

Discussion
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Post COVID-19 Challenges of Pharmaceutical Industry in Thailand

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Abstract

From the past to the present, Thailand's pharmaceutical sector has remained in the imitation stage. In other words, it develops generic drugs after the original's patents have expired and their monopoly rights no longer exist. While, biologics and vaccines are still in the early stages of development. R&D, innovation, and technological investment are restricted because they demand a significant budget for development. However, the coronavirus disease 2019 (COVID-19) pandemic expanded globally in late 2019, affecting millions of people around the globe. To handle this health emergency, the scientific community in Thailand has organised the flow of research and development, particularly research on the COVID-19 vaccine, in order to lessen the adverse health impact. The R&D activities have been activated to expedite the development of all vaccine platforms for this novel coronavirus, and all R&D efforts in Thailand have been enhanced throughout the whole pharmaceutical supply chain. The significant advancement in the development of the COVID-19 vaccine has created various challenges for Thailand's pharmaceutical industry in the near future. For example, the development of the COVID-19 vaccine presents an opportunity for Thailand's pharmaceutical industry to sustainably boost innovation, including related R&D infrastructure. Supporting fundraising activities in order to match innovators with investors. To develop such a mechanism will enable collaboration between science, academia, and business. This challenge includes the future high demand for pharmaceutical products, which is critical for health security issues. In conclusion, these challenges highlight the need for appropriate policy to improve Thailand's pharmaceutical industry.

Keywords: Thailand's pharmaceutical industry, industrial development, pharmaceutical supply chain

JEL Classification: F13, L52, L65, O14, O24, O32

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1. Introduction

The Thai government aims to develop the pharmaceutical sector as a key part of its medical hub industry, which is one of its new S-curve industries. This is part of their plan for a new model of economic development that prioritizes to upgrade technology, innovation, and research and development (R&D). The government has created a policy to make Thailand a major player in the regional medical hub industry (Cabinet resolution, November 17, 2015). Specifically, the development of the pharmaceutical sector is addressed in national drug policies and “*The National Drug System Development Strategies for 2020-2022*,” with a focus on developing vaccines, chemical drugs, active pharmaceutical ingredients (APIs), biologics, and herbal extracts. The goal is to increase competitiveness through R&D, reduce imports, boost exports, and enhance the quality of healthcare for the Thai people (National Drug Policy Group, 2021).

The pharmaceutical industry plays a critical role in maintaining a stable supply of medicines and driving economic development. This is due to several factors such as the emergence of new diseases, rising cases of non-communicable diseases (NCDs), an aging population, and technological advancements. The COVID-19 pandemic has highlighted the importance of being prepared for future health crises by having the manufacturing industry ready and promoting partnerships between academia and other countries for the development of medicine, vaccines, and medical supplies. Effective crisis management requires proper planning and policies in place to respond to outbreaks quickly and effectively.

The primary public health issue in Thailand at present is non-communicable diseases (NCDs) (Non-Communicable Diseases Division, 2020), which are likely to persist due to contemporary lifestyles, unhealthy habits, and environmental factors contributing to accumulated biological risk factors. This results in health conditions such as diabetes, high blood pressure, heart disease, cancer, and kidney disease. Furthermore, as Thailand’s population grows older, with a life expectancy of around 75 years (Department of Older Persons, 2021), there is a growing concern for an aging population that is vulnerable to frailty, chronic illness, and a heightened demand for medical and healthcare services.

The COVID-19 pandemic presents both challenges and opportunities for the pharmaceutical industry. The government has invested significant resources into R&D for COVID-19 vaccines, creating opportunities for industry development. However, the future holds ongoing financial difficulties for the Thai government. Therefore, it is imperative that the government is prepared to address these challenges. The purpose of this research is to better understand the global and Thai pharmaceutical industry in the context of COVID-19, as well as how they have responded to the epidemic. It provides valuable insights into the role of the pharmaceutical industry in managing disease outbreaks and preparing for future public health emergencies. These findings will inform practical policy recommendations for the continued development of the industry, covering original drugs, generic drugs, biologics, and vaccines.

2. Objectives of the Study

2.1. To study the global pharmaceutical industry landscape and assess the capability of Thailand's pharmaceutical industry in the context of the global pharmaceutical industry.

2.2. To study challenging pharmaceutical industry issues in the post-COVID-19 crisis and present government policies related to such challenges.

3. Methods

This study employed a systematic investigation and comprehensive analysis, including in-depth interviews covering issues according to the research objectives, to evaluate the readiness and capability of Thailand's pharmaceutical industry to deal with the industry's challenges after the COVID-19 crisis. The study was divided into three approaches:

Method 1 Literature Investigation: This entails examining, integrating, and interpreting data from scholarly articles, research studies, and relevant government documents. It makes use of facts and statistics from these sources as supporting evidence for the analysis.

Method 2 Examination of Secondary Data: This involves interpreting data through applicable economic and statistical methodologies and markers. For example, the Herfindahl-Hirschman Index (HHI) is calculated to determine the concentration structure of exports, the Concentration Ratio (CR) is computed to scrutinize the concentration structures within industries, and the Import Dependency Ratio (IDR) is used to evaluate the dependency on imports for specific pharmaceutical goods. Drug demand forecasting is also conducted via the Linear Trend Model technique. Further explanation on the calculation methods can be found in Appendix B.

Method 3 In-depth Interview: This method incorporates discussions with representatives from the pharmaceutical industry, supporting sectors, and related government agencies. This conducted interviews with seven in-house researchers and entrepreneurs from academic institutions, the private sector, and state enterprises in the biological and vaccine sectors, four entrepreneurs in the chemical pharmaceutical industries, and representatives of the Thai Modern Medicine Industry Association. (Additional details on data sources are in Appendix D.)

4. Scope of Study and Definitions of Related Terms

This research was carried out in the setting of Thailand's pharmaceutical industry, with a primary emphasis on local pharmaceutical production. The investigation covered modern medications utilized in human healthcare, such as brand-name drugs, generic medications, biologics, and vaccines. However, the study did not include herbal medicines and traditional drug formulations.

The definitions of key terms are as follows:

Original or brand-name drugs refer to chemical medications that have been invented, studied, and evolved into unique drug formulations through patented pharmacological procedures. These drugs have been tested for their efficacy and efficiency in disease treatment.

Generic drugs are medications composed of active components that adhere to the same quality and safety benchmarks as brand-name or original drugs. They are typically produced once the patent of the original drug has expired, providing a more cost-effective alternative while maintaining the therapeutic benefits of their brand-name counterparts.

Biologics are medicinal products derived from living entities using biotechnological methods and expertise. As per the declaration from the Ministry of Health, biologic medicines are categorized into four groups: vaccines, serums, products isolated from blood or plasma, and substances utilized for disease diagnosis. These medicines, given their biological origin, often offer targeted and sophisticated treatment approaches for various health conditions. (Government Gazette, Volume 135, Special Section 160(Nor), 6 July 2018)

5. Results

The findings of the research are segmented into three primary topics: *Topic 1* introduces the Global Pharmaceutical Industry Landscape, aimed at understanding the international pharmaceutical industry via aspects of industry wave changes, the influence of research and development (R&D) on industry structure, and the dynamics of industrial structural shifts. *Topic 2* demonstrates the structure and degree of technological advancement in Thailand's pharmaceutical industry. It provides a comparison between the supply chain structures of Thailand's pharmaceutical industry and the global pharmaceutical industry and evaluates the level of technological progression and innovation in Thailand's pharmaceutical industry. *Topic 3* outlines the impacts and challenges stemming from the COVID-19 crisis, elucidating the effects of the COVID-19 pandemic. Furthermore, the discussion highlights challenges faced by the pharmaceutical industry, including the requirement for R&D to boost the industry's development, the interconnection between academic institutions and the industry, and the increasing demand pressure on domestic medications.

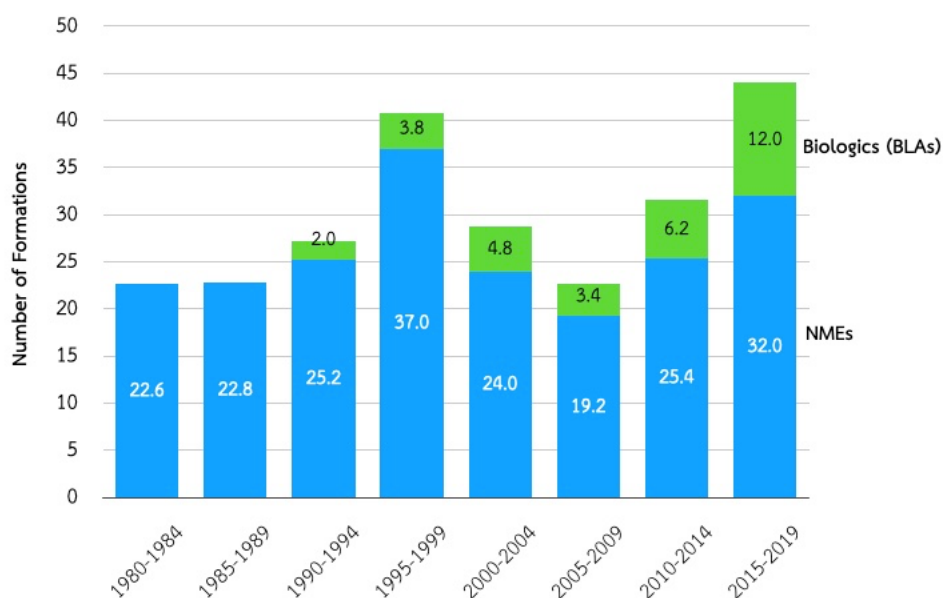
5.1 Global Pharmaceutical Industry Landscape

5.1.1 Waves of change in the pharmaceutical industry

The pharmaceutical industry, from its inception to the present day, has undergone four major transformative waves. *The first wave*, tracing back to the late 1980s and early 1990s, laid the groundwork for the modern pharmaceutical industry through significant advancements in modern pharmacology and organic chemistry. This era witnessed the birth and development of multinational pharmaceutical giants such as Merck, Eli Lilly, Roche, Bayer, and Pfizer & Sandoz (Taylor, 2015). The subsequent phase, termed *the second wave*, was characterized by the "*patent cliff*" phenomenon, where multiple blockbuster drugs (those generating over \$1 billion in annual sales) simultaneously lost their patent protection (Lines, 2012). This opened up opportunities for existing players to venture into the generic drug market via authorized generic strategies or other approaches to offset the dip in revenue (Chao et al., 2016; Song & Han, 2016). In addition, the entrance of new generic drug manufacturers altered the industry's competitive landscape and

drug pricing structures. Structural changes also occurred in emerging export nations such as China and India, which started producing generic drugs to compete for a larger global export share. *The third wave* is marked by a transition towards the development of biologics, viewed as a ground-breaking innovation in the pharmaceutical industry, largely powered by advancements in biotechnological science. Since the 1990s, the US Food and Drug Administration (FDA) has noted a consistent rise in the approval of biological drugs relative to chemical ones (refer to *Figure 1*). However, the discovery and development costs for biological drugs are typically higher than for their chemical counterparts, which consequently leads to elevated drug prices. This restricts access to these medicines primarily to wealthier population segments (Makurvet, 2021).

Figure 1: Average Annual Number of Formulations Approved by the Food and Drug Administration



Source: Congressional Budget Office (as of January 10, 2022)

- Note: 1) FDA is the U.S. Food and Drug Administration;
 2) NME is New molecular entity
 3) Biological Drug Registrations (BLAs) before 1990 are included in NMEs.

This issue of access and affordability is a global concern for policymakers. Notably, the advent of biosimilar drug development has the potential to make medication more affordable and accessible. The regulatory sector's engagement in this area is evident, with agencies like the European Medicines Agency (EMA) in Europe and the FDA in the United States having established clear policies to encourage the development of biosimilar drugs (Gherghescu and Delgado-Charro, 2020; Makurvet, 2021). *The fourth wave* is characterized by the “*The future of*

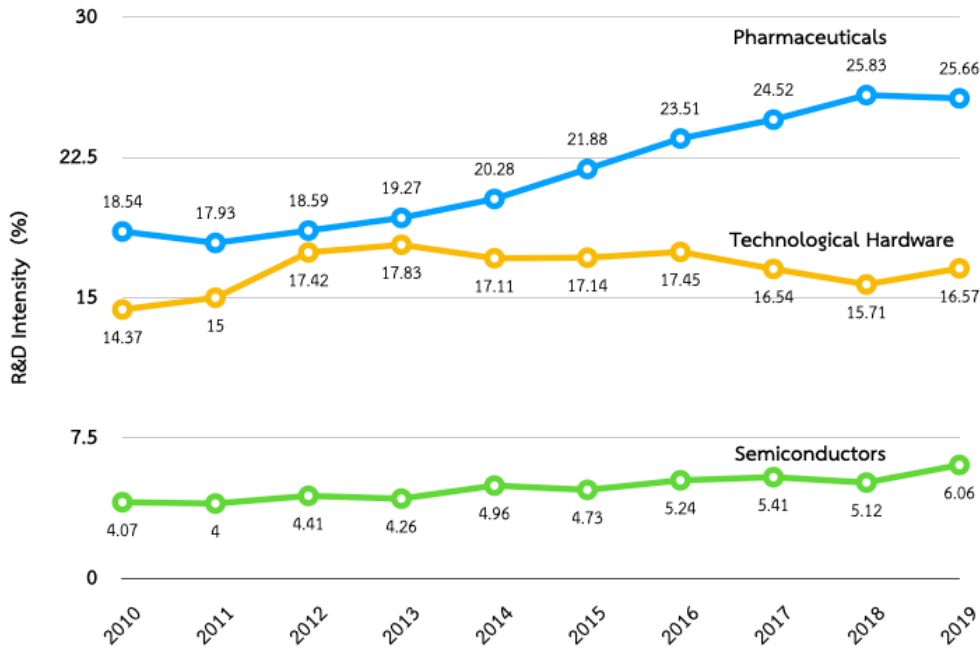
drug discovery and development". This signifies a transformation in the pharmaceutical industry landscape due to limitations encountered with traditional drug development methods. These older methods were found to be less adaptive to innovations due to their inherent restrictions and outdated nature. Specifically, disruptive technologies have greatly influenced the rapidly evolving public health ecosystem, encompassing both technology and new paradigms of drug discovery and R&D. These technologies and paradigms aim to speed up clinical trials, reduce failure rates, mitigate risks associated with R&D, and enhance the overall performance of drug research and development using tools such as artificial intelligence (AI) and future applications of databases and big data analytics. Another driving factor in this wave is the shifting paradigm in disease treatment. Future drug development aims for increased precision and personalized medicine (Harvey et al., 2012; Archanun et al., 2022). This patient-centered drug development necessitates the capability to analyse data to identify biomarkers for predicting, diagnosing, or even treating specific subtypes of certain diseases. This progression marks a departure from the traditional paradigm of "*one-size-fits-all medicine*", where a single type of treatment is expected to cure all patients. It indicates a move towards precision medicine, guided by the principle of delivering the right medicine, to the right patient, in the right dosage, at the right time (Hartl et al., 2021).

5.1.2 R&D Intensity and Its Impact on the Pharmaceutical Industry Structure

The pharmaceutical industry is fundamentally a science-based sector that heavily relies on advanced scientific knowledge for drug discovery and development (Pla-Barber & Alegre, 2007). It is an industry propelled by innovation, underscored by substantial investments in rigorous R&D activities. With an average R&D investment-to-sale ratio or R&D intensity, reaching approximately 20%, it exceeds other industries harnessing high-level technology in comparison (refer to *Figure 2*). Given the substantial investment required for R&D, the strategic approach of globally renowned pharmaceutical corporations necessitates funding into medications with high market potential that can be distributed on a global scale. This tactic enables the production of large volumes while decreasing the average cost per unit, effectively taking advantage of economies of scale.

The research and development process for each drug formula takes about 13 years to reach the market (Pinnow et al., 2017), requiring a significant investment and a longer timeframe to generate income compared to typical business operations (refer to *Figure 3*). Innovation investment in the pharmaceutical industry is notably costly and coupled with the long waiting time for generating income, presenting a considerable obstacle and a natural barrier to entry into the industry's drug discovery and development market. The success rate for drug development is relatively low, with only about 13.8% of drugs reaching market approval (Wong et al., 2018), making it a risky venture. Wouters et al. (2020) analysed the cost structure of research and development for 63 chemical drugs and biologics disclosed in four official US databases from 2009 to 2018: the US Securities and Exchange Commission, the Drugs@FDA database, ClinicalTrials.gov, and documents detailing drug development success rates. They found the median drug R&D cost to be \$985.3 million (95% CI, \$683.6 million to \$1,228.9 million).

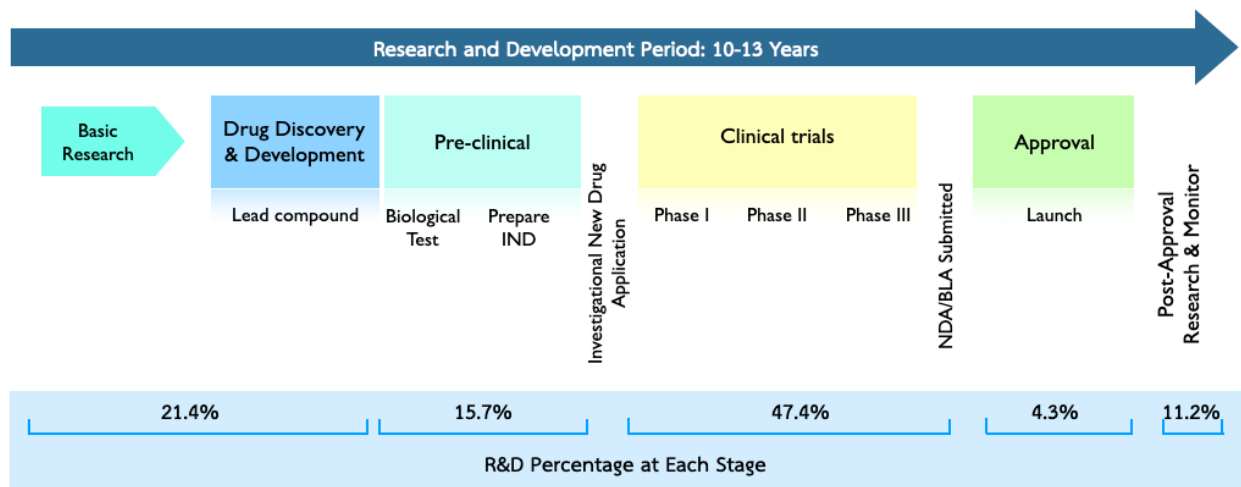
Figure 2: Comparison of R&D Intensity in Pharmaceutical vs. Other High-Tech Industries



Source: Congressional Budget Office (as of January 10, 2022)

- Notes:
- 1) R&D intensity means the ratio of research investment value compared to income.
 - 2) The above data shows US companies' average value, representing industrialized countries driven by advanced technology.

Figure 3: The R&D investment ratio throughout the pharmaceutical industry chain

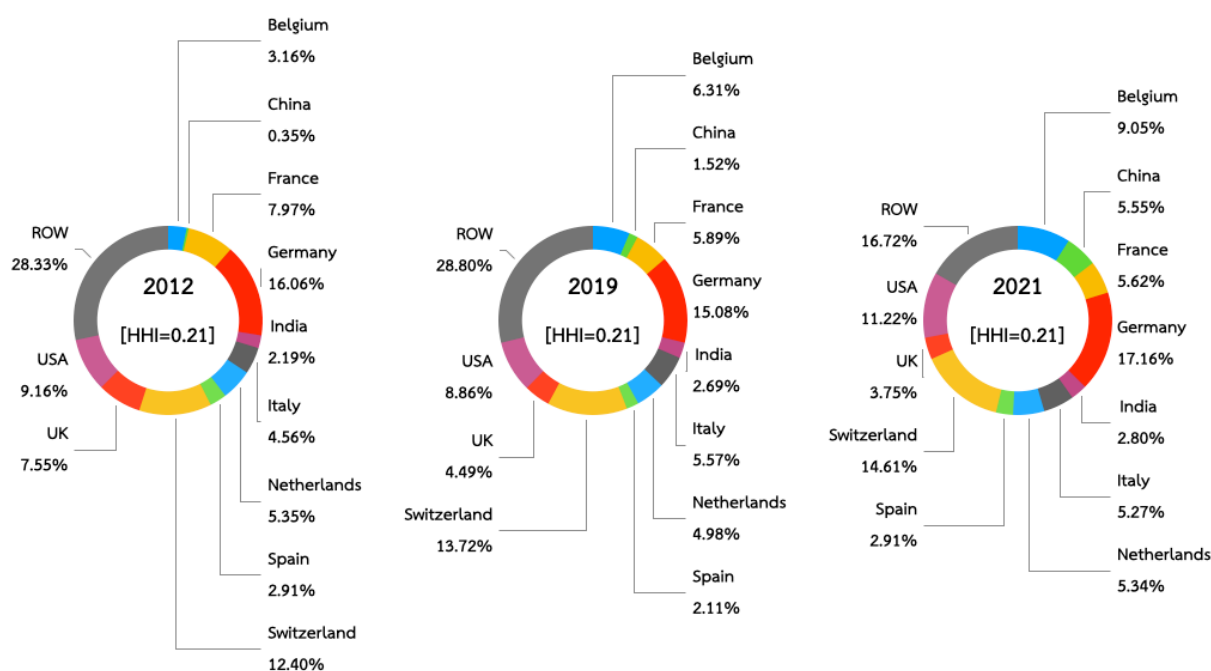


Source: European Federation of Pharmaceutical Industries and Associations (2021)

Given these challenges, companies with the potential to succeed in this field are predominantly multinational corporations (MNCs) located in developed countries. These corporations' benefit from substantial capital availability, advanced technology, skilled personnel (scientists), and a broad global export market base.

In analysing the global market for pharmaceutical exports using the Herfindahl–Hirschman Index (HHI) and international trade data from the UN Comtrade database, according to the 6-digit level Harmonised System Code 2022 (HS2022) for pharmaceutical products (HS 30), we found that the average export concentration from 2012 to 2021 was approximately 0.21. This indicates a relatively low concentration of exports. The dominant exporting countries largely maintained their share of the global export market prior to the COVID-19 crisis (2012-2019). However, the structure of export ratios shifted significantly in 2021 due to the impact of the COVID-19 crisis, particularly favouring countries that possess COVID-19 vaccine technology and production capabilities. These countries, including Germany, the United States, and China, which host vaccine technology and manufacturing facilities, along with Switzerland and Belgium, known for vaccine production, saw their export shares increase substantially post-COVID-19 crisis (refer to *Figure 4*). The concentration structure and proportion of pharmaceutical exports in the global market are unlikely to change significantly in the near future. This stability can be attributed to the capital advantages and technological advancements that enable a constant level of R&D. Additionally, experience in foreign markets allows multinational pharmaceutical companies to gain a thorough understanding of regulatory mechanisms and registration systems in destination countries.

Figure 4: Export Value Share and HHI Index in 2012, 2019 and 2021



Source: Calculated by the author based on the UN Comtrade database.

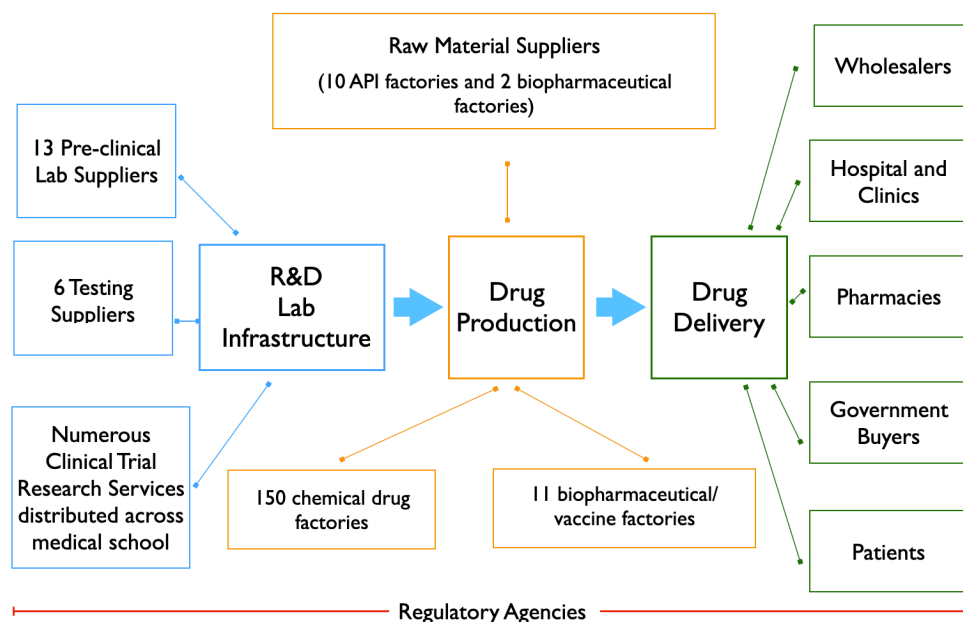
5.2 Technological advancement of Thailand's pharmaceutical industry

Compared to the overall global pharmaceutical industry, Thailand's pharmaceutical industry is in the Imitation Stage of development, according to the innovation development stages outlined by Muller and Tilton (1969). This stage focuses on producing generic drugs after the patents of original drugs have expired, eliminating the possibility of monopolization. Despite this, Thai generics play a crucial role in Thailand's public health system, which relies on low-cost medicines to manage drug costs under the Universal Health Coverage Scheme. While biologics and vaccines are still in the early stages of academic and partial commercial development, they are expected to become increasingly important in the future.

5.2.1 Thailand's pharmaceutical industry supply chain

A study on the structure of the Thailand pharmaceutical industry's supply chain was conducted using the analytical framework of Chircu et al. (2014). The main components of the pharmaceutical supply chain are divided into three parts: Part 1: R&D Lab Infrastructure, Part 2: Drug Production, and Part 3: Drug Delivery. This study primarily focuses on Parts 1 and 2, as detailed in the research and analysis presented in *Figure 5*.

Figure 5: The structure of Thailand's pharmaceutical industry



Source: The author revised the drug supply chain mapping framework, drawing from the study by Chircu et al. (2014), to align with the National Vaccine Security Policy and Strategy for 2023-2027. This revision was based on the “Modern Drug Production Facility Certification Situation” report published by the Food and Drug Administration (FDA) and information from websites of related companies and institutions.

Notes: 1) Latest factory information as of July 2022.

2) Factories may produce more than one activity, excluding factories in the inspection plan.

Part 1 R&D Lab Infrastructure: The research and development infrastructure supporting the Thai pharmaceutical industry includes government services, educational institutes, and the private sector, divided into three main areas.

Pre-clinical laboratory animal centers, which comprise two private centers, M-Clear Io Resources Co., Ltd. and Nomura Siam International Co., Ltd., along with ten additional centers. These include the National Laboratory Animal Center at Mahidol University, the Northeastern Laboratory Animal Center at Khon Kaen University, the Laboratory Animal Center at Thammasat University, the National Primate Research Center of Thailand at Chulalongkorn University, and the Laboratory Animal Center at the Thailand Institute of Scientific and Technological Research.

Testing centers, consisting of the public National Institute of Health of Thailand, the Department of Medical Sciences (with an emphasis on toxicity studies), the Institute of Biological Products (focusing on the quality of medicines, biologics/vaccines), the National Center for Genetic Engineering and Biotechnology (specializing in extract analysis), the Biopharmaceutical Characterization Laboratory (BPCL), the Expert Centre of Innovative Herbal Products, the NSTDA Characterization and Testing Service Center (NCTC), and the National Biopharmaceutical Facility.

Clinical Trial Research Services, offered at medical schools and hospitals in the form of project-based research, involve collaboration from the public and private sectors, along with medical institutions participating in the research projects.

Part 2 Drug Production: The structure of Thailand's pharmaceutical industry can be divided into three main categories based on production activities: chemical drug manufacturers (including both original and generic drugs), manufacturers of biological drugs and vaccines, and producers of Active Pharmaceutical Ingredients (APIs) and biopharmaceuticals, detailed as follows.

Chemical Drugs: Chemical drug manufacturers are central to Thailand's pharmaceutical industry, producing both generic and original drugs. Nationwide, there are 150 certified standard factories and 862 private entrepreneurs manufacturing pharmaceuticals and chemicals for disease treatment. Pharmaceutical production may be conducted in-house or outsourced to contract manufacturers for domestic and international pharmaceutical companies under Original Design Manufacturer (ODM) and Original Equipment Manufacturer (OEM) models. Additionally, the Government Pharmaceutical Organization and the Defence Pharmaceutical Factory, as government and state enterprises, play crucial roles in the industry. The industry concentration ratio (CR), calculated from the revenue share of the top four and eight operators, reveals $CR_4 = 0.31$ and $CR_8 = 0.38$. This suggests that, despite numerous market participants, a few dominant entrepreneurs significantly impact the industry. However, this observation does not fully explain the industry's competitiveness, which is influenced by the unique medicinal properties of drugs treating specific diseases and often sees limited competition. Interviews also revealed that the private sector typically avoids producing drugs that are also made by the Government

Pharmaceutical Organization due to disadvantages related to government procurement requirements.

Biologics/Vaccines: The biologics and vaccine sector is still in the early development stages, with potential demonstrated by five entrepreneurs from both state enterprises and the private sector. Notable entities include Bionet-Asia Co., Ltd., Siam Bioscience Co., Ltd., Thai Red Cross Society, the Government Pharmaceutical Organization, and the Pharmaceutical Organization-Merrier joint venture. Additionally, academic and scientific institutions are initiating research projects and developing infrastructure for the future growth of the biologics and vaccine industries. Collaborations include the National Biopharmaceutical Facility by King Mongkut's University of Technology Thonburi (KMUTT) with the National Science and Technology Development Agency (NSTDA), the Center for Vaccine Development at Mahidol University, and the Vaccine Research Center at Chulalongkorn University.

Active Pharmaceutical Ingredients (APIs) and Biopharmaceutical: Among ten API producers, only three focus primarily on producing APIs for direct distribution as raw materials. The rest produce APIs for use in their own finished drugs. Two biopharmaceutical manufacturers, Bionet-Asia Co., Ltd. and Siam Bioscience Co., Ltd., utilize APIs for raw materials and testing in human clinical trials (refer to *Table 1*).

Table 1: List of producers of active pharmaceutical ingredients (APIs) and biopharmaceuticals in Thailand

Producer	Active Pharmaceutical Ingredients (APIs)
1. Solvay Peroxythai Co., Ltd. ^a	Sodium Bicarbonate
2. T.S. Polyproducts Co., Ltd. ^b	Aluminum hydroxide compress gel, Magnesium hydroxide paste
3. Thai Nakorn Phatthana Co., Ltd. ^b	Aluminum hydroxide gel
4. Thai Meiji Pharmaceutical Co., Ltd. ^b	kanamycin (acid) sulfate, Bekanamycin, Gentamicin sulfate, Mamyase
5. Novasil (Thailand) Co., Ltd. ^a	Aspirin, Aspirin Starch
6. Biolab Company Ltd. ^b	Aluminum hydroxide gel
7. Millimed Co., Ltd. ^b	API: Atorvastatin granules, Metformin hydrochloride granules, Glucosamine sulfate granules, Alumina, Magnesia and Simethicone granules, Doxazosin granules, Pioglitazone hydrochloride granules, Glipizide granules, Fexofenadine hydrochloride granules, Paracetamol & Chlorpheniramine maleate and Phenylephrine

Producer	Active Pharmaceutical Ingredients (APIs)
	hydrochloride granules, Paracetamol & Orphenadrine citrate granules, Paracetamol granules, Calcium carbonate granules, Calcium with vitamin D granules, Calcium and vitamin D with minerals granules
8. Linaria Chemical (Thailand) Co., Ltd. ^a	Erythromycin base, Erythromycin stearate, Erythromycin estolate, Erythromycin ethylsuccinate, Pyrazinamide, Rifampicin, Ethambutol hydrochloride
9. Government Pharmaceutical Organization	Deferiprone
10. OLIC (Thailand) Co., Ltd. ^b	Benzocaine Paste 5%
<i>Biologics</i>	
1. Bionet-Asia Co., Ltd. ^c	Vaccine Platform aP, rPT adsorbed bulk, FHA adsorbed bulk
2. Siam Biosciences ^c	PEG-Filgrastim, Filgrastim, Epoetin alpha (Erythropoietin Alfa)

Source: Retrieved from accreditation pharmaceutical manufacturer published by the Food and Drug Administration (2022).

Note: *a* is Company's main business, *b* is Company's finished drugs, and *c* is Company's drugs, vaccines, biologics, and human clinical trials.

In the United States, only 10% of produced active pharmaceutical raw materials (APIs) are used in finished drugs, with the remaining 90% requiring importation, predominantly from China. Nevertheless, the Thai government aims to increase domestic API production, in line with the national drug policy and the National Drug System Development Strategic Plan 2020-2022. However, the private sector's ability to procure cheaper raw materials from international suppliers suggests a need for further research into the implications of such practices on the industry's competitiveness, including a comprehensive cost-benefit analysis.

5.2.2 Technological Advancement and Innovation in Thailand's Pharmaceutical Industry

Myths within the Thai pharmaceutical industry suggest that production is simple because it relies on unskilled labor for the final fill and finish stages. However, insights gained from interviews with leading entrepreneurs among generic drug manufacturers, along with detailed information from Thailand's innovation list, indicate that innovation is indeed required in the production of generic drugs. Bioequivalence studies, for example, are conducted by the company's

R&D department or through joint research projects with the country's scientific, pharmaceutical, and medical institutions. For examples, see *Table 2*.

Table 2: Examples of innovative development characteristics of generic drugs in the Thai Innovation List

Innovation	Company	Innovation Properties
Bestatin (Medicine for abnormal blood lipids)	Berlin Pharmaceutical Industry joint research with Ramathibodi Hospital, Siriraj Hospital, Chulalongkorn Hospital, Police Hospital, Chaingmai University, Phramoongkutkloa Hospital, Maharat Hospital	1) Have done bioequivalence and clinical studies 2) Listed on the new generic product with original drug equivalence
Deferasirox (for iron chelation)	Bio-Lab Co., Ltd.	1) Has done a bioequivalence study. It was found that the pharmacokinetic values were not different from the original drug. 2) It is a drug with a shelf life of 3 years, stored at 30 °C 75% RH, corresponding to the temperature in Thailand.
Etoricoxib (relieve Osteoarthritis)	Polipharm Co., Ltd	1) New generic drugs with original drug equivalence. 2) R&D in the formulation that has good disintegration and dissolution
Fexofenadine Hydrochloride (relieve allergics)	Pharma Nueva Co., Ltd.	1) The development of the 2nd generation Antihistamine reducing side effects (drowsiness) better than the 1st generation.

Source: Compiled from Thai Innovation Database (accessed on 15 July 2022)

The country's leading generic drug manufacturers boast research and development departments and in-house researchers, with relatively high investment levels. The R&D-to-sales ratio exceeds 20%. Notably, these entrepreneurs are capable of developing new generics recently off-patent, along with innovative drug forms, Incremental Modified Drugs (IMD), and Advanced

Therapy Medicinal Products (ATMP), among others. The ability of several entrepreneurs to serve as contract manufacturers for multinational pharmaceutical companies indicates internationally certified production standards, partly because technology transfer for some production activities demands time to meet specific standards.

The manufacturing process for biologics and vaccines is more complex than for generic drugs. Thailand's biochemical medications and vaccines development can be categorized into five groups: Self-developed biologics and vaccines, such as Filgrastim (a white blood cell-enhancing drug) by Siam Bioscience Co., Ltd., Freeze-dried BCG Vaccine by the Thai Red Cross Society, and snake venom serum and rabies vaccine by the Queen Saovabha Memorial Institute. Vaccines producible from start to finish, including the pertussis vaccine with Acellular pertussis technology by Bionet-Asia and the COVID-19 vaccine by Siam Bioscience Co., Ltd., utilizing technology transferred from AstraZeneca. Biological drugs and vaccines produced downstream but requiring technology transfer from the innovators, including Erythropoietin Alfa by Siam Bioscience and various vaccines for Rabies, JE (inactivated), and influenza. Biological medicines undergoing technology transfer and industrial study, such as the collaboration between the Thai Red Cross Society and South Korea's GCC for plasma products and the joint efforts of King Mongkut's University of Technology Thonburi (KMUTT), Biotech, Chulabhorn Research Institute, and international partners on growth hormone, Erythropoietin (pending registration after technology transfer from Biosidus of Argentina), and the anti-cancer drug, Trastuzumab (under study). COVID-19 vaccines currently under research.

The progress in drug and vaccine innovation is marked by its all-stage invention and development process, from inception to national registration and distribution, achieving Technology Readiness Levels (TRLs) of level 9. Examples include Filgrastim by Siam Bioscience Co., Ltd., the Recombinant acellular pertussis vaccine by Bionet-Asia Co., Ltd., and the tetanus toxoid, reduced diphtheria toxoid, and recombinant acellular pertussis vaccine by Bionet-Asia Co., Ltd. This innovation stage involves joint research with Mahidol University's Faculty of Science, Department of Tropical Pediatrics, the vaccine testing center of the Faculty of Tropical Medicine, and Siriraj Hospital's Department of Pediatrics.

The COVID-19 Vaccine Development Project and the P218 Antimalarial Drug Research Project represent two pivotal developments in Thailand's scientific sector, marking significant progress in the country's pharmaceutical and vaccine innovation. Initiated early in the country's research timeline, these projects possess considerable potential for future industrial production. Among them, the Chula-Cov19 project, spearheaded by the Vaccine Research Center at Chulalongkorn University, stands out as the most promising. Should this vaccine be successfully developed, it will be produced domestically by Bionet-Asia Co., Ltd., which has previously developed a prototype vaccine for research purposes. This achievement would represent a major advancement, enhancing R&D across the entire pharmaceutical industry supply chain and significantly contributing to the progress of Thailand's pharmaceutical industry, paving the way for future advanced innovations (refer to *Table 3*).

Table 3: Level of technological advancement of Thailand's pharmaceutical industry

Developed by	Technology Platform	Status of Development	Level of Advancement
<i>Chemical Drugs</i>			
1. Antimalarai P218 / Biotec Scientist team	Pyrimethamine P218	Phase 1 clinical trials	TRL6
<i>Biologics</i>			
1. Filgrastim /Siam Biosciences Co., Ltd	Colony-stimulating factor	Now Available	TRL9
<i>Vaccines</i>			
1. Pertussis Vaccine /Bionet Asia co., Ltd	Acellular pertussis	Now Available	TRL9
2. DPaP (Diphtheria, Tetanus, Pertussis /Bionet- Asia co., Ltd. collaborated with Mahidol University	Recombinant acellular pertussis vaccine	Now Available	TRL9
3. Chula-Cov19 /Vaccine Center of Chulalongkorn University	mRNA	Phase 3 clinical trials	TRL8
4. NDV-HXP-S COVID-19 /GPO collaborated with Mahidol University	Egg-based vaccine platform	Phase 2 clinical trials	TRL7
5. Baiya SARS CoV-2 Vax 2 /Baiya Phytopharm co., Ltd.	Subunit vaccine	Phase 1 clinical trials	TRL6
6. Covigent project /Bionet-Asia Co., Ltd.	DNA vaccines	Phase 1 clinical trials	TRL6
7. NASTVAC nasal spray /NSTDA	Viral vector	Preparing to Phase 1 clinical trials	TRL5

Source: Compiled by the author

Note: TRL with criteria set by the European Union (see Appendix A)

5.3 COVID-19 Impact and Future Challenges in Thailand's Pharmaceutical Industry

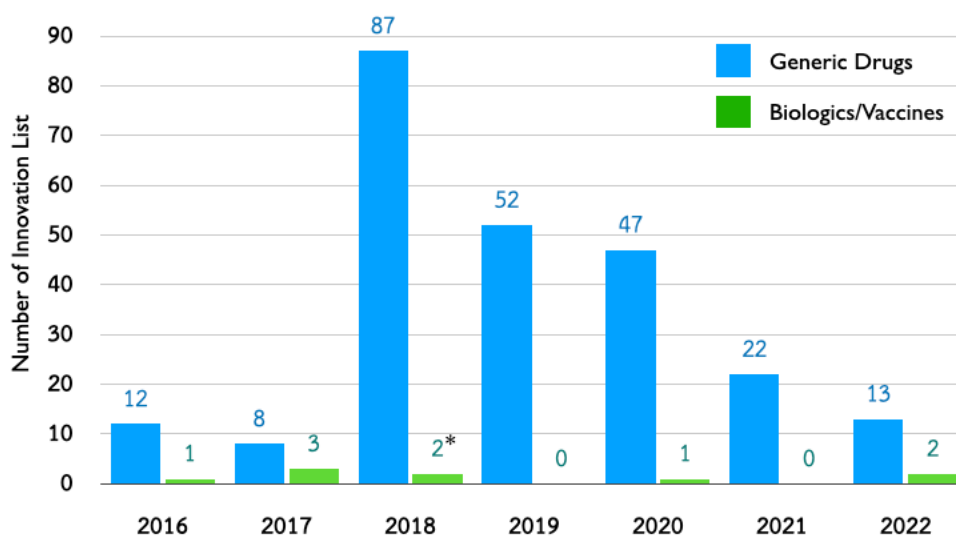
The COVID-19 pandemic has posed significant challenges for the supply side of manufacturing activities due to movement and travel restrictions worldwide, leading to supply chain disruptions, delays in industrial processes, and competition for resources needed for COVID-19 production activities. This has resulted in increased costs of raw materials and production. Thai entrepreneurs, in interviews, described these impacts as temporary, noting improvement as industrial factories globally resumed production. On the demand side, the cancellation of in-person medical activities, such as medical appointments, surgeries, and the reduced incidence of seasonal illnesses like colds, flu, and other respiratory diseases due to mask-wearing and public health measures, led to a decrease in demand for pharmaceuticals in these categories, subsequently lowering company earnings. This observation aligns with macro-level data from the Food and Drug Administration's (FDA) Drug Division, which showed that imports and production volumes throughout 2020 were comparable to those before the COVID-19 crisis in 2019. However, the crisis has offered crucial lessons for future preparedness, especially in manufacturing and academic collaboration with international partners. With appropriate planning and policies, the country can overcome such crises with an adequate supply of medicines, vaccines, and other essentials. The text concludes by hinting at future challenges for the pharmaceutical industry without specifying them.

Challenge 1: Advancing Innovation Through Enhanced R&D

Research and development within the chemical and pharmaceutical sector can be categorized into three distinct types. Type 1 involves the research and development of conventional dosage forms, primarily generics and new generic drugs, through bioequivalence studies. Type 2 focuses on the research and development of generic drugs in high-technology dosage forms, emphasizing product development, such as modified-release drugs, sterile lyophilized products, inhalers, and nasal sprays. The goal of research and development in this category is to create market differentiation. The third type is dedicated to new drug research and development. Historically, the country has seen very few new drug formulas developed and approved for formula registration. An example includes innovative combinations of chemical drugs, like the anti-AIDS drug GPO-VIR (Rungpet et al., 2020).

A review of the national innovation list reveals a predominance of generics (refer to *Figure 6*), with most falling under type-1 research based on bioequivalence studies. Looking forward, a significant challenge in enhancing the development of chemical medications (generic drugs) lies in promoting more research and development in the second and third categories. One approach to addressing this challenge is to increase privileges and incentives through the public procurement process, encouraging a broader scope of R&D activities.

Figure 6: List of drugs in the National Innovation List 2016-2022



Source: Compiled from Thai Innovation Database (accessed on 15 July 2022)

Note: *Vaccine

Challenge 2: Securing Sustainable Funding for R&D and Invention

The advancement of the pharmaceutical industry, especially in inventing and developing pharmaceutical innovations, requires significant investment and a long-term commitment to producing medication or vaccines. Drawing lessons from the development of the COVID-19 vaccine, it becomes clear that although some funding comes from the private sector and the general public, the bulk of development funds are provided by the government. For the initial phase of vaccine development, a budget of 1,647.47 million baht was approved, with an additional 3,832.75 million baht allocated for clinical research, bringing the total budget for COVID-19 vaccine development to 5,480.22 million baht (refer to *Table 4*).

A critical observation is the heavy reliance on government funding, which carries high uncertainties in the long term due to the potential for policy changes or the reallocation of funds to other emergencies. A significant challenge in drug discovery and development is finding sustainable funding sources. This involves efforts such as fundraising and crowdfunding to match innovators with investors to ensure the continuity of innovation and development. According to an interview with a Thai COVID-19 vaccine developer, efforts to attract potential investors or Venture Capitals (VCs) through roadshows were unsuccessful, as the long payback periods and business risks deterred investor interest. Ultimately, only donations were secured for the vaccine development.

Table 4: Budget to support Thailand's COVID-19 vaccine development project

Research Project / Developed by	First Budget (Million Baht)	Second Budget (Million Baht)
1. Chula-Cov19/ Vaccine Research Center, Chulalongkorn University	398.79	2,316.8
2. NDV-HXP-S COVID-19/ GPO with Mahidol University	238.68	150+56.95 ^a
3. Baiya SARS CoV-2 Vax 2/ Baiya Phytopharm Co., Ltd.	160	1,309
4. Covigent project / Bionet-Asia Co., Ltd.	650	Not yet receiving fund
5. NASTVAC nasal spray/NSTDA	200	Not yet receiving fund
Total	1,647.47	3,832.75

Source: Compiled from Cabinet Resolutions (29 December 2020); Loan expenditure screening committee documents (No. 1106/427); Center for Situation Management of the Coronavirus 2019 Outbreak Meeting 7/65 (22 April 2022)

Notes: a) Budget of the National Research Council of Thailand (NRCT) of 56.95 million baht, and the budget of the Administration and Capital Management Unit-Increasing the country's competitiveness (KorKhor.) 150 million baht

b) Has not yet received additional funding, try to raise funds by donating.

Challenge 3: Strengthening Academia-Industry Collaboration

Thailand boasts a significant number of highly skilled upstream researchers within its academic institutions and the National Academy of Sciences, who have contributed to a vast array of internationally recognized basic research publications. This is evidenced by the 11,765 papers in the fields of Pharmacology, Toxicology, and Pharmaceuticals listed in the Scopus database and ranked by the Scimago Journal & Country Rank from 1996 to 2021, placing the country 32nd globally. However, the primary issue lies in the insufficient connections between academic institutions and the industry. Since much of the research is aimed at publication, there is a lack of focus on drug discovery research that could be applied for industrial purposes.

The future challenge, therefore, is to foster collaboration between researchers in educational institutions and professionals in the private sector. This includes the creation of research support units designed to facilitate the matching of academic institutions with entrepreneurs in the private sector, such as the Technology and Innovation Development Support Program (iTab) and the Center of Excellence for Life Sciences (TCELS). These initiatives can

help generate research that meets industry demands, bridging the gap between academic achievements and their practical application in the pharmaceutical sector.

Challenge 4: Enhancing R&D Infrastructure for Future Innovation

Interviews with pharmaceutical and vaccine developers in Thailand have highlighted that the research infrastructure in laboratories and testing centers is underutilized due to a lack of experts in various industrial testing technologies. Moreover, there is a notable deficiency in work experience within regulatory units, unlike in other countries where testing centers and laboratories possess both the expertise and experience, along with an understanding of the operational processes of regulatory organizations. This allows them to promptly provide services that meet the needs of researchers in submitting evidence papers to advance to the next stage of testing.

The development of the COVID-19 vaccine marked a pioneering venture for Thai regulators, revealing that initial encounters with suspicious or misunderstood academic findings often lead to the application of the strictest safety regulations. This results in extended clearance times for testing across various phases and deviations from the original plan, compelling some developers to pursue clinical studies abroad. However, the knowledge gained from developing the COVID-19 vaccine is invaluable, fostering a learning process through trial and error across different sectors of the supply chain. This “learning by doing” approach promises long-term cost savings.

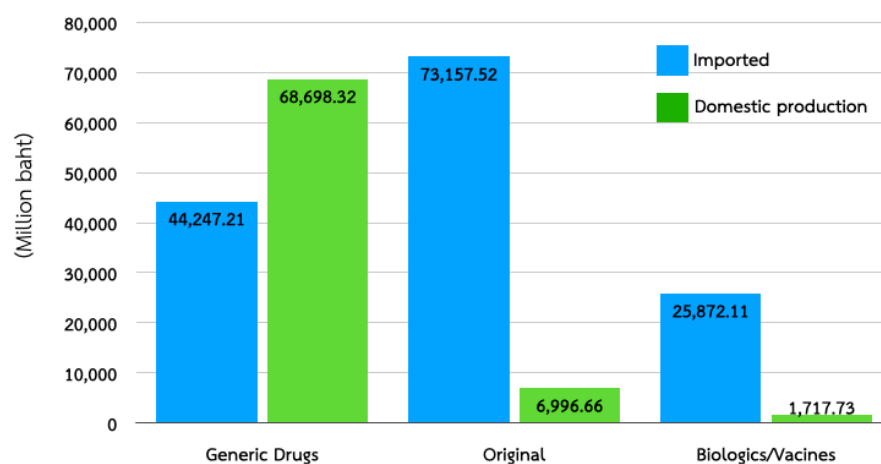
The challenge lies in capitalizing on opportunities to fortify the entire R&D ecosystem, encompassing invention, testing, manufacturing, and governance. Achieving this requires the implementation of continuous, appropriate policies and support to ensure a robust and efficient infrastructure for future research and development endeavours.

Challenge 5: Balancing Demand, Drug Security, and Self-Reliance

The domestic demand for medicines is gauged by combining the value of imports with the production value for domestic use. While this metric does not directly represent the expenditure by end-users on drugs, it effectively illustrates the overall demand and usage trends within the country. In 2022, the pharmaceutical market was valued at 220,689 million baht, with imports constituting the majority of this market value. A breakdown by drug type showed that only generic drugs had a higher production value domestically compared to imports, whereas original drugs and biologics/vaccines were predominantly import-dependent (refer to *Figure 7*).

Analysing the import dependency ratio (IDR) reveals the country’s reliance on imported pharmaceuticals has remained relatively stable since 2017. However, dependence on imported generics has decreased, unlike the sustained or growing dependence on original drugs and biologics (refer to *Figure 8*). An essential aspect of understanding this dynamic involves analysing demand factors, including the prevalence of noncommunicable diseases (NCDs), transitioning to an aging society, policies promoting Thailand as a medical hub, and the impact of emerging diseases like the COVID-19 pandemic.

Figure 7: Value of the domestic pharmaceutical market in 2020, classified by drug type



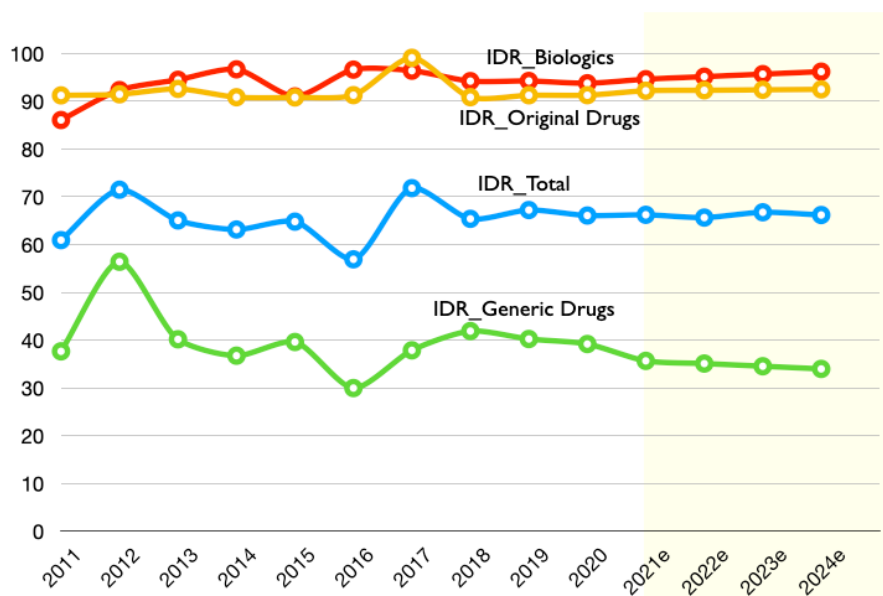
Source: Drug Division, Food and Drug Administration (as of 15 June 2022)

Notes: 1) Import Value = Total Import Value – Import Value for Export

2) Domestic production value = Total production value - Export production value

3) The above statistical Information is the production of modern human medicines. Some drug information may be listed over each other when classified by registration type, but this did not significantly impact the macro-level study.

Figure 8: Import Dependency Ratio of Thailand Pharmaceuticals between 2011-2020 and forecast 2021-2024



Source: Calculated by the author from the Drug Division database, Food and Drug Administration (retrieved on 15 June 2022)

Note: Data between 2021-2024 is forecast using the Linear Trend Model method at a 95% CI level.

Another factor to consider is the cost of vaccines, which includes scenarios where the government provides free COVID-19 vaccinations and situations where individuals pay for the vaccine themselves. From February 2021 to July 2022, 141 million vaccine doses were administered to both Thai and foreign residents in Thailand, costing a total of 60 billion baht. Concurrently, Marks et al. (2022) suggest that an annual booster dose of the COVID-19 vaccine may be required in the future. Therefore, if we assume two doses of COVID-19 vaccination per year, based on the original cost framework, the estimated annual cost for a 50% vaccination rate would be 28 billion baht. For a 60% vaccination rate, the cost would increase to 34 billion baht per year, and for a 70% vaccination rate, it would be approximately 39 billion baht per year.

Table 5: Thailand's COVID-19 vaccine costs

Types of Vaccine	Vaccinated (Dose) ^a	Price/Dose (Baht) ^b	Expenses (Baht) ^c
Pfizer	44,634,000	475	21,181,332,397
AstraZeneca	48,581,000	313	15,190,482,740
Sinovac	26,541,000	355	9,408,784,500
Sinopharm	14,923,000	777	11,595,171,000
Moderna	6,983,000	946	6,605,918,000
Johnson&Johnson	7,000	340	2,380,000
COVOVAX	6,000	138	829,548
Total	141,675,000	-	63,984,898,185
<i>Cost evaluation for vaccines COVID-19 (annual)^d:</i>			
<i>Scenario 1 50% of people are vaccinated</i>			<i>28,487,226,960</i>
<i>Scenario 2 60% of people are vaccinated</i>			<i>34,184,672,352</i>
<i>Scenario 3 70% of people are vaccinated</i>			<i>39,882,117,744</i>

Source: Data collected from “Mhor Prompt” application (reported by MOPH-Immunization Center); database of cabinet resolutions related to vaccine procurement budget and population database, National Statistical Office

Notes: a) Number of injected doses as of the end of July 2022;

b) Estimated price per dose based on government procurement budget;

c) This is the overall book value calculation, even if some vaccines are donated or operated by the private sector;

d) Calculated from the population age five years and older, including the birth and mortality rates.

(See also Appendix C for cost estimation methods and assumptions.)

This presents a critical challenge for Thailand's policy direction: Will the country continue to rely on imported vaccines, or will it seek to bolster domestic vaccine production to mitigate import costs and enhance future export capabilities?

6. Conclusion

The pharmaceutical industry, being science-based, necessitates advanced scientific knowledge for drug discovery and innovation development, underpinned by substantial investment in research and development (R&D) activities. The investment-to-revenue ratio, or R&D intensity, averages as high as 20%. However, pharmaceutical innovation investment is notably high and time-consuming to yield returns, coupled with a relatively low success rate. Consequently, the entities most capable of undertaking such ventures are multinational corporations in developed countries, equipped with financial resources, technology, skilled scientists, and access to a global export market. This observation aligns with findings from the Herfindahl-Hirschman Index (HHI) analysis, which revealed that the average export concentration from 2012 to 2021 was approximately 0.21, suggesting that the export concentration is not excessively high. Nonetheless, countries dominating exports are those possessing advanced technology and a significant pharmaceutical production base.

In Thailand, the pharmaceutical industry predominantly focuses on producing generic drugs once the original patents expire, with biologics and vaccines still in early development stages. The level of research, development, and innovation, including the capacity for technological investment and production, requires enhancement. Yet, the COVID-19 pandemic has served both as a crisis and an opportunity, catalysing advancements in the fundamental R&D system for vaccine development and production in response to public health emergencies. This period witnessed unprecedented collaboration among public and private sectors, including international organizations, culminating in government-funded support amounting to 5,480.22 million baht—the largest drug development budget in Thailand's history. A critical challenge remains: determining how this R&D advancement will influence the pharmaceutical industry's long-term growth.

Future challenges encompass leveraging R&D to further innovation sparked by COVID-19 vaccine development, securing funding for ongoing research and development, enhancing connections between academic institutions and the industry, and building infrastructure to support future R&D endeavours, including addressing demand and ensuring national drug security. Addressing these challenges is vital for Thailand to develop policies that bolster the pharmaceutical industry's development, align with national drug policy, and aim to enhance the development of vaccines, chemical drugs, active pharmaceutical ingredients (APIs), biologics, and herbal extracts. This will increase competitiveness through R&D, manufacturing, and service improvements, aiming to reduce imports, boost exports, and enhance the health security of the Thai population.

7. Strategic Directions for Policy Enhancement

The aftermath of the COVID-19 crisis has underscored the necessity for strategic policy enhancements in Thailand's pharmaceutical industry, focusing on five pivotal areas:

Strategy 1: Revamp the incentive and support framework within the National Innovation system to elevate research and development (R&D) and foster innovation. A precise delineation of R&D activities and innovative drug developments deserving support is crucial. Enhancing rewards and incentives through public procurement or alternative investment support strategies is essential.

Strategy 2: Initiate a National Innovation Fund aimed at bolstering the drug discovery and development journey. This fund should exceed the conventional annual government budget, facilitating financing, crowdfunding, business matching, investor roadshows, and business development ventures.

Strategy 3: Craft support structures to fortify the linkage between academia and the industrial sector. Tailoring national research project policies to more closely align with the demands of the industrial sector, encouraging joint funding ventures between academic institutions and the private sector for drug development, and prioritizing research that advances the Technology Advancement Level (TRL) are crucial steps.

Strategy 4: Advance the development of R&D infrastructure beyond the acquisition of laboratories and technology. The cultivation of human resources with a comprehensive understanding of the drug discovery and development process, including regulatory landscapes, is vital. Investment in staff development to assimilate knowledge and expertise from premier global laboratories is critical for sustained infrastructure improvement.

Strategy 5: Formulate a coherent policy to reinforce the domestic pharmaceutical industry and secure national drug stability. While Thailand may not currently produce original drugs autonomously, ensuring drug stability in light of the universal health insurance policy is paramount. For biologics and vaccines, the imperative to persist in innovation, supported by appropriate budgeting and institutional backing, remains. Additionally, applying the learnings from the development of the COVID-19 vaccine can vastly improve the pharmaceutical supply chain. Streamlining the support functions of regulatory bodies to expedite the drug discovery and development process is also paramount.

These strategic directions are designed to address the nuanced challenges within Thailand's pharmaceutical sector, promoting a landscape ripe for innovation, collaboration, and streamlined operations to enhance national drug security and propel industry growth forward.

8. Limitations

Data to analyse international production and trade was gathered from several databases; for domestic data, drug registration data from the Food and Drug Administration's Drug Division (FDA) was utilized. However, international trade data collected from the UN Comtrade may have inconsistencies in the information that does not align with the unit level of pharmaceutical products. Nonetheless, this did not impact the macro-analysis. When examining the overall industry landscape, this approach is considered a robust representation of the industry overview, with no significant discrepancies observed.

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Appendices

Appendix A: Technology readiness level (TRL) grading criteria for the pharmaceutical industry

TRL1 Findings reviewed	Scientific findings are reviewed and assessed as a foundation for characterizing new technologies.
TRL2 Research idea	The main focus is on the problem itself and on generating research ideas. Hypothesis is formed, and preliminary studies are set to define parameters and identify candidate concepts and/or therapeutic drugs.
TRL3 A design proof of concept	Testing the hypothesis and collecting data, limited in-vitro and in-vivo research models are carried out to set the initial proof of concept.
TRL4 Demonstrate proof of concept	First preclinical studies, using animal models, identify and assess the potential safety and toxicity problems, adverse events, and side effects. Demonstrating proof-of-concept and safety of candidate drug formulations.
TRL5 Pilot drug produced	Pilot lots drug candidates are produced for further development, GLP safety and toxicity studies in animal model systems, and clinical protocols for Phase 1 clinical testing are used.
TRL6 Phase 1 clinical trials	The pre-IND meeting is held with the European Medicines Agency (EMA) and/or the US Food and Drug Administration (FDS-CDER). Phase 1 clinical trials are conducted to demonstrate the safety of candidates in a small number of humans.
TRL7 Phase 2 clinical trials	Phase 2 clinical trials are conducted to demonstrate initial efficacy (preliminary evidence). Updated IND application, amended with a new clinical protocol to support phase 3 clinical trials or surrogate test plan I submitted.
TRL8 New drug registration	Safety and effectiveness of the candidate drug are tested in Phase 3 clinical trials or surrogate tests. New drug application (NDA) is prepared and submitted to EMA/FDA.
TRL9 Drug distributed and marketed	The new pharmaceutical drug, now can be distributed and marketed. Phase 4 studies such as safety surveillance studies to support use in special populations, and clinical trials are performed.

Source: European Commission (2022)

Appendix B: Analysis of secondary data

1) The formula for the Herfindahl–Hirschman Index (HHI):

$$\text{Formula} \quad H_i = \frac{\sqrt{\sum_{j=1}^N \left(\frac{X_{i,j}}{X_i}\right)^2} - \sqrt{\frac{1}{N}}}{1 - \sqrt{\frac{1}{N}}}$$

where $X_{i,j}$ is the export value of commodity i by country j

X_i is the total export value in the world market of product i.

N is the total number of exporting countries.

Note: HHI values range from 0 to 1, with higher values indicating a high concentration of exports.

2) The formula for Concentration Ratio (CR):

Concentration Ratio (CR):

$$CR_n = CR_1 + CR_2 + \dots + CR_n$$

Where CR_n is the market share of the n^{th} largest firm.

n is the number of firms.

Note: The Concentration Ratio, ranging from 0% to 100%, analyzes industry concentration. Values near 0% suggest low concentration (more competition), while those near 100% indicate high concentration (monopolies).

3) The formula for Import Dependency Ratio (IDR):

$$IDR = \left(\frac{\text{Imported}}{\text{Imported} + \text{Production} - \text{Exported}} \right) \times 100$$

where Imported is the import value; Production is the value of domestic production and Exported is the value of exports.

Note: IDR values range from 0% to 100%, with values approaching 100% indicating a high dependency on imports.

4) Forecasting using Linear Trend Model method:

A Linear Trend Model was used to forecast the Import Dependency Ratio (IDR) over the next 4 years with a confidence level of 95%CI based on a simple linear relationship as follows:

$$IDR_t = a + bt$$

Where IDR_t means the Import Dependency Ratio at time t.

Parameters a and b are the values estimated through the model.

Appendix C: Methods and assumptions for estimating future costs of COVID-19 vaccines.

The assumptions for estimating vaccine costs are as follows:

1) Vaccinated persons aged five years or older in 2023 (0.3% birth rate and about 400,000 deaths per year), i.e., 63,028,524 eligible people for vaccination.

2) Calculating future vaccination Based on the proportion of vaccines used by different brands as of July 2022.

3) There has yet to be a Thai nationality vaccine.

The method of calculation is shown in this table.

Brands of Vaccine	Qualification of person	Price per dose	[Qualified person x Vaccine price x 2 doses x portion of vaccinated]		
			Vaccinated 50%	Vaccinated 60%	Vaccinated 70%
Pfizer	19,856,821.31	475	9,431,990,122.41	11318388147	13204786171
AZ	21,612,766.86	313	6,764,796,027.52	8117755233	9470714439
Sinovac	11,807,588.26	355	4,191,693,832.30	5030032599	5868371365
SinoPharm	6,638,960.08	777	5,158,471,985.70	6190166383	7221860780
Moderna	3,106,604.45	946	2,938,847,813.70	3526617376	4114386939
J&J	3,114.17	340	1,058,816.93	1270580.312	1482343.698
COVOVAX	2,669.29	138	368,361.52	442033.823	515706.1268
Total cost			28,487,226,960	34,184,672,352	39,882,117,744

Source: Calculated by the author

Appendix D: Additional details on resources for in-depth interviews

Date of interview	Source of information (company/organization representative)	Group representative
February 21, 2022	Siam Bioscience Co., Ltd.	Biological drugs/vaccine
February 22, 2022	Bionet-Asia Co., Ltd	Biological drugs/vaccine
March 9, 2022	Baiya Phytopharm Co., Ltd.	Biological drugs/vaccine
March 9, 2022	GPO (no. 1)	Biological drugs/vaccine
March 9, 2022	GPO (no. 1)	Chemical drugs
March 10, 2022	Queen Saovabha Memorial Institute Thai Red Cross Society Biological Vaccine Research Center, Faculty of Medicine, Chulalongkorn University	Biologic drugs/Vaccines
March 22, 2022		Biologic drugs/Vaccines
March 23, 2022	Atlantic Pharma Co., Ltd.	Chemical drugs
March 23, 2022	Siam Pharmaceutical Co., Ltd.	Chemical drugs
March 30, 2022	Association of modern medicines	Association
March 30, 2022	Inpac Pharma Co., Ltd	Chemical drugs

Note: Lists are not disclosed as they respect the privacy of those who provide information. according to research ethics.