industries *and* institutions evolve, then, there must be some pragmatic theory-policy middle ground. Markets and non-market institutions do mix after all. A country or industry association that can create a new market for diagnostic kits or manage the regulatory capability of medical devices requires other types of resilience—such as bureaucracies at lower levels of government, reliable rules for tendering and procurement that are robust and routine, and transparent systems for fiscal disbursement. Many COVID-19 industrial adaptations—such as converting oxygen to fast freight routes and scaling up turnaround time for testing, which is a decentralized function and requires both public- and private-sector input—also depends on other types of resilience, especially during lockdowns. These include strong food supply logistics, whether public, private or hybrid systems. A plethora of “industrial” institutions and organizations norms are thus created quite rapidly.

Table 13 outlines IV across these more or less “industrialized” contexts of the three cases discussed in this paper and highlights their promise for future development.

Table 13: Institutional variety in three industries, during COVID-19 and post-pandemic

Case	Potential global industrial impact	Institutional variety (IV)	IV characteristics and industrial organization of sub-systems
1. Ayurveda	Yes, strongly recommended. “Traditional”, “Alternative” are misleading terms. The two economies with the largest populations (India and China) have distinct ancient, widely used, medicine systems with significant cross-country industrial implications. Industrial policy attention to Ayurvedic sourcing, manufacturing and certification can aid multiple industrial sectors.	<p>Co-existing, overlapping, competing industrial systems and sub-systems.</p> <p>Example of IV in long timelines (over a century of competition and dismantling of Indic systems of science and medicine).</p> <p>Challenges of homogenized manufacturing policies: “raw materials” are not primary commodities but have biodiverse complexity; processing norms, quality and formulation certification conflicts.</p> <p>High IV within the Ayurveda system:</p> <ul style="list-style-type: none"> - Norms for specialized supplier quality - Conflicts of extant vs expanded knowledge base -Ayurveda manufacturers vs. other pharma, food, cosmetics, etc. -Small-batch Ayurveda “authentic” expert-based, just-in-time production versus scaled-up multi-house/brand manufacturers and distributors -Other norms, such as where authoritative councils and government policies may conflict 	<p>Prevention and treatment healthcare, ecologically sound and affordable, highly specialized knowledge base and large growth potential, high but variable demand, complex inputs, sourcing and tagging, but with biodiversity and GI industrial needs, shrinking natural resources and ambiguous quality certification, partially overlapping supply chains and competition with chemicals, food, “nutriceuticals” and cosmetics industry, both commodity and specialized processing techniques, certification/audit service potential.</p> <p>Yet, biodiversity tagging, natural source material refinement, local embedding and certification have strong long-term industrial development potential that steers economies into new pathways.</p> <p>Countries with strong natural resources can strengthen and expand Ayurveda’s strong knowledge base in India and extend its individual practice and customization elements.</p>
2. Oxygen production	Long-term potential needs to be coordinated across a very high number of industrial	Low IV and convergence of standards over several decades in globally and domestically regulated large-scale industrial oxygen production. Mergers and	In oxygen supply, which is broadly defined by stringent industrial procedures of the convergent global value chains debate, and highly regulated as a

and delivery	sectors beyond health. Since closely linked to urban infrastructure investment and food processing and storage, for example, multi-industry site plans and policies are needed.	<p>acquisition hasten convergence on safety and quality standards as well as regulations.</p> <p>High IV in closer-to-patient segments of industrializing countries.</p> <p>Many innovative oxygen delivery design, storage and business models are unregulated or confusingly regulated because the pressures of effective delivery require industrial regulations of the convergence patterns (industrial guidelines on storage, transport and hospital facilities) to convert to last-mile regulation at high speed, volume vs flow, decentralized, and in several untested contexts. This means that the different types of oxygen products are delivery innovations and require manufacturing and service delivery combinations for regulation and impact.</p>	heavy industry output, there are nevertheless significant institutional variety. Even in industrialized economies, there are major differences in equipment regulation which have come to the fore, and the consequences for policy redesign are not clear. Medical gases are pharmaceutical products but equipment is differently tracked and regulated. For example, air separation units (ASUs) are pieces of equipment that produce liquid oxygen in bulk, and transfillers, which are governed by Food and Drug Administration, transfer bulk liquid or gas oxygen to smaller containers, while oxygen concentrators, governed under the Federal Food, Drug, and Cosmetics Act are not manufacturing equipment, but medical devices. ³⁷
3. COVID-19 diagnostics	Yes (international variation substantial in kit production and goals). Long-term, health-led industrial development should be attentive to local health priorities. “Make versus buy” should be planned accordingly.	<p>Consolidation of IV into short timelines (1.5 years since first case or start of pandemic and establishment of WHO nodal guidelines).</p> <p>Challenge is highly centralized WHO clinical guidance with few correlated industrial norms or technical standards. Industrial policy is a necessity to clarify goals and long-term economic development potential. Significant national variety and sub-systems of management in which COVID-19 testing has been produced and deployed.</p>	Just-in-time and fast turnaround time, “gold standard” kit design, procurement and centralization, rapid new markets and technical specifications including multi-application goals. Diagnostic kit industrial policy among other clinical and industrial responses (generic drugs, masking, vaccinations, etc.). Challenges to manufacturing and industrial diversification cases, bottlenecks to regional hubs and cross-industry demand.

³⁷ See Smith et al. (2020), Figure 2: Oxygen sources and storage options.

		<p>Senegal, India, Nigeria and Republic of Korea for example have made diagnostics through different public, private, hybrid, non-profit or military efforts. Only some have moved under import embargoes and limited opening to higher quality, competitive improvements, improved turnaround testing, or multi-disease use.</p> <p>Diagnostics that can attend to chronic, neglected or widespread diseases with much higher morbidity and mortality should be prioritized and combined with other aspects of health industry policy.</p>	
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4.1 Policy implications

Taken together, the three cases discussed in this paper offer differing degrees to which the health industry leads from resilience, recovery and long-term strategic industrial policy design. It is evident that countries need to consider and urgently respond to whether better health is possible without well-designed and well-administered industrial policies, but also how industries and industrial policies are undermining health improvements or enhancing a disease focus (Srinivas 2021b).

The Ayurveda and COVID-19 diagnostic kit cases are examples of health-care supply chains. Yet, Ayurveda has potentially a much more longer term impact on industrial and regulatory framing. It offers a unique industrial development path and can enhance several aspects of the economy and culture. Its ties to multiple industries—medicine, food, cosmetics, ecology – including land, trees, and plant nurseries-agricultural processing and logistics—and encourages in principle new strategies for preserving biodiversity and augment healthy lifestyles. It has the industrial backbone of a system to streamline biodiversity and climate effects on health such as geographical indications and local skills, value addition and ownership—which can prioritize inclusion of existing knowledge, more systematic inquiry into customised medicine, and sustainable manufacture. In contrast, COVID-19 diagnostic kits are a critical but more predictable industrial product, although they, too, can be extended to become more useful as multi-disease and early-stage industrial interventions. These tests will continue to be in demand after the pandemic and constitute a significant contribution to the industrial structures and skills advantages within any economy. Their opportunity may be in greater attention to merely pathology labs and trained personnel, to a multi-disease, multi-modal deployment, biohazard waste processing and recycled materials use.

The case of transforming industrial oxygen to widescale use as medical oxygen in India demonstrates multi-industry impact and systemic policy linkages. India has demonstrated a very rapid ramp-up of industrial oxygen on a scale perhaps not seen since WWII.³⁸ This has involved not only the shutting down of industrial use of oxygen (not desirable, but seemingly essential) and the re-steering of industrial oxygen and its ramp-up for medical use and liquid storage and transport. This agility is to be commended and has taken a tremendous effort coordinating

³⁸ As the oxygen case has shown, this requires strong planning and linkages to road and rail freight, multi-modal partnerships, including storage facilities, cargo ramps, at-plant supply cylinders, small and medium plants and tanker capacity, and an ability to manage “green channels” for dedicated transport at speed. Some countries with low vaccination rates and high fatalities are now investing in industrial oxygen plants. See Associated Press (2021b).

multiple industrial sites, facilities, public-sector railways and private- and public-sector industrial sites in the east and west of the country, as well as delivery across the entire country.

One challenge for Ayurveda and COVID-19 diagnostics is co-existing specialist protocols and the need to create and sustain alternate standards and procurement norms. In the case of COVID-19 diagnostics kit production, the IV inherent across countries has been artificially suppressed and firm numbers boosted over short timelines to respond to the crisis. In the longer term, the consolidation of designs, protocols, firms and wider IV will occur in the move toward a standardized and more useful product (multi-modal, multi-disease or other). Both Ayurveda and the last-mile oxygen innovation both show adaptability, but also shallow industrial diversification without skilled personnel or investments in a decentralized infrastructure. These features may not assist long-term deepening of the industrial base.

4.2 Knowledge foundations, planning skills and local operational personnel

The cases here have been brief, but recently uncovered primary and secondary data show that a commitment to knowledge foundations with depth and external expertise, combined with industrial policy capability and governance, have played a crucial role. Both private- and public-sector personnel require high levels of commitment, risk-exposure and professionalism within a context of high uncertainty. Therefore, expertise and authenticity come from both standardization from within and with policy supports. Ayurveda's potential for success is high, but policy supports, while existing, need a much bigger boost after decades of neglect. One end of oxygen production is well-governed and has high future demand; the other, dominated by smaller devices and business delivery systems, could do with more clarity on policy supports and outcome measures.

Industrial policy ("big P") is nationally and often centrally determined, linked to the nation-state and the object of multilateral industrial governance and technical cooperation systems, which are not exclusive of but separated by the "small p" of industrial plans and public administrative capabilities³⁹. It is worth mentioning that colonial history and post-independence policy has been antithetical to consistently building domestic knowledge systems such as Ayurveda—or has resulted in inconsistent policy application in past cases of some diagnostics, where solutions have often remained dormant by developing countries or have been indiscriminately and expensively purchased but not deployed. LMICs have developed technological capabilities through diverse combinations of national and overarching controls of regional industrial investment and fiscal

³⁹ For a full discussion of industrial health systems and country comparisons, see Srinivas (2012). In African manufacturing challenges under Covid-19, see Banda et al. (2021); for global health, Fransen et al. (2021).

disbursements. A focus on industrial policy instruments such as standardization and procurement show some wider problem-solving and devolution planning as well as rapid manufacturing of essential commodities, including distributed networks of warehousing, clean rooms and small-batch manufacturing and materials re-use. “Authenticity” in Ayurveda is highly valued and can be a value addition to sourcing authenticity and medical certification.

The three cases discussed in this paper offer examples of national, cross-national and multi-industry production capabilities as well as demand and delivery. From an institutional and evolutionary standpoint, this co-evolutionary set of considerations in one industry is challenging to regulate—even more so across multiple industries. “Small p” is therefore complex because the industrial regulation of productive facilities; personnel; feed-in infrastructure such as water, power or land; or outputs from safe products to effluents are managed by sub-national governments. In the COVID-19 diagnostic kit and oxygen cases, the difference between “big P” and “small p” is especially stark because the evidence is derived from all failure modes of “small p” even when “big P” is working smoothly. Even successful cases of resilience, therefore, should seek the low-ecological impact and enhanced biodiversity-generating manufacturing potential of sectors such as Ayurveda, with its many related sectors, from food to beauty products, but which is currently at some distance from this ideal.

Box 6: Post-pandemic COVID-19 diagnostic kits

COVID-19 diagnostic kits are here to stay. Yet, a small number of global suppliers of diagnostics production (for example, India, Korea, new African consortia, and the United States and United Kingdom) will see significant future global competition and in-home markets comprising several companies. Once COVID-19 becomes endemic, the scale and scope of testing will reduce, and multi-disease and multi-modal testing for co-circulating pathogens and non-communicable diseases will require explicit industrial policy attention. For example, there may be pressures to use more strategic selection effects from competition as well as patenting strategies combined with procurement and outcomes-driven or insurance-led purchases. At the same time, limited and fine-tuned subsidies or at-market rewards should be available for especially innovative firms. UNIDO can play an important role clarifying which types of public production investments should remain, and what public finance models are best suited to converting the gains made from COVID-19 diagnostic activity and the high numbers of firms into sustainable business models through rapid feedback procurement and stocking at sub-national levels. UNIDO can also convert procurement design training and upgrading strategies from existing national to district-level or cross-national training programmes (for example, African consortia for regional manufacturing hubs).

COVID-19 and worries about immunity and ecology highlighted multi-faceted lifestyle systems such as Ayurveda as long-term manufacturing and regional development models. Yet for Ayurveda, no sustainable industrial improvements in manufacturing can result without some policy clarity on how to acknowledge and expand its unique source material. its scientific

knowledge base or its customized patient system. While Ayurveda’s trajectory diverges from generic or on-patent pharmaceuticals, the reality is that the latter’s competitive strategy (and that of nutraceuticals and cosmetics) is premised on sourcing Ayurvedic scientific knowledge such as molecules derived from identified Ayurvedic remedies or patenting strategies based on Ayurvedic ingredients. Patent classifications will also need direct industrial strategy within and across countries if Ayurveda and TCM manufacturing are to sustainably expand and survive. Current “traditional” and “alternative WHO classifications sidestep the industrial and technological elements of Ayurveda and its significant positive advantages for the environment (regarding food and biodiversity), health and agriculture. Assuming that lead suppliers from pharmaceuticals can automatically authenticate or preserve inputs or processes in Ayurvedic manufacturing would be a significant mistake and would actively undermine local specialization and higher value-added segments that make Ayurveda self-sustaining. Small-batch and just-in-time manufacturing may have distinct features for Ayurveda, and decades of actively policy neglect pre- and post-independence have to be addressed.

Box 7: Ayurveda as an industrial policy priority¹

Institutional variety exists across all three cases discussed in this paper. For Ayurveda, UNIDO can play an important role to reduce IV in especially fragmented, inchoate policy segments and uneven supplier capabilities that are harming source materials, innovation and quality controls. It can provide technical capacity to especially well-established and authentic “houses” of Ayurveda to expand and make more resilient their supplier networks. This can help boost quality control and expansion of biological source materials. UNIDO can also play a critical future role in supporting Indian policy goals, working with influential Ayurveda clinicians, traditional regional specialists and nurseries. These industrial improvements have to work together to present a coherent policy that addresses geographic indication, geo-tagging and biodiversity boosting of plant nursery supply chains, multiple sourcing and procurement improvements, small-batch and just-in-time manufacturing systems, and third-party accreditation and certification systems that can retain hallmarks of authentic Ayurveda.

All the cases presented here, but especially Ayurveda—as a system of medicine linked to the expansion, not depletion of biodiversity and industrial supply chains for its growth—require multilateral governance on other fronts if industrial policy is to be effective in any country or across countries. Four areas of governance are listed below as priorities for UNIDO, WTO and other multilateral actors. In the absence of such coordination, it would be difficult for countries to develop a robust strategy.

Table 14: Four multilateral spheres requiring industrial and trade policy coordination for successful industrial policy

Biodiversity zones	Dynamic regulation, stakeholder models, biodiversity concentration and growth safeguards and geographic indications coordination.
mSME manufacturer networks and representation in standards-setting	With increased international mergers and acquisitions in steel, chemicals and oxygen, more attention to developing country-led standards bodies and procedures for decentralized oxygen storage and delivery. These processes of new stakeholder consultation could be applicable to other decentralized sites and facility standards and supervision guidelines.
Patent-free or protected domains	of knowledge systems and accreditation systems that have important health and industrial consequences. Private actors <u>could be</u> offered other incentives that reward them for authenticity and quality.
Service professional mutual recognition	of skills and accreditation systems, industry-specific and not company-specific project management, budgeting, maintenance and repair-service credentials.

Source: Author's elaboration

When regulations are built for extant industrial organization, technological innovation can fuel a shift and require new norms, customs, guidelines, regulations or laws. Any context that has to juggle substantial IV may have ambiguous outcomes for industrial development. For instance, with diagnostic kits, oxygen storage products or other medical devices, we see innovation from new technology intermediaries that play both an outsourced business service role and also act in interpretive design roles better suited for prototyping and delivering to the end consumer. These “design firms” may be for-profit, but also include cooperative platforms, NGOs or charitable service organizations. In the three cases in this paper, we see that high IV—in other words, where there are many different ways of doing things—may be a boost to innovation, but IV can also limit innovation because of the regulatory and fiscal disincentives associated with high uncertainty.

A core task for industrial development is to develop a detailed taxonomy of technological capabilities in their combinatorial contexts within and across sectors. This can provide a problem-solving roadmap toward more clearly articulated policy goals and outcome measures.⁴⁰ Personnel and skills programmes are thus an input to better industrial plans and can act as focused investments with links to higher education and training:

⁴⁰ On industrial problem-solving in the health industry, see Srinivas (2016) and several examples from African sites in Mackintosh et al. (2016).

Box 8: High IV: No substitute for problem-solving skills and training programmes

- The building of individual and firm-level group technological capabilities remains an essential learning element of any economic development strategy. However, the three cases demonstrate new learning requirements in cross-industry linkages, long-term health and biodiversity challenges, investment in last-mile logistics, service quality and safety. These require a multi-pronged learning and training priority with significant employment analysis and mSME opportunity.
- Policymakers and local and regional development planning officials should seed incentives to improve development capacity: long-term, low carbon investments and gaps in skills responses to the pandemic. Administrators need to work closely with private, for-profit and non-profit groups, including resident/citizen groups, to identify in each region and nationally, those industry sectors that will have long-term growth and capability needs.
- Planning remains a critical technical capability, and personnel professionalism in financing, foresight, and project management are essential across industries to address complexity and stabilize and routinize supply chains. All cases require personnel training, testing, rotation, back-up personnel, ongoing training in safety and repairs and technical staffing and certification protocols. While production (at industrial sites of manufacture) is, ideally, a well-organized process, the industrial and technology components of training for demand and delivery is far less routine, often ad hoc and organized through hospital administrators, pharmacies, district officials and private-sector logistics.
- Planning and administrative capacity, with private-sector logistics feedback and iteration, remain essential to any manufacturing strategy. The “industrial development of services” is as essential as manufacturing: for example, digitalization and point-of-service and point-of-care business models, logistics, freight and “heavy industry” linkages. The three cases exemplify contexts in which drone delivery or digital payments can be important new areas of technological capabilities to enhance services. Yet, all will continue to rely on the administrative, safety, quality and consumer response.

The three cases have shown that supply-chain resilience, robustness and switching capability across multiple sub-sectors is an important measure of demand responsiveness. Staffing needs for logistics, quality and safety certification, last-mile delivery and new point-of-care approaches, will not only transform hospitals, but will ensure at-home safety, design and use, repair, refilling, restocking and in-situ upgrading of facilities.

4.3 The way forward for industrial policy

Institutional variety (IV) addresses the practical industrial policy context of multiple co-evolving institutions and co-existing knowledge systems. As this paper has shown, COVID-19 diagnostic products are governed primarily by public procurement strategies. However, India’s ministry dedicated to Ayurveda is distinct from industrial governance of chemicals and pharmaceuticals, but the public procurement process and health and industrial goals of Ayurveda are less clearly defined and internally coherent. In oxygen, public procurement processes have been contested because private production, demand and delivery might have been better internally coordinated with available “backup” public systems. Focusing on how policy design and localised

customization arrangements help firms adapt to uncertainty is thus a critical element of improved procurement goals and their design.

For all three diverse cases, any future improvement in industrial development strategy (“build back better”) will need to ask whether there are new and viable combinations of IV that show benefits, whether to health, the environment, affordability or other sustainability measures. There is no single automatic industrial strategy. Improving industrial development requires a contextual assessment of which norms, customs, guidelines, standards, regulations and laws (industrial and non-industrial) matter and why. These can be better designed to determine which types of institutional varieties are evident in different industries, and which specific institutions dominate manufacturing, its resource extraction models, and its local materials use, which then generate unsustainable and exclusive forms of development.

The three cases covered here point to new health-led industrial development in the health industry, rather than traditional upgrading for its own sake. Technical strategy or policy advice focused on narrow manufacturing-led value-addition to investment can give way to a new approach to policy assistance, aid accountability and coordinated technical and training strategies, especially for smaller countries or sub-national governments. These cases also demonstrate that new sector-specific country partnerships may be relevant across the industrialized-industrializing divide, since there are many lessons for the former to learn from the latter.

Finally, UNIDO can play a sustained role in national policy design improvements by working across multiple industrial stakeholders, from end users to highly local regional producers, from small “cottage” labs and non-profits, to mSMEs and multinationals. This will require policy and capacity-building attention to acknowledge the challenge that single industries may have significant IV at different processing stages, and wide stakeholders, to adapt learning within firms to regulation strategies and vice versa. Such stakeholder engagement will require the expansion of traditional finance and economic methods and techniques of analysis to focus on long-term health sourcing and manufacturing goals and to simultaneously strengthen regulatory design to boost learning and new knowledge in different sub-sectors.

References

- African News Agency, 2021. South African Doctors, Engineers Invent Device for Oxygen Delivery to Covid-19 Patients. Engineering News. Published online 3 January 2021. Available at: https://www.engineeringnews.co.za/article/south-african-doctors-engineers-invent-device-for-oxygen-delivery-to-covid-19-patients-2021-01-12/rep_id:4136.
- Antara News, 2021. *Indonesia Instructs Oxygen Supplies to be Converted for Medical Use*. Published online 5 July 2021. Available at: <https://en.antaranews.com/news/178306/indonesia-instructs-oxygen-supplies-to-be-converted-for-medical-use>.
- Assam Tribune, The, 2021. *Assam Govt will Provide Support to Private Hospitals in Setting Up of Oxygen Units*. Published 25 April 2021. Available at: <https://assamtribune.com/guwahati/assam-govt-will-provide-support-to-private-hospitals-in-setting-up-of-oxygen-units-1090507>.
- Associated Press, 2021a. *Oxygen Supply Disruption Kills 22 COVID-19 Patients in India*. Published online 21 April 2021. Available at: <https://abcnews.go.com/International/wireStory/disruption-oxygen-supply-kills-22-indian-hospital-77210246>.
- Associated Press, 2021b. *Somalia Opens Nation's 1st Public Oxygen Plant Amid Pandemic*. Published online 1 October 2021. Available at: <https://abcnews.go.com/Health/wireStory/somalia-opens-nations-1st-public-oxygen-plant-amid-80344608>.
- Banda, G., Mugwagwa, J., Wanjala, C., Mackintosh, M., & Kale, D. (2021). Local manufacturing, local supply chains and health security in Africa: lessons from COVID-19. *BMJ Global Health*, 6(6), e006362.
- Banka, R., 2021. 'Centre, State Responsible for O2 supply': Delhi High Court. *Hindustan Times*. Published online 27 April 2021. Available at: <https://www.hindustantimes.com/cities/delhi-news/centre-state-responsible-for-o2-supply-delhi-high-court-101619482951824.html>.
- Barnagarwala, T., 2021. First, India Lacked Oxygen Plants in Hospitals. Now, it Lacks Technicians to Operate Them. *Scroll.in*. Published online 16 October 2021. Available at: <https://scroll.in/article/1007579/first-india-lacked-oxygen-plants-in-hospitals-now-it-lacks-technicians-to-operate-them>.
- Better India Community, The, 2021. *How This IAS Officer Cut Nandurbar's Single-Day COVID-19 Spike By 75%*. Published online 26 April 2021. Available at: <https://www.thebetterindia.com/253438/ias-hero-nandurbar-district-collector-maharashtra-second-wave-coronavirus-vaccination-oxygen-plant-beds-ventilator-pandemic-india-inspiring-gop94/>.
- Bikkina, S., Manda, V.K. and Rao, U.A., 2021. Medical Oxygen Supply During COVID-19: A Study with Specific Reference to State of Andhra Pradesh, India. *Materials Today Proceedings*. Published online 26 January 2021. Available at: <https://www.sciencedirect.com/science/article/pii/S2214785321002856>.

- Business Today, 2021. *Govt Launches 'Project O2 for India' to Increase supply of Medical Oxygen*. Published online 13 June 2021. Available at: <https://www.businesstoday.in/latest/economy-politics/story/govt-launches-project-o2-for-india-to-increase-supply-of-medical-oxygen-298580-2021-06-13>.
- Chawla, V., 2021. Global Market for Ayurveda is Growing. *ET HealthWorld*. Published online 30 April 2021. Available at: <https://health.economictimes.indiatimes.com/news/pharma/global-market-for-ayurveda-is-growing/82327174>.
- Chellaney, B., 2021. The Lurid Orientalism of Western Media. *Project Syndicate*. Published online 4 May 2021. Available at: <https://www.project-syndicate.org/commentary/western-media-double-standard-for-crises-in-foreign-countries-by-brahma-chellaney-2021-05?barrier=accesspaylog>.
- Chitlangia, R., 2021. 1,183 PSA Oxygen Plants Under PM CARES Fund Operational, Says Govt. *Hindustan Times*. Published online 14 October 2021. Available at: <https://www.hindustantimes.com/india-news/1183-psa-oxygen-plants-under-pm-cares-fund-operational-says-govt-101634151341606.html>.
- CNA (Channel News Asia), 2021. *Indonesia Seeks More Oxygen for COVID-19 Sick Amid Shortage*. Published online 5 July 2021. Available at: <https://www.channelnewsasia.com/news/asia/indonesia-seeks-more-oxygen-for-covid-19-sick-amid-shortage-15158150>.
- CII (Confederation of Indian Industry), 2021. *Vision 2022: Road Map to Achieve USD 9 Billion by 2022. A Threefold Increase in Market Size in 5 Years*. New Delhi: Confederation of Indian Industry.
- Cleary, K., 2020. COVID-19: How High-Flow Nasal Oxygen is Saving Lives and Sparing Some Patients the Trauma of Intubation. *The Citizen*. Published online 2 July 2020. Available at: <https://citizen.co.za/news/south-africa/health/2314044/covid-19-how-high-flow-nasal-oxygen-is-saving-lives-and-sparing-some-patients-the-trauma-of-intubation/>.
- Dejouhanet, L., 2014. Supply of Medicinal Raw Materials: The Achilles Heel of Today's Manufacturing Sector for Ayurvedic Drugs in Kerala. *Asian Medicine*, 9(1-2), pp. 206-235.
- Devpura, G., Tomar, B.S., Nathiya, D., Sharma, A., Bhandari, D., Haldar, S., Balkrishna, A. and Varshney, A., 2021. Randomized Placebo-Controlled Pilot Clinical Trial on the Efficacy of Ayurvedic Treatment Regime on COVID-19 Positive Patients. *Phytomedicine*. Published online 4 February 2021.
- Economic Times, The, 2021a. *Industrialists Setting Up Oxygen Plants in Karnataka Will Get Attractive Sops: Minister*. Published online 26 May 2021. Available at: <https://economictimes.indiatimes.com/news/india/industrialists-setting-up-oxygen-plants-in-karnataka-will-get-attractive-sops-minister/articleshow/82975712.cms>.
- Economic Times, The, 2021b. *Steel, Oil Industry Supplying 6,650 MT Oxygen Per day; Setting Health Infra: Dharmendra Pradhan*. Published 16 May 2021. Available at:

<https://economictimes.indiatimes.com/news/india/steel-oil-industry-supplying-6650-mt-oxygen-per-day-setting-health-infra-dharmendra-pradhan/articleshow/82681240.cms>.

Economic Times, The, 2021c. *Top Ayurveda Institute Incorporates Allopathy, Modern Tech; Successfully Treats 600 Covid Patients*. Published online 2 June 2021. Available at: <https://economictimes.indiatimes.com/industry/healthcare/biotech/healthcare/top-ayurveda-institute-incorporates-allopathy-modern-tech-successfully-treats-600-covid-patients/articleshow/83173799.cms>.

Fransen, L., J. Nkengason, S. Srinivas, and S. Vella (2021) 'Boosting equitable access and production of diagnostics, therapeutics and vaccines to confront COVID-19 on a global footing', T20 Task Force 1 Global Health and COVID-19 Policy Brief, September.

Frayner, L. and Pathak, S., 2021. Why Is India Running Out Of Oxygen? *NPR WBEZ Chicago*. Published online 5 May 2021. Available at: <https://www.npr.org/sections/goatsandsoda/2021/05/05/989461528/why-is-india-running-out-of-oxygen>.

Future Market Insights, 2019. *Global Demand for Industrial Oxygen Likely to Rise at 6% CAGR through 2029*. Published online 22 August 2019. Available online:

<https://www.globenewswire.com/news-release/2019/08/22/1905632/0/en/Global-Demand-for-Industrial-Oxygen-Likely-to-Rise-at-6-CAGR-through-2029-Future-Market-Insights.html>.

Girija P.L.T., Sivan, N., 2020. Ayurvedic Treatment of COVID-19/SARS-CoV-2: A Case Report. *Journal of Ayurveda Integrative Medicine*. Published online 2020 June 19.

Graham, H. and Falade, A., 2021. It's Possible to Build Stronger Systems to Deliver Oxygen: Here's What it Takes. *Medical Express*. Published online 6 May 2021. Available at:

<https://medicalxpress.com/news/2021-05-stronger-oxygen.html>.

Gunasekar, A., 2021. "Do Not Divert Oxygen To Other States," Delhi High Court Tells Company. *NDTV*. Published online 26 April 2021. Available at: <https://www.ndtv.com/india-news/oxygen-firm-told-not-to-divert-supply-from-delhi-after-arvind-kejriwal-government-approaches-high-court-2417096>.

Harilal, M. S. (2009). 'Commercialising Traditional Medicine': Ayurvedic Manufacturing in Kerala. *Economic and Political Weekly*, 44-51.

Hindu Business Line, The, 2018. *Ayurveda Sector Touches \$4.4 Billion Market Size: Study*. Published online 19 November 2018. Available at: <https://www.thehindubusinessline.com/news/ayurveda-sector-touches-44-billion-market-size-study/article25539687.ece>.

Hindu Business Line, The, 2021. *Auto Hub Starved of Industrial Oxygen as Covid-19 Crisis Worsens*. Published online 12 April 2021. Available at: <https://www.thehindubusinessline.com/news/auto-hub-starved-of-industrial-oxygen-as-covid-19-crisis-worsens/article34302065.ece>.

Hixenbaugh, M., Trevizo, P. and Churchill, L., 2021. *Texas Recovering from COVID-19 Needed Oxygen. Then the Power Went Out*. ProPublica. Published online 9 March 2021. Available at:

- <https://www.msn.com/en-us/health/medical/texans-recovering-from-covid-19-needed-oxygen-then-the-power-went-out/ar-BB1epIBU>.
- Holmes, E. and Elaroussi, A., 2021. First, Surges in Covid-19 Infections Led to Shortages of Hospital Beds and Staff. Now it's Oxygen. *CNN*. Published online 30 August 2021. Available at: <https://edition.cnn.com/2021/08/29/health/us-coronavirus-sunday/index.html>.
- Jestin, P., 2021. *India's Oxygen Shortage Slowing Down Industrial Production*. Independent Commodity Intelligence Services (ICIS). Published online 6 May 2021. Available at: <https://www.icis.com/explore/resources/news/2021/05/06/10635697/india-s-oxygen-shortage-slowing-down-industrial-production>.
- Kamath, P., 2021. 'Not Allopathy Vs Ayurveda But Misinformation & Vested Interest': IMA To PM On Baba Ramdev. *RepublicWorld.com*. Published online 6 June 2021. Available at: <https://www.republicworld.com/lifestyle/health/not-allopathy-vs-ayurveda-but-misinformation-and-vested-interest-ima-to-pm-on-baba-ramdev.html>.
- Kaul, R., 2021. Ayush Ministry to Launch Portal to Document Alternate Therapy Outcomes. *Hindustani Times*. Published online at MSN.com 27 May 2021. Available at: <https://www.msn.com/en-in/news/newsindia/ayush-ministry-to-launch-portal-to-document-alternate-therapy-outcomes/ar-AAKqsVz>.
- Keohane, K. and Miller, J., 2020. Oxygen Suppliers Push for Looser Regulations. *Financial Times*. Published online 26 March 2020. Available at: <https://www.ft.com/content/013d3bb8-5d4a-4cac-a53f-5eb44303d6eb>.
- Kumar Das, A., 2021. With Over 20,000 Tonnes of Oxygen Delivery, Indian Railways Marks Yet Another Milestone. *Swarajyamag*. Published online 30 May 2021. Available at: <https://swarajyamag.com/news-brief/with-over-20000-tonnes-of-oxygen-delivery-indian-railways-marks-yet-another-milestone>.
- Leatherby, L., Keefe, J., Tompkins, L., Smart, C. and Conlen, M., 2021. There's No Place for Them to Go: ICU Beds Near Capacity Across the U.S. *New York Times*. Published online 9 December 2020. Available at: <https://www.nytimes.com/interactive/2020/12/09/us/covid-hospitals-icu-capacity.html>.
- Mackintosh, M., Banda, M., Wamae, W. and Tibandebage, P., 2016. *Making Medicines in Africa: The Political Economy of Industrializing for Local Health*. Cheltenham: Palgrave MacMillan.
- Madhavan, H. and Gaudillière, J-P., 2020. Reformulation and Appropriation of Traditional Knowledge in Industrial Ayurveda: The Trajectory of Jeevani. *East Asian Science, Technology and Society*. 14(4), pp. 603–621.
- Melley, B., 2021. California Hospital, in Midst of COVID-19 Crisis, Maxes Out. *Medical Express*. Published online 6 January 2021. Available at: <https://medicalxpress.com/news/2021-01-california-hospital-midst-covid-crisis.html>.
- Mishra, K., 2021. Ayurvedic Drugs Effective in Mild to Moderate Covid Cases. *Times of India*. Published online 29 May 2021. Available at: <http://timesofindia.indiatimes.com/articleshow/82486888.cms>.

- Mittal, A., 2020. Nov “Ayurvedic Products, Local Wellness Practices Big Hit During Covid Times. *The Economic Times*. Published online 20 November 2020. Available at: <https://economictimes.indiatimes.com/magazines/panache/local-wellness-practices-find-many-takers-in-covid-times/articleshow/79416118.cms>.
- Moole, J., 2021. A Nightmare on Repeat - India is Running Out of Oxygen Again. *BBCNews*. Published online 23 April 2021. Available at: <https://www.bbc.com/news/uk-56841381>.
- Mukul, J., 2021. INOX Air Products Announces Rs 2,000 cr Investment in Industrial Gases. *Business Standard*. Published online 19 February 2021. Available at: https://www.business-standard.com/article/companies/inox-air-products-announces-rs-2-000-cr-investment-in-industrial-gases-121021900512_1.html.
- Murphy, P., 2020. There is a Shortage of Oxygen Tanks in this New York City Hospital. *CNN*. Published online 30 March 2020. Available at: https://edition.cnn.com/world/live-news/coronavirus-outbreak-03-30-20-intl-hnk/h_a2baf-110ce6d017101728193fdb3dd5f.
- Muthukumar, R., 2021. *How an ‘Uber’ for Oxygen Concentrators Helps Bengalureans Use The Machines for Free*. The Better India Community. Published online 19 May 2021. Available at: <https://www.thebetterindia.com/255305/oxygen-concentrators-in-bengaluru-isb-alumni-volunteer-community-citizen-initiative-oxygen4blr-free-service-covid-19-pandemic-coronavirus-second-wave-ros174/>.
- News18, 2021. *Oxygen, Beds, Medicines and Mismanagement: High Courts Pull up Centre, States Govts as Covid Rages*. Published online 20 April 2021. Available at: <https://in.news.yahoo.com/oxygen-beds-medicines-mismanagement-high-125300568.html>.
- New Statesman, 2021. *PM to Dedicate 35 PSA Oxygen Plants Estd Under PM Cares to States, UTs*. Published online 6 October 2021. Available at: <https://www.thestatesman.com/india/modi-dedicate-35-psa-oxygen-plants-across-35-states-uts-thur-1503015290.html>.
- Nitnaware, H., 2021. *COVID-19: How ‘Oxygen-at-Home’ via Concentrators Can Be a Life Saver*. The Better India Community. Published online 22 April 2021. Available at: <https://www.thebetterindia.com/253282/oxygen-concentrator-covid-19-patients-coronavirus-second-wave-ima-pune-aarti-nikar-ventilator-beds-chest-research-foundation-him16/>.
- Office of the Prime Minister of India, 2021. *PM CARES Fund Trust allocates Rs.201.58 Crores for Installation of 162 Dedicated PSA Medical Oxygen Generation Plants in Public Health Facilities*. Press release. Published online 5 January 2021. Available at: https://www.pmindia.gov.in/en/news_updates/pm-cares-fund-trust-allocates-rs-201-58-crores-for-installation-of-162-dedicated-psa-medical-oxygen-generation-plants-in-public-health-facilities/.
- OmmcomNews, 2021. *Inox Meets India’s 60% Oxygen Need, Reduces Bottlenecks*. Published online 22 April 2021. Available at: <https://ommcomnews.com/business-news/inox-meets-indias-60-oxygen-need-reduces-bottlenecks>.
- Pant, J., Singh, R.M., and Marwah, H., 2021. Methods Employed in Quality Control in Ayurveda. *Journal of Medicinal Plants Studies*, 9(3), pp. 141-155.

- Papaioannou, T., Watkins, A., Mugwagwa, J. and Kale, D., 2016. To Lobby or To Partner? Investigating the Shifting Political Strategies of Biopharmaceutical Industry Associations in Innovation Systems of South Africa and India. *World Development*, 78, pp. 66-79.
- Parker, N., 2021. Suicide on Streets. Covid Victims in India ‘Jumping Off Buildings’ as Oxygen Supplies and Beds Run Out at Hospitals. *The Sun*. Published online 26 April 2021. Available at: <https://www.thesun.co.uk/news/14773381/covid-victims-india-jumping-off-buildings/>.
- Patil, A., 2021. As the Coronavirus Rages in California, L.A. Medics are Told to Ration Oxygen. *New York Times*. Published online 5 January 2021. Available at: <https://www.nytimes.com/2021/01/05/world/california-covid-oxygen-coronavirus.html>.
- Pettersson, H., Manley, B. and Hernandez, S., 2021a. Tracking COVID-19 Global Spread. *CNNHealth*. Available at: <https://edition.cnn.com/interactive/2020/health/coronavirus-maps-and-cases/> [Accessed 11 October 2021].
- Pettersson, H., Manley, B., Hernandez, S., McPhillips, D. and Arias, T., 2021b. Tracking COVID-19 Infections Worldwide. *CNNHealth*. Available at: <https://edition.cnn.com/interactive/2021/health/global-covid-vaccinations/> [Accessed 28 June 2021].
- Press Trust of India, 2021. Kejriwal Govt Responsible for Recent Medical Oxygen Shortage In Delhi: BJP. *Republic World*. Published online 20 May 2021. Available at: <https://www.republicworld.com/india-news/politics/kejriwal-govt-responsible-for-recent-medical-oxygen-shortage-in-delhi-bjp.html>.
- Reddy, J., 2021. Andhra is Managing its Medical Oxygen Supply but Grappling with Distribution. *The News Minute*. Published online 23 April 2021. Available at: <https://www.thenewsminute.com/article/andhra-managing-its-medical-oxygen-supply-grappling-distribution-147706>.
- Rastogi, S., Pandey, D.N. and Singh, R.H., 2020. COVID-19 Pandemic: A Pragmatic Plan for Ayurveda Intervention. *Journal of Ayurveda and Integrative Medicine*. Published online 23 April 2020.
- Saaliq, S., 2021. Open-Air Cremations, Oxygen Shortages and Panic as Coronavirus Overwhelms India. *Los Angeles Times*. Published online 26 April 2021. Available at: <https://www.latimes.com/world-nation/story/2021-04-26/cremations-lack-of-oxygen-panic-coronavirus-overwhelm-india>.
- Salyer, S., Maeda, J., et al., 2021. The First and Second Waves of the COVID-19 Pandemic in Africa: a Cross-Sectional Study. *The Lancet*, 397(10281), pp. 1265-1275.
- Sarkar, K., 2021. ‘Delhi Got More Oxygen than they Asked, Up to AAP Govt to Rationalise’: Harsh Vardhan. *Hindustan Times*. Published online 24 April 2021. Available at: <https://www.hindustantimes.com/cities/delhi-news/delhi-given-more-oxygen-than-they-asked-upto-aap-govt-to-rationalise-harsh-varadhan-101619278415820.html>.
- Shandilya, A., 2021. ‘Mission Oxygen’: India Inc Action Plan to Combat Oxygen Shortage. *NewsX*. Published online 24 April 2021. Available at:

<https://www.newsx.com/national/mission-oxygen-india-inc-action-plan-to-combat-oxygen-shortage.html>.

Sharma, N., 2021. "Nobody is understanding the challenges of supplying oxygen to a nation that is at war." *Quartz India*. Published online 12 May 2021. Available at: <https://qz.com/india/2006925/indias-largest-oxygen-maker-inox-explains-why-theres-a-shortage/>.

Sharma, P., 2021. PM Modi Dedicates 35 PSA Oxygen Plants to Nation Under PM CARES. *Republic World*. Published online 7 Oct 2021, Available at: <https://www.republicworld.com/india-news/general-news/pm-modi-dedicates-35-psa-oxygen-plants-to-nation-under-pm-cares.html>.

Shirkande, A.S. and Shirkande, A.A., 2021. Ayurvedic Evaluation and Treatment of Covid 19: A Case Report. *Journal of Ayurveda and Integrative Medicine*. Published online 14 July 2021. Available at: <https://www.sciencedirect.com/science/article/pii/S0975947621001364?via%3Dihub>.

Smith, L., Baker, T., Demombynes, G. and P. Yadav, P., 2020. *COVID-19 and Oxygen: Selecting Supply Options in LMICs that Balance Immediate Needs with Long-Term Cost-Effectiveness*. Centre for Global Development. Published online: 5 May 2020. Available at: <https://www.cgdev.org/publication/covid-19-and-oxygen-selecting-supply-options-lmics-balance-immediate-needs-long-term>.

Srinivas, S., 2012. *Market Menagerie: Health and Development in Late Industrial States*. Palo Alto: Stanford University Press.

Srinivas, S., 2016. Healthy Industries, Unhealthy Populations: Lessons from Indian Problem-Solving. In: *Making Medicines in Africa: The Political Economy of Industrializing for Local Health*, eds., M. Mackintosh, G. Banda, W. Wamae and P. Tibandebage, pp. 183-189, Cheltenham: Palgrave MacMillan.

Srinivas, S., 2020a. A New Economics for Health. In: *Health of the Nation: Perspective for a New India*, eds., A. Mehdi and I. Rajan, Oxford: Oxford University Press.

Srinivas, S., 2020b. Institutional Variety and the Future of Economics. *Review of Evolutionary Political Economy*, 1, pp. 13–35.

Srinivas, S., 2021a. Heuristics and the Microeconomics of Innovation and Development. *Innovation and Development*. Published online 22 October 2021. Available online: <https://www.tandfonline.com/doi/full/10.1080/2157930X.2021.1986894>.

Srinivas, S., 2021b. Industrial Policies for Health: The G20 Must Act Now. *The International Spectator*. IAI Commentaries. Rome: Istituto Affari Internazionali (IAI).

Srinivas, S. & D. Kale (2022) New approaches to learning and regulation in medical devices and diagnostics: insights from Indian cancer care, *Innovation and Development*, DOI: [10.1080/2157930X.2021.2000145](https://doi.org/10.1080/2157930X.2021.2000145)

Srinivas, S., Prasad, R.K. and Rao, P., 2020. *The Clinical Foreground and Industrial Background: Customizing National Strategy for COVID-19 Testing*. IKD Working Paper

- Series No. 87. Innovation Knowledge Development. Milton Keynes: The Open University. Available at: <http://www.open.ac.uk/ikd/publications/working-papers/87>.
- Sutton, C., 2021. Los Angeles Issues Brutal Letter: Do Not Treat Dying Patients. *News.com.au*. Published online 5 January 2021. Available at: <https://www.news.com.au/world/north-america/los-angeles-issues-brutal-letter-do-not-treat-dying-patients/news-story/d7d1c44e21c7abf636010c605d45a221>.
- Thadhani, A., 2021. *Preventing a Repeat of the COVID-19 Second-Wave Oxygen Crisis in India*. ORF Special Report No. 151. New Delhi: Observer Research Foundation (ORF).
- The Week, 2021. 'Attempt to Tarnish Me': IMA Chief on Christian Conversion claims Amid Ramdev Row. Published online 26 May 2021. Available at: <https://www.theweek.in/news/india/2021/05/26/attempt-to-tarnish-me-ima-chief-on-christian-conversion-claims-amid-ramdev-row.html>.
- Times of India, 2021a. *AAP Government was not Serious about Oxygen Needs of Patients: BJP*. Published online 20 May 2021. Available at: <https://timesofindia.indiatimes.com/city/delhi/govt-was-not-serious-about-oxygen-needs-of-patients-bjp/articleshow/82781290.cms?>
- Times of India, 2021b. *Centre Looking into Mumbai's Experience of Using Oxygen*. Published online 5 May 2021. Available at: <http://timesofindia.indiatimes.com/articleshow/82395073.cms>.
- Times of India, 2021c. *Maharashtra: High-flow Tube is Guzzler of Oxygen, Avoid It, Says Task Force*. Published online 16 April 2021. Available at: <https://timesofindia.indiatimes.com/city/mumbai/maharashtra-high-flow-tube-is-guzzler-of-oxygen-avoid-it-says-task-force/articleshow/82091980.cms>.
- Times of India, 2021d. *Steel, oil industry supplying 6,650 MT oxygen per day; setting health infra: Dharmendra Pradhan*. Published online 16 May 2021. Available at: <https://economictimes.indiatimes.com/news/india/steel-oil-industry-supplying-6650-mt-oxygen-per-day-setting-health-infra-dharmendra-pradhan/articleshow/82681240.cms>.
- TimesNowNews, 2021. *Green Tea May Help Fight COVID-19: Study - 5 Reasons Why You Should Add this Beverage to your Diet*. Published online 7 June 2021. Available at: <https://www.timesnownews.com/health/article/green-tea-may-help-fight-covid-19-study-5-reasons-why-you-should-add-this-beverage-to-your-diet/766934>.
- Toner, E., 2021. *Potential Solutions to the COVID-19 Oxygen Crisis in the United States*. Johns Hopkins Center for Health Security. Baltimore: Johns Hopkins University.
- Upadhyaya, K., 2011. *A Comprehensive Study on Standardization and Quality Control of Medical Plant Raw Materials with Special Reference to the plant Species Traded Under the Name 'Bala'*. Dissertation (Rajasthan University, Jodhpur, 2011).
- Watkins, A., Papaioannou, T., Mugwagwa, J., and Kale, D., 2015. National Innovation Systems and the Intermediary Role of Industry Associations in Building Institutional Capacities for Innovation in Developing countries: A Critical Review of the Literature. *Research Policy*, 44(8), pp. 1407-1418.

Weber, C., 2021. California Reports a Record 585 Virus Deaths in Single Day. *NBC Bay Area*. Published online 1 January 2021. Available at: <https://www.nbcbayarea.com/news/california/california-reports-a-record-585-virus-deaths-in-one-day/2435111/>.

WHO (World Health Organization), 2002. *Traditional Medicines, Growing Needs and Potential*. WHO Policy Perspectives on Medicines, No. 2. Geneva: World Health Organization.

WHO (World Health Organization), 2003. *WHO Guidelines on Good Agricultural and Collection Practices (GACP) for Medicinal Plants*. Geneva: World Health Organization.



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