MRI PRODUCTION IN TÜRKİYE & BRAZIL: HOW DO DIFFERENT STATE STRATEGIES AFFECT TECHNOLOGICAL LEARNING?

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF SOCIAL SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

CEREN YAVUZ

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
THE DEPARTMENT OF SCIENCE AND TECHNOLOGY POLICY STUDIES

SEPTEMBER 2024

Approval of the thesis:

MRI PRODUCTION IN TÜRKİYE & BRAZIL: HOW DO DIFFERENT STATE STRATEGIES AFFECT TECHNOLOGICAL LEARNING?

submitted by **CEREN YAVUZ** in partial fulfillment of the requirements for the degree of **Master of Science in Science and Technology Policy Studies, the Graduate School of Social Sciences of Middle East Technical University** by,

Prof. Dr. Sadettin KİRAZCI
Dean
Graduate School of Social Sciences ____________________

Prof. Dr. Mehmet Teoman PAMUKÇU
Head of Department
Department of Science and Technology Policy Studies ____________________

Prof. Dr. İbrahim Semih AKÇOMAK
Supervisor
Department of Science and Technology Policy Studies ____________________

Examining Committee Members:

Prof. Dr. Erkan ERDİL (Head of the Examining Committee)
Middle East Technical University
Department of Science and Technology Policy Studies ____________________

Prof. Dr. İbrahim Semih AKÇOMAK (Supervisor)
Middle East Technical University
Department of Science and Technology Policy Studies ____________________

Prof. Dr. Pınar YILGÖR HURİ
Ankara University
Department of Biomedical Engineering ____________________

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: Ceren Yavuz

Signature:

ABSTRACT

MRI PRODUCTION IN BRAZIL AND TÜRKİYE: HOW DO DIFFERENT STATE STRATEGIES AFFECT TECHNOLOGICAL LEARNING?

YAVUZ, Ceren
M.S., The Department of Science and Technology Policy Studies
Supervisor: Prof. Dr. İbrahim Semih AKÇOMAK

September 2024, 168 pages

This study employs a qualitative approach to investigate how different state strategies impact technological learning, as examined through a case study of MRI production in Turkey and Brazil. Drawing on a conceptual framework focused on the government's role in technological learning, I have conducted in-depth interviews with various experts, including field engineers, sectoral experts, and policymakers, to collect empirical data. The research design follows a qualitative inductive methodology. In this study, as a result of the comparison between BRIC countries, the study was conducted between Türkiye and Brazil. In both countries, the MRI industry is highly specialized, dominated by large global companies, and presents high barriers to entry for new and small players. Attempts were made to produce MRI devices in both countries, and while production was possible in Brazil, the process failed in the research phase in Turkey. The “nationalization” trend in Turkey's technology and industry generated excitement for an MRI project, but it ultimately failed. In contrast, Brazil has met this need through a significant inflow of foreign direct investments. A key difference is that Brazil implements "localization" policies, whereas Turkey's approach has been one of "nationalization" in MRI technology.

Keywords: Qualitative Research, MRI Production, Comparative Analysis, Government Role.

ÖZ

BREZİLYA VE TÜRKİYE'DE MR ÜRETİMİ: FARKLI DEVLET STRATEJİLERİ TEKNOLOJİK ÖĞRENMEYİ NASIL ETKİLER?

YAVUZ, Ceren
Yüksek Lisans, Bilim ve Teknoloji Politikaları Çalışmaları Bölümü
Danışman: Prof. Dr. İbrahim Semih AKÇOMAK

Eylül 2024, 168 sayfa

Bu çalışma, Türkiye ve Brezilya'da MRG (Manyetik Rezonans Görüntüleme) üretimi üzerine bir durum çalışması aracılığıyla, farklı devlet stratejilerinin teknolojik öğrenme üzerindeki etkilerini araştırmak için nitel bir yaklaşım kullanmaktadır. Devletin teknolojik öğrenmedeki rolüne odaklanan kavramsal bir çerçeveden yararlanarak, saha mühendisleri, sektör uzmanları ve politika yapıcılar gibi çeşitli uzmanlarla derinlemesine görüşmeler yaparak ampirik veri toplandı. Araştırma tasarımı, nitel indüktif bir metodoloji izlemektedir. Bu çalışmada, BRIC ülkeleri arasındaki karşılaştırma yapılmış, Türkiye ve Brezilya arasında bir inceleme gerçekleştirilmiştir. Her iki ülkede de MRI pazarı son derece güçlü ve yüksek düzeyde olup, büyük küresel şirketlerin hakimiyetindedir ve yeni ve küçük oyuncular için yüksek giriş engelleri sunmaktadır. Her iki ülkede de MRI cihazları için üretim girişimlerinde bulunulmuş, Brezilya'da üretim mümkünken, Türkiye'de araştırma aşamasında başarısız olunmuştur. Türkiye'nin teknoloji ve sanayide "millileşme" eğilimi, bir MRI projesi için heyecan yaratmış, ancak nihayetinde başarısız olmuştur. Buna karşılık, Brezilya, önemli bir doğrudan yabancı yatırım akışı ile bu ihtiyacı karşılamıştır. Temel bir fark, Brezilya'nın "yerelleştirme" politikalarını uygulaması, Türkiye'nin ise MRI teknolojisinde "millileşme" yaklaşımını benimsemiş olmasıdır.

Anahtar Sözcükler: Nitel Araştırma, MRI Üretimi, Karşılaştırmalı Analiz, Devletin Rolü.

In memory of my dear uncle, Hüseyin ÇAĞMEL,
&
In memory of Metin PALA,
who repaired electronic medical equipment for more than fifty years.

ACKNOWLEDGEMENTS

I am deeply grateful to my supervisor, Prof. Dr. İbrahim Semih AKÇOMAK, for his continuous support, expert advice, and thoughtful guidance throughout this project. His mentorship has been invaluable to my academic and personal growth.

Additionally, I would like to express my deepest gratitude to my esteemed professors, Assist. Prof. Dr. Arsev Umur AYDINOĞLU and Prof. Dr. Mehmet Teoman PAMUKÇU, whose insightful lessons and guidance have greatly expanded my perspective and played a pivotal role in my development throughout this journey. I also would like to send my special thank to Res. Asst. Seda KILÇASLAN ÖZÇAKIR for her unwavering support and willingness to assist whenever needed during my academic journey.

Last but not least, my sincere thanks go my family and friends, for always supporting me with all their heart by my side.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

In the current era of rapid technological advancement, the role of technology in driving economic growth has become increasingly pivotal. The 21st century has witnessed unprecedented global competition, compelling nations and businesses alike to innovate continuously and embrace new technologies to maintain competitiveness and foster sustainable economic development. Technological learning, defined as the acquisition and accumulation of technological knowledge and skills, has emerged as a critical mechanism through which countries, particularly developing ones, can enhance their economic contributions and reduce the technological gap with developed economies (Bell & Pavitt, 1993; Kocoglu et al., 2012).

The significance of technological learning is especially pronounced in the context of globalization and the digital revolution, which have profoundly impacted the economies of developing nations. Unlike their developed counterparts, which primarily advance through cutting-edge research and development, developing economies often rely on their ability to engage in technological learning to innovate and improve their technological capabilities (Steenhuis & Bruijn, 2012). This process involves a diverse array of strategies, from technology transfer and imitation to more sophisticated methods such as joint ventures, licensing, and indigenous innovation (Chen & Qu, 2003; Lee, 2005).

In this thesis, the production and development of high-tech medical devices, specifically Magnetic Resonance Imaging (MRI) technology, serve as a lens to explore the dynamics of technological learning in emerging economies. The focus on MRI technology is particularly relevant, given its critical role in modern healthcare and its association with high levels of technological and manufacturing sophistication. By examining the recent initiatives to produce MRI devices in Brazil and Türkiye, this study seeks to uncover the complex interplay between state policies, and technological learning processes.

Despite the growing body of literature on technological learning and innovation, there remains a notable gap in understanding how these processes unfold in the context of emerging economies attempting to enter high-tech industries. Most studies have focused on developed countries or industries with established technological bases, leaving a paucity of research on the challenges and strategies of latecomer countries in acquiring and developing advanced technologies (Bell & Figueiredo, 2012; Lai et al., 2020). This thesis aims to fill this gap by investigating the state-led efforts and policy frameworks that have influenced the MRI production projects in Brazil and Türkiye, two countries with comparable economic and MRI market levels.

The primary objectives of this study are threefold: First, to assess the role of the state in facilitating technological learning and innovation within the medical device sector in emerging economies. Second, to analyze the success factors and barriers encountered by Brazil and Türkiye in their attempts to establish a domestic MRI production capability. Third, to derive policy insights that could enhance technological learning and industrial competitiveness in similar contexts. To achieve these objectives, this thesis employs a comparative analysis of the two case studies, drawing on a range of data sources including industry reports, government policies, and semi-structured interviews. The research questions this thesis addresses are:

1. How does the technological learning process differ in MRI production between Türkiye and Brazil?
2. What role does state intervention play in enhancing technological learning in the production of MRI devices in these two countries?

The study presents two hypotheses:

1. The technological learning process differs significantly between Türkiye and Brazil, with Brazil focusing more on state-led policies, while Türkiye places greater emphasis on private-sector-driven technology transfer with the previous experiences gained from the Defense Industry. However, it has

become clear that the nature and needs of technological learning in the medical device industry are different.

2. State intervention through policy incentives, such as Brazil's Local Content Policy, leads to more effective technological learning outcomes and domestic production capabilities compared to Türkiye, where state involvement is less extensive.

Through a comparative analysis of the MRI production initiatives in Brazil and Türkiye, this thesis seeks to provide new insights into the role of state policies in facilitating technological learning and innovation in emerging economies. The empirical findings will contribute to a broader understanding of the success factors and barriers encountered by these countries as they attempt to establish domestic production of MRI technology.

Contributions of this study include the development of a policy framework that can be applied to other emerging economies seeking to enhance their technological learning processes. Additionally, by focusing on the high-tech medical device sector, this research offers practical insights into how countries can foster innovation, enhance industrial competitiveness, and reduce reliance on foreign technologies. The findings will be relevant not only to policymakers but also to industries looking to engage in technology-intensive sectors.

The structure of this thesis is organized as follows: Chapter 2 provides a comprehensive review of the literature on technological learning, with a particular emphasis on its implications for developing economies. Chapter 3 details the historical and economic contexts of Brazil and Türkiye, focusing on their respective healthcare sectors and industrial policies. Chapter 4 presents the empirical findings from the case studies, analyzing the technological learning trajectories and outcomes of the MRI production initiatives in both countries. Chapter 5 discusses the broader implications of these findings for policy and practice, while Chapter 6 concludes with a summary of key insights and recommendations for future research.

By exploring the nuanced relationship between state intervention, technological learning, and industrial development, this thesis contributes to a deeper understanding of how emerging economies can effectively navigate the challenges of technological catch-up and achieve sustainable economic growth.

CHAPTER 2

LITERATURE REVIEW

This section attempts to give information regarding existing literature about the technological learning, which is the study's academic framework, and MRI technology, which makes up the research's primary themes.

2.1. MRI Technology

Magnetic Resonance Imaging is a powerful medical imaging technique that has revolutionized the field of diagnostic radiology. Today, MRI is an indispensable tool in the field of medicine, with applications spanning disease detection, characterization, staging, response evaluation, and post-therapeutic follow-up (Guimarães et al., 2014). Since its inception in the 1970s, MRI technology has undergone significant advancements, enabling clinicians and researchers to obtain high-quality, detailed images of the human body without the use of ion (Guimarães et al., 2014) (Pal & Rathi, 2021). MRI's ability to provide exceptional soft tissue contrast and the absence of ionizing radiation make it a preferred imaging modality for various medical applications, including cancer diagnosis and management. It is less dangerous for the participants than computed tomography (CT) because it can produce detailed images of the soft tissue and doesn't involve radiation (Azad et al., 2022).

The origins of MRI can be traced back to the 1930s, when scientists discovered the phenomenon of nuclear magnetic resonance (Kabasawa, 2022). Over the following decades, researchers and engineers made significant strides in developing the MRI technology, culminating in the first clinical MRI scanner in the 1970s. Since then, there have been numerous advancements in MRI technology, including improvements in data acquisition, image reconstruction, and hardware systems. The development of new techniques, such as functional MRI and diffusion-weighted imaging, has further expanded the capabilities of MRI, allowing for the visualization of physiological processes and the detection of subtle pathological changes.

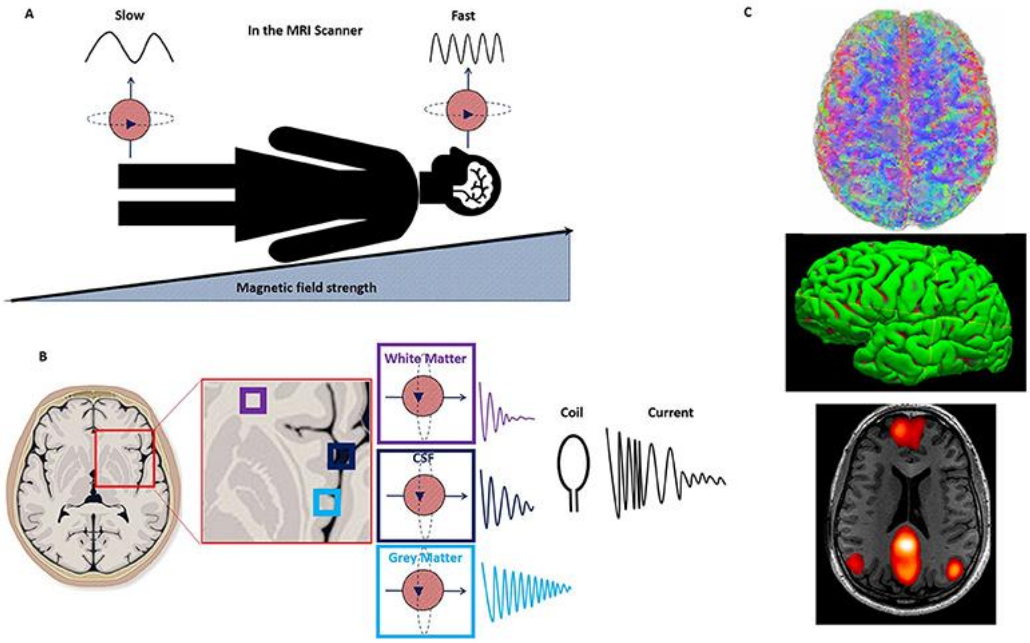

Figure 1. Physical working principle of the MRI.
Source: (Broadhouse, K., 2019).

MRI technology operates based on the principles of nuclear magnetic resonance, where atomic nuclei, primarily hydrogen due to its abundance in the human body, align with an external magnetic field and precess at a frequency known as the Larmor frequency (Kabasawa, 2022). When subjected to a radiofrequency (RF) pulse, these nuclei absorb energy and transition to a higher energy state. Upon removal of the RF pulse, the nuclei return to their equilibrium state, emitting signals that can be detected and processed to create detailed images of the body's internal structures. This process involves both T1 (longitudinal) and T2 (transverse) relaxation times, which contribute to the contrast seen in MRI images based on the different tissue properties (Alzola-Aldamizetxebarria et al., 2022). As illustrated in the Figure 1, diffenent tissues in the body emit and vary different amount of energy based on the different spin cycles of the nuclei. Thus, this situation creates the contrast in the images. In the following figure, (A) represents the B1 field is being applied, causing hydrogen protons in the head to spin faster than those in the feet. (B) represents the different tissues' emitting and varying different amounts of energy. A coil around the head measures the energy emitted by protons after the RF pulse is turned off. (C) represetns the MRI technique provides images showing: (top right) structural connections via white matter, (middle right) the volume of gray matter where information is processed, and (bottom right) functional connections between brain regions (Broadhouse, K., 2019).

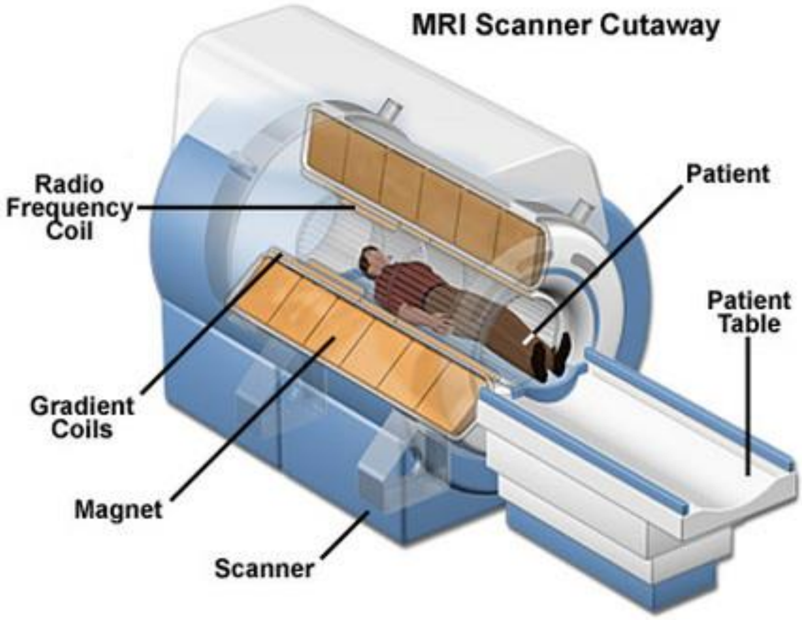

Figure 2. Basic components of the MRI system.

(Source: Abeyasinghe, P., 2015)

The hardware of an MRI system includes a powerful superconducting magnet that generates a strong, stable magnetic field, gradient coils that create variations in the magnetic field for spatial encoding, and RF coils that both transmit and receive signals. The software component controls pulse sequences, manages data acquisition, and processes the signals to reconstruct images using techniques such as the Fourier transform. Advanced software algorithms further enhance image quality by correcting for motion artifacts and reducing noise, making MRI a versatile tool for diagnostic imaging in various clinical applications (Grover et al., 2015).

Recent trends in MRI technology are largely shaped by advancements in artificial intelligence (AI) and machine learning (ML). These technologies have transformed the capabilities of MRI imaging by enhancing image reconstruction, automating diagnostics, and providing more precise and faster imaging solutions. AI-powered algorithms are being integrated into MRI systems to optimize image acquisition and reduce noise, which significantly improves image quality. Furthermore, deep learning models are being used for faster image interpretation, reducing human error and facilitating early diagnosis of conditions like cancer and neurological disorders (Ali, 2024). This transformation is expected to increase MRI's role in personalized medicine by enabling real-time data analysis and more accurate predictive modeling.

Another significant trend is the development of portable MRI systems, aimed at making imaging more accessible, particularly in remote or underserved areas. These portable devices reduce costs, improve patient outcomes, and are essential for providing imaging services in emergency situations. In addition, the integration of MRI with other imaging techniques, such as Positron Emission Tomography (PET) and functional MRI (fMRI), is creating multimodal imaging systems that offer detailed insights into both structural and functional aspects of tissues, especially in brain imaging and oncology (Hadi et al., 2024). This trend towards multimodality is expected to enhance the diagnostic accuracy of MRI technology and broaden its application in clinical settings. At its core, MRI technology operates on the principles of nuclear magnetic resonance. The process involves powerful magnets aligning the protons in the body’s water molecules, which are then disturbed by a radiofrequency pulse. As the protons realign, they emit signals that are captured and processed to create detailed, high-resolution images of the body's internal structures. This ability to distinguish between soft tissues without ionizing radiation has made MRI indispensable in diagnosing and monitoring a wide range of conditions. As these technological advancements continue, MRI is expected to become even more integral in medical diagnostics, offering faster, more accurate insights while remaining a safe, non-invasive tool for clinicians.

2.2. Technological Learning

In the current era of technological advancement, technology plays a primary role in the economic growth of nations. From this angle, it would not be incorrect to argue that the twenty-first century has brought about intense global competition. In this situation, businesses must be innovative and willing to take risks in order to thrive. While accomplishing these, businesses must also take care to minimize unanticipated side effects, be adaptable in the face of ambiguity, and account for uncertainty. The dynamic nature of these systems is crucial to an organization's ability to survive (Lei et al.,1996). *Thus, the concept of "technological learning" is crucial for companies to innovate, adapt to uncertainty, and maintain competitiveness. It involves acquiring existing technologies and developing new knowledge through internal efforts (such as R&D) and external sources (like collaborations and technology transfers).*

2.2.1 Knowledge Management

Technological progress plays a pivotal role in shaping the global economy. The ability of nations—particularly developing ones—to absorb and integrate technological knowledge is essential in this age of rapid digital transformation (Steenhuis & Bruijn, 2012). Knowledge management, which involves the creation, codification, and efficient utilization of knowledge, is central to this process. Through dedicated knowledge management programs, firms can consolidate scattered knowledge resources and use them to gain a competitive advantage (Hatowska-Zycka et al., 2022).

Gaining technological knowledge is not just about accessing cutting-edge tools and R&D experiences; it also requires the effective management and dissemination of that knowledge within organizations and across industries. As Kogut and Zander (1992) argue, the ability of companies to generate new knowledge from existing resources allows them to exploit untapped technological potential and secure a competitive edge. Since technological knowledge is dynamic, its effective management becomes critical for organizational success, despite the challenges associated with managing tacit, intangible knowledge (Al-Qdah & Salim, 2013).

2.2.2 Technological Knowledge

Technological knowledge, which refers to the understanding of how technologies work and interact within both natural and artificial systems, can be categorized as either explicit or tacit. While explicit knowledge is often emphasized in the knowledge economy, tacit knowledge also offers significant value for companies by fostering innovation and enhancing competitiveness (Barney, 1986). Hitt et al. (2000) identified two primary channels through which companies acquire technological knowledge: internal development through R&D, manufacturing, and marketing efforts, and external acquisition through sources like partnerships, technology transfers, and acquisitions (Gulati, 1999).

Companies generate internal technological knowledge primarily through their R&D efforts, which often lead to innovation. The allocation of time and resources to R&D drives the creation of new technological knowledge and helps businesses maintain their competitive advantage (Spender, 1996). Organizational culture also plays a significant role in fostering technological innovation, as creative problem-solving within companies often leads to breakthroughs (Drazin et al., 1999). Thus, a company's ability to internally generate technological knowledge directly impacts its success.

In addition to internal efforts, companies must also tap into external sources of technological knowledge to remain competitive. External technological knowledge can be acquired through various methods, such as reverse engineering, licensing, joint ventures, and patent acquisitions (Reger, 2002). The concept of "absorptive capacity" refers to a firm's ability to identify, assimilate, and apply external knowledge, which is vital for innovation (Hitt et al., 2000). Firms in developing economies often begin by imitating advanced technologies and gradually progress toward more complex innovations through these external sources (Johannessen & Olsen, 2006; Lee, 2005).

Moreover, collaboration between companies and academic institutions has become a key avenue for external technological knowledge acquisition. Partnerships with universities provide firms access to cutting-edge research, equipment, and expertise, which helps in the development of innovative products and services (Evans et al., 2023).

For firms in developing economies, mastering existing technologies takes precedence over innovation. As firms mature, the focus gradually shifts toward more complex technological tasks and innovation through formalized R&D efforts (Greitemann et al., 2014). Striking a balance between acquiring external knowledge and fostering internal innovation is crucial for these firms to move up the value chain and compete globally.

2.2.3. Technological Learning Strategies

Technological learning can also be viewed as the strategic response of firms to opportunities that arise from technological discontinuities (Perez & Soete, 1988). Firms typically respond in offensive, defensive, or imitative ways, depending on their strategic goals (Figueiredo & Piana, 2022). Offensive strategies focus on leading the market through innovation, while defensive strategies involve rapidly catching up with global leaders. Imitative strategies, on the other hand, focus on making incremental improvements to existing technologies. The success of these strategies depends on a firm's ability to integrate internal and external knowledge (Bell & Figueiredo, 2012).

Partnerships, alliances, and collaborations with universities and research institutes further support firms' technological learning processes by providing access to external expertise and resources. Integrating this external knowledge is critical for building long-term technological capabilities (Johannessen & Olsen, 2006; Ghassim & Foss, 2021).

Technological learning is a critical driver of innovation and competitiveness in the modern economy, allowing firms to adapt to uncertainty and maintain their edge in the global market. Through a combination of internal R&D efforts and external knowledge acquisition, companies can create and leverage new technological knowledge. Internal efforts such as R&D, supported by a conducive organizational culture, lead to the development of unique innovations, while external sources such as partnerships, technology transfers, and collaborations with academic institutions provide valuable insights and resources that complement internal efforts.

The dynamic nature of technological knowledge, which can be both explicit and tacit, necessitates robust knowledge management practices. The concept of absorptive capacity plays a vital role, enabling firms to effectively assimilate and apply external knowledge. As firms, especially in developing economies, progress from imitation to innovation, they must strike a balance between mastering existing technologies and pursuing novel advancements. By adopting appropriate technological learning strategies—whether offensive, defensive, or imitative—firms can enhance their innovation capabilities, create value, and ensure long-term competitiveness in a rapidly evolving global landscape.

2.2.4. Position of The State in Technological Learning

The state plays a pivotal role in technological learning by employing various policy tools and incentives that influence the advancement and commercialization of technology. In the early phases of industrialization, the government stimulates demand for technology through industrial policies, which provide the necessary framework for technological growth. These policies are further supported by science and technology initiatives aimed at creating a conducive environment for innovation. State incentives that align with market objectives, such as providing quality goods and services at competitive prices, elicit a strong response from the market (Merchant, 1997). To promote technology transfer and commercialization, governments can employ tools like funding R&D, tax incentives, public-private partnerships, and the establishment of technology transfer offices (TTOs) (Schuh et al., 2022).

As industries mature, the state's role should evolve from technology provider to facilitator, fostering an environment that promotes technology development and diffusion. In this phase, the focus shifts to improving intellectual property rights, enhancing access to financing, and streamlining regulations to encourage innovation (Lai et al., 2004). In East Asian economies, governments often target specific industries or sectors for strategic development, using selective policies to prioritize industries based on national goals (Kim, 2005). These policies are categorized into functional interventions, which enhance markets without targeting specific sectors, and horizontal interventions, which promote technological development across multiple sectors (Lall & Pietrobelli, 2005).

2.2.4.1. State as a Priorty Setter

One of the government's primary responsibilities in fostering technological learning is to identify priority sectors and create an enabling environment for innovation, knowledge diffusion, and technology transfer. The state plays a pivotal role in determining which sectors hold the highest potential for economic growth and national competitiveness, particularly in emerging economies. By strategically allocating resources, the state can enhance the efficiency of its innovation efforts and stimulate technological advancements in key sectors (Sharif, 1989).

In this context, the state employs **selective policies** focusing on high-potential industries, which can drive economic transformation. For example, governments may prioritize sectors such as information and communication technologies (ICT), biotechnology, or renewable energy, depending on national capabilities and global market trends (Salinas et al., 2022). Through these policies, the state channels investments, incentives, and infrastructure development toward targeted sectors, ensuring that they become engines of growth and technological innovation.

Beyond selective policies, the state also engages in **functional and horizontal interventions**, which are essential for supporting a broader technological ecosystem. **Functional interventions** aim to improve the foundational conditions necessary for innovation. These may include developing well-functioning factor markets, such as capital, labor, and technology markets; strengthening human resource capabilities through education and training programs; and increasing national knowledge capacity by investing in research institutions and universities. By addressing these fundamental elements, the state enhances the overall capacity for technological learning and innovation (Osman, 2014).

In parallel, **horizontal interventions** address market failures that impede innovation across sectors. These interventions often target areas where market forces alone are insufficient, such as financing early-stage technological ventures or supporting research and development (R&D) activities that may not attract private investment due to high risk or long-term payoffs. For instance, the state may offer subsidies for R&D initiatives, provide tax incentives for innovation activities, or establish public-private partnerships to reduce the costs and risks associated with technological development (Mazzucato, 2015). By mitigating these market failures, horizontal interventions ensure that innovation is not confined to isolated industries but instead permeates the entire economy.

Additionally, the state as a priority setter must continually assess and recalibrate its strategies to adapt to changing global dynamics and technological disruptions. For instance, the rapid pace of digital transformation or the growing importance of sustainable technologies requires governments to remain agile in their policy frameworks. Through dynamic and responsive policy-making, the state can anticipate trends and align its priorities to foster long-term technological competitiveness.

The state's role as a priority setter is crucial in guiding the development of national innovation systems. By identifying key industries, supporting well-functioning markets, and addressing market failures through targeted interventions, governments play a vital part in fostering technological learning, enhancing national innovation capabilities, and preparing their economies for success in the rapidly changing global landscape.

2.2.4.2. State as an Institution Provider

The state's role in technological learning extends beyond providing resources and policy direction—it includes the critical function of institution building. Institution building refers to creating and developing formal and informal structures between the stakeholders that facilitate technological advancement, innovation, and knowledge transfer. Through establishing key institutions, governments create the foundation for technological learning to thrive, enabling collaboration between the public and private sectors, academia, and international partners (Jugessur, 1996).

One of the most significant responsibilities of the state when it comes to "institution building" is to ensure that the pertinent stakeholders are brought together and collaborate to ensure that they operate effectively. Building an institution entails more than just starting a new research facility. For instance, a commercial corporation and an established research laboratory can serve as excellent examples of collaboration. Additionally, creating the required institution is a subcategory of this topic if there are no stakeholders for the technology the nation plans to develop.

The state's role as an institution builder involves creating a **supportive infrastructure for innovation** that spans education, research, and development (R&D) and digital ecosystems (King et al., 1994). These institutions provide the necessary conditions for technology development, ensuring that industries and sectors have access to the resources, knowledge, and networks required to compete in a rapidly evolving global market.

Under the “institution building” umbrella, the state is vital in establishing **R&D institutions and innovation hubs** that drive scientific discovery and technological innovation. These organizations conduct basic and applied research and serve as bridges between academia, industry, and government, facilitating the commercialization of new technologies. Public-sector technology institutions provide public goods such as industry standards, advanced technological services, and support for intellectual property management. These institutions are crucial for fostering an environment where innovation can flourish, especially in sectors that require long-term investment and high levels of expertise (Frenkel et al., 2015).

In addition to creating specific organizations, the state fosters a broader **innovation ecosystem** through public-private partnerships (PPPs). PPPs enable governments to collaborate with businesses, universities, and nonprofit organizations, leveraging collective resources, infrastructure, and expertise. This collaboration is crucial for addressing challenges that require multidisciplinary efforts, such as developing advanced technologies in healthcare, clean energy, and digital transformation. Through these partnerships, the state helps reduce the risks associated with innovation, providing incentives, funding, and regulatory support to encourage private-sector engagement (McGeary & Hanna, 2004).

Furthermore, institution-building involves **international collaboration**. Governments engage with multilateral organizations, foreign nations, and global innovation networks to share knowledge, best practices, and technological advancements. These international partnerships enable states to access global expertise, collaborate on joint R&D projects, and co-develop technologies. By participating in international innovation networks, states can accelerate their own technological learning and gain access to cutting-edge research and innovation (Klasa et al., 2020).

In conclusion, the state's role in institution building is a fundamental aspect of technological learning. By creating and nurturing R&D organizations and innovation ecosystems, the state sets the stage for sustainable technological progress. These institutions support technological innovation, foster collaboration, bridge gaps between stakeholders, and ensure that technological advancements contribute to national and global economic development.

2.2.4.3. State as an Incentıve Provıder

The state plays a critical role in incentivizing technological learning, shaping the conditions under which firms and industries engage in innovation and adopt new technologies. Government incentives are designed to encourage economic agents to pursue technological advancements, leveraging both fiscal measures and strategic policies that enhance national capabilities. These incentives are essential for creating an environment conducive to technological learning, particularly in emerging economies where market mechanisms alone may not be sufficient.

Government incentives can take various forms, including fiscal measures such as tax breaks, subsidies, and grants, which directly lower the cost of engaging in technological activities. For instance, subsidies for R&D can enable firms to undertake high-risk, long-term innovation projects, while tax incentives may encourage the adoption of cutting-edge technologies. In addition to these direct financial incentives, governments also implement public-private partnerships (PPPs) and establish specialized financial institutions to support innovation, enabling firms to access the necessary capital for technological investments.

A strong macroeconomic environment is crucial for fostering technological learning. National policies related to trade, industrial development, and factor markets directly shape the opportunities for innovation. Trade policy, for example, is often leveraged to promote competitiveness in sectors with high potential for technological growth. Governments may adjust import tariffs or implement stringent registration requirements for foreign products to create a more favorable market for domestic technologies. For example, to encourage the adoption of domestically produced medical devices, a government might increase tariffs on foreign imports or impose additional regulatory hurdles, as seen in countries like Brazil and Russia, where medical device regulations create significant barriers for foreign brands (French-Mowat & Burnett, 2012).

In addition to trade policies, industrial policy plays a central role in driving technological advancement. Through targeted policies that remove market barriers and support key industries, governments can facilitate the emergence of competitive domestic firms. National industrial policy is particularly effective when aligned with broader economic goals, such as increasing innovation capacity and fostering domestic production. For example, newly industrialized economies like South Korea and Taiwan used industrial policy to restrict multinational corporations from entering certain domestic markets until local firms had developed sufficient technological and competitive capabilities (Chang, 1998). This approach allowed these countries to build domestic industries that could compete globally in sectors like electronics and automotive manufacturing.

The state's role as an incentive provider also extends to intellectual property rights (IPR) regimes, which are essential for encouraging innovation by protecting firms' technological investments. Well-defined IPRs provide firms with the confidence that their innovations will be safeguarded, thus incentivizing investment in new technologies. However, these regimes must be carefully balanced with pro-competition policies to prevent monopolistic practices and ensure that knowledge diffusion occurs across the economy. This is particularly important in emerging knowledge-based sectors, where the cost of patents can be prohibitive and counterproductive to innovation (Andrews & Criscuolo, 2013).

Foreign direct investment (FDI) is another avenue through which governments incentivize technological learning, particularly in sectors where domestic production capabilities are limited. By shaping trade policies that attract foreign firms, governments can foster the development of parallel sectors that provide access to necessary technologies. For instance, in industries such as medical devices, governments can encourage foreign businesses to enter the market through favorable FDI policies, creating opportunities for local firms to learn and adapt advanced technologies (Shenkar et al., 2021).

Additionally, the state plays a pivotal role in stimulating domestic demand for advanced technologies. In many developing countries, demand for high-tech products does not emerge naturally due to limited market size or purchasing power. Therefore, governments must actively create and sustain this demand through strategic public policies. For example, public procurement policies can prioritize domestic products, thus providing local firms with a market for their innovations. As demand grows, firms are incentivized to improve product quality and enhance their technological capabilities, further supporting the overall learning process (Chandra, 2006).

To sum up, the state's role as an incentive provider in technological learning is multifaceted. Through fiscal measures, trade and industrial policies, intellectual property rights, and efforts to stimulate domestic demand, governments create an environment that encourages firms to innovate, adopt new technologies, and enhance their competitiveness. By strategically deploying these incentives, the state ensures that technological learning becomes a cornerstone of economic development, enabling industries to thrive in an increasingly technology-driven global economy.

The comprehensive review of the literature proved instrumental in identifying various patterns of technological learning prevalent in emerging economies. By thoroughly examining these patterns, I was able to develop a nuanced understanding of how different countries navigate the complexities of technological advancement, particularly in the context of state intervention and market dynamics. This understanding significantly informed the formulation of the interview questions utilized in my study, allowing for a more targeted exploration of the key factors influencing technological learning in specific national contexts.

Moreover, the insights gained from the literature review were essential in shaping the conceptual framework that underpins the analysis of my research data. Specifically, the framework focuses on the multifaceted role of the state as a priority setter, institution builder, and incentive provider. This triadic approach to state intervention allowed for a structured analysis of how governments can facilitate technological learning and innovation in growing economies. By situating my research within this framework, I was able to systematically examine the interplay between state policies, institutional development, and technological outcomes, providing a robust foundation for analyzing the data collected during the study. Thus, the literature review not only guided the methodological aspects of my research, such as the design of interview questions, but also provided the theoretical lens through which the data was interpreted, ultimately enhancing the academic rigor and depth of the study.

2.3. Existing Literature

In today's rapidly advancing technological landscape, technology plays a central role in driving economic progress. The 21st century has brought about intense global competition, compelling businesses to embrace innovation and adaptability to survive and thrive. In this environment, organizations must navigate uncertainty, manage risks, and remain agile to maintain their competitive edge.

Technological learning, defined as the acquisition and accumulation of technological knowledge and skills, particularly through technology transfer, has garnered significant scholarly attention. It serves as a vital mechanism for firms to enhance competitiveness, foster innovation, and solidify their market positions. Since the Industrial Revolution, technological learning has become increasingly crucial, particularly with globalization and the information revolution impacting developing economies (Bell & Pavitt, 1993).

Technological learning is especially important in developing economies, where access to resources for conducting basic research and R&D is often limited, compared to developed nations. This makes the ability to learn and adopt existing technologies critical in closing the gap and accelerating development (Goñi & Maloney, 2017). The academic framework of this thesis explores the role of the state in facilitating technological learning, particularly in the production and development of high-tech medical devices in emerging economies. Here, technological learning serves as a catalyst for knowledge transfer, driving innovation and boosting the economic contributions of local companies (Kocoglu et al., 2012).

In particular, the theoretical framework of this thesis, "The Role of the State in Technological Learning", is the cornerstone of technological learning for countries with emerging economies. For these countries, correctly understanding and evaluating the concept of technological learning and the role of the state in technological learning will make it easier to take the right steps. The role of the state in technological learning within emerging economies has been extensively explored in various studies, highlighting the critical impact of government policies and state-led initiatives on fostering technological innovation and capability building. Roztocki and Weistroffer (2008) discuss how technology investments, particularly in IT, play a crucial role in the development of businesses in emerging economies, underscoring the importance of state involvement. Ricz (2019) further explores the evolving role of the state in development through a developmental state perspective, emphasizing the influence of state-led initiatives in emerging economies. Carayannis et al. (2006) investigate the roles that technological learning and information dissemination play in the entrepreneurial development of firms, demonstrating the significant contribution of state policies in these processes. Genin, Tan, and Song (2021) provide an in-depth analysis of state governance and technological innovation, using

China's high-speed train sector as a case study to illustrate the impact of state-owned enterprise restructuration on innovation.

The study by Qu et al. (2013) focuses on R&D offshoring and its relationship with technological learning in emerging economies, highlighting how state policies can enhance local firms' R&D capabilities. George and Prabhu (2003) examine the role of developmental financial institutions as technology policy instruments, illustrating how state-led financial mechanisms can foster innovation and entrepreneurship. Hong, Wang, and Kafouros (2015) highlight the importance of state involvement in the technological advancement and internationalization of firms from emerging markets. Dalmarco, Hulsink, and Blois (2018) explore the creation of entrepreneurial universities in Brazil, showing how state policies and university-industry linkages facilitate technological learning and innovation. Lastly, Hansen and Ockwell (2014) analyze technological learning and capability building in Malaysia's biomass power equipment industry, emphasizing the critical role of state policies in supporting technological development. Collectively, these studies underline the multifaceted role of the state in promoting technological learning and innovation in emerging economies, providing valuable insights into the strategies and challenges faced by latecomer countries in their pursuit of technological advancement.

This study aims to contribute to the literature as investigating the state's role in technological learning within the high-tech medical device sector, specifically focusing on the MRI industry in Brazil and Türkiye. It explores the state's involvement through three key functions: setting priorities, building institutions, and providing incentives. The research highlights the lack of studies addressing technological learning in the medical device industry, making it a significant contribution. By analyzing MRI production projects in Brazil and Türkiye, the study offers insights into the development and challenges faced in these emerging economies, contrasting with previous research that focused primarily on developed countries. Additionally, it examines the policies and outcomes of MRI projects, shedding light on the reasons for the failure of the initiative in Türkiye, thereby filling a gap in the literature on technological learning in less-studied regions. In addition, the study also clarifies the reasons of the failed past projects, implemented policies, and the fate of the recent MRI production initiative in Brazil and Türkiye. Unlike previous studies that primarily focused on developed economies like the USA or European countries, this research aims to fill the gap in the literature by exploring the role of the state in the production of a specific technology, MRI, in two countries with a comparable level of economic development. By shedding light on the MRI production attempt and the reasons for its failure, the study provides valuable insights into the dynamics of technological learning in emerging economies.

CHAPTER 3

MRI INDUSTRY IN BRAZIL AND TÜRKİYE: COMPARATIVE ANALYSIS

The medical device sector, which produces a vast array of goods for use in monitoring, diagnosis, and treatment—from basic equipment to sophisticated devices—is an essential part of healthcare systems around the globe. The medical device business is expanding significantly in economically growing nations including Brazil, China, Türkiye, India, and Russia. This expansion is being driven by various factors, including the growing demand for healthcare services, government initiatives, and advancements in technology (Cordero, 2014).

The medical device industry has become an increasingly important economic sector, offering significant opportunities for growth and expansion, particularly in emerging markets. As these countries continue to develop their healthcare infrastructures, the demand for innovative and cost-effective medical devices is on the rise, leading to a growing number of local manufacturers and enterprises focused on creating solutions tailored to their specific market needs . Moreover, the involvement of government investments in these markets is crucial, as it not only supports the sector's growth but also ensures that healthcare improvements are sustainable and aligned with local needs, thereby attracting further interest from investors and fostering successful partnerships with local stakeholders.

The aim in conducting this comparative study between the BRICs (Brazil, Russia, India and China) is to obtain a more applicable policy outcome by comparing a country with similar conditions in terms of the health system, composition and structure of economic activities and similar innovation systems to Türkiye, rather than conducting a comparative study with developed and technologically advanced countries. Because, the development of high-technology medical devices like MRI, for low-resource settings often faces significant challenges, as the traditional approaches used in high-income countries may overlook essential realities concerning production, regulations, marketing, cultural acceptance, distribution, supply chain, after-sales support, maintenance, and overall practicality for the end-users (Cordero, 2014). These challenges underscore the necessity of adopting a more localized strategy that takes into account the unique economic landscapes and healthcare needs of each country, ultimately enhancing the effectiveness of medical device innovations in improving health outcomes and addressing unmet medical needs within these populations (Cordero, 2014). In this context, a general analysis of the healthcare system, medical device market, especially MRI market, history and economic structure in Brazil, Türkiye, India, China, and Russia is conducted.

Table 1. Key Health System Indicators in BRICs

Indicator	China	Türkiye	Brazil	Russia	India
Health Status					
Life Expectancy at Birth (years)	77.3	77.7	75.3	72.3	70.8
Infant Mortality Rate (per 1,000 live births)	5.4	8.7	11.8	5.6	27.7
Risk Factors for Health					
Smoking Prevalence (% of adults)	24.7	27.5	14.7	30.9	11.7
Alcohol Consumption (liters per capita, age 15+)	7.4	1.4	7	11.7	5
Overweight Prevalence (% of adults)	55.7	61.9	56.5	57.1	20
Health System Capacity					
Hospital Beds (per 1,000 people)	4.3	2.8	2.1	8.1	0.5
Doctors (per 1,000 people)	2.1	2.1	2.2	4	0.9
Nurses (per 1,000 people)	2.5	2.4	1	8	1.7
Health Spending per Capita (USD)	535	509	1024	957	75
Health System Financing					
Health Spending as % of GDP	6.6	4.5	9.6	5.7	3.1
Health Spending as % of Total Government Spending	6.3	5	10.5	8.5	4.7

Table 1. (continued)

Health Spending, Government Schemes and Compulsory Health Insurance (% of total health spending)	68	78	60	68	35

Source: OECD, 2019.

Firstly, Table 1 was prepared to show the key system indicators in the BRIC countries. The data highlights variations in health status, risk factors, and health system capacity and provides a comparative overview of major health system variables for China, Türkiye, Brazil, Russia, and India. These nations differ in terms of birth weight life expectancy; Türkiye leads the group at 77.7 years, closely followed by China, while India has the lowest life expectancy at 70.8 years. There are notable differences in infant mortality rates, with India having the highest rate at 27.7 per 1,000 live births. These discrepancies are a reflection of the difficulties facing maternal and child healthcare. On the other hand, lower infant mortality rates in China and Russia suggest that newborns there have better access to healthcare and better outcomes. Russia has the highest rates of alcohol intake and smoking prevalence, which may explain why its life expectancy is comparatively shorter. All countries have a significantly high frequency of overweight people, with Türkiye having the highest percentage. This suggests that nutrition and lifestyle choices are major public health concerns.

The availability of hospital beds, physicians, and nurses reveals significant variations in the capacity of the health system. Owing to its sophisticated healthcare system, Russia has the most hospital beds and medical specialists per 1,000 residents. India, on the other hand, is far behind, especially when it comes to the quantity of doctors and hospital beds, which makes it difficult to provide its enormous population with quality healthcare. Brazil has the largest health spending per capita, followed by China and Russia, suggesting higher financial resources devoted to healthcare. But compared to the other nations, Brazil spends a higher percentage of its resources on healthcare, as evidenced by the ratio of health spending to GDP and overall government spending. These countries also tend to rely heavily on government programs and mandated health insurance; Türkiye has the highest percentage, indicating a significant level of government engagement in the funding of healthcare.

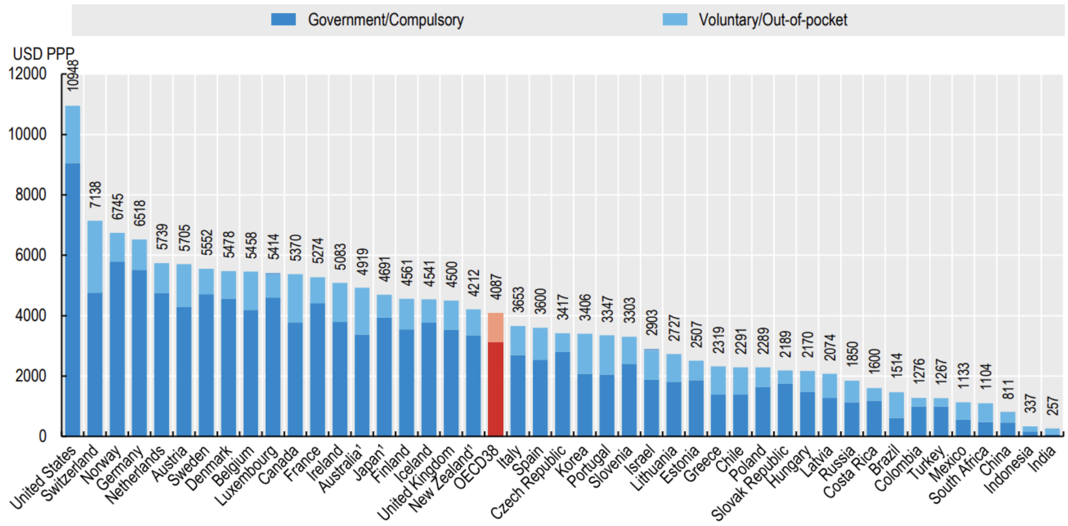

Figure 3. Health expenditure per capita, 2019.

Source: OECD Health Statistics, 2021.

Figure 3 displays the per-capita health expenditure in USD PPP (Purchasing Power Parity) for a number of different nations, including OECD and non-OECD countries which emphasises the contributions from both government and private sources as well as voluntary and out-of-pocket expenses.

When the BRIC countries are examined, which are the subject of the research, Figure 3, it is seen that the health expenditure per capita for Türkiye is shown to be approximately $1,500 USD PPP, with a significant portion of this expenditure coming from government/compulsive sources. This indicates that Türkiye has a relatively strong government contribution to healthcare spending, but the overall expenditure per capita remains on the lower end compared to more developed nations. On the Brazil side, it is seen that the Brazil's health expenditure per capita is around $1,100 USD PPP, slightly lower than both Türkiye and Russia. Like Türkiye, Brazil has a mixed healthcare funding model with contributions from both government and voluntary/out-of-pocket sources. However, the lower overall expenditure indicates that Brazil allocates fewer resources per person compared to Türkiye. On the other hand, Russia's health expenditure per capita is depicted at about $1,500 USD PPP, which is very close to that of Türkiye. Russia also shows a significant contribution from government/compulsive sources. The near parity between Russia and Türkiye indicates similar levels of government commitment to healthcare funding, although the overall efficiency and outcomes of these expenditures may vary. China's health spending is estimated to be approximately $1,200 USD PPP per person. Like Türkiye, a sizable amount of China's spending comes from compulsive or government sources, but overall per capita spending is marginally less than Türkiye's. This shows that although the financing systems for healthcare in the two nations are comparable, Türkiye spends a little bit more per person on medical treatment. Finally, India has the lowest per capita healthcare spending of the countries in the chart, at around US$250 PPP. The majority of this spending appears to come from voluntary/out-of-pocket sources rather than government contributions, suggesting a heavy reliance on personal spending for healthcare. Türkiye’s spending is significantly higher than India’s, reflecting a more robust healthcare spending framework in Türkiye.

Although health spending per capita varies, both Brazil and Türkiye have a high dependence on government programs and mandatory health insurance, accounting for 60% of health spending in Brazil and 78% in Türkiye, respectively. Table 1 and figure 3 are created to comprehend the status of health in each of the nations. The countries' health systems and medical device marketplaces are thoroughly studied in the next section. Key health system indicators in the BRIC countries are shown in Table 1, which was created to provide concise information about the overall structure of the health system. This section continues with brief information regarding the health system, medical device market, legislation about medical devices, demographics, economy, and, most importantly, the MRI market for each BRIC countries. The research's focal points—the similarities between Brazil and Turkey—are highlighted at the end of this section.

3.1 China

China, the world’s most populous nation with over 1.4 billion people, has undergone significant social and economic transformations, especially since the late 20th century. Transitioning from a centrally planned economy to a socialist market economy, China has embraced industrialization, international trade, and technological advancement, becoming the second-largest economy globally. Demographically, China faces challenges with a slowing population growth rate, an aging population, and disparities between urban and rural regions in terms of access to services like healthcare. Despite reforms aimed at improving health coverage and infrastructure, inequalities persist, especially in rural areas. The healthcare system now integrates both public and private services, with Traditional Chinese Medicine playing a significant role. In addition, China has developed a robust regulatory framework for medical devices, overseen by the National Medical Products Administration (NMPA), with a focus on ensuring safety and efficacy through classification and clinical trial requirements.

Additionally, China represents one of the largest and fastest-growing medical device markets globally, with an estimated market value surpassing $42 billion in 2022. This growth is driven by the country's aging population, government investment in healthcare infrastructure, and a strong focus on innovation. The National Medical Products Administration (NMPA) governs the regulatory landscape, with recent trends showing a preference for domestically produced devices over imports. The market is poised to continue expanding as China integrates new technologies such as AI and big data into healthcare.

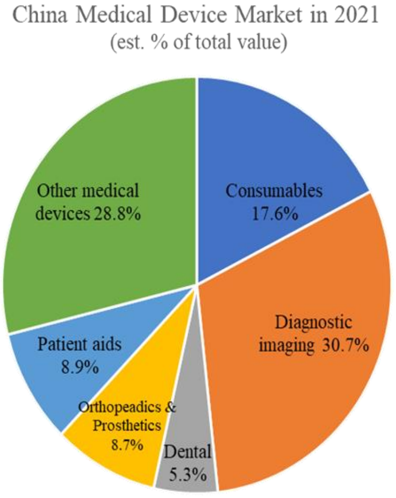

Figure 4. Medical Device Market Share - China (Fitch Solutions, 2023).

The market is distinguished by a combination of high-tech categories (such as cardiovascular and medical imaging devices) and necessary consumables, reflecting both sophisticated and fundamental healthcare needs. A sizable "Others" category indicates that a wide range of specialty devices are contributing to the industry as a whole, which implies prospects for specialized developments and expansion in less crowded markets.

It is worth to highlight tat that the medical imaging holds the largest shre of the medical device market in China which reflects the growing demand for diagnostic imaging including MRI, CT scans and ultrasound equipment. China's MRI market has seen significant growth, with the country now considered the world's second-largest MRI market after the United States (Medical Magnetic Resonance Imaging (MRI): Technologies and Global Markets, 2023). The size of the China Magnetic Resonance Imaging Market is projected to be USD 367.41 million in 2024 and is anticipated to increase at a compound annual growth rate (CAGR) of 5.49% to reach USD 479.96 million by 2029 (MordorIntelligence, 2023).

There are a number of significant competitors in China's fiercely competitive magnetic resonance imaging market. Currently, a small number of the main competitors control the majority of the market share. These are the Siemens AG, Canon Medical Systems, GE Hehalthcare, Koninklijke Philips V, JiangSu Magspin Instrument Co. Ltd. However, mid-size to smaller businesses are expanding their market presence by launching new items at lower rates due to technical improvements and the supply of high-quality services(MordorIntelligence, 2023).

3.2. India

India, the second-most populous country globally with over 1.4 billion people, has a diverse cultural and geographic landscape, divided into 28 states and 8 Union Territories. It ranks as the fifth-largest economy, with growth driven by agriculture, industry, and an expanding service sector. Like China, India has a large and varied market for medical devices, presenting opportunities for growth. India has undergone significant economic reforms since 1991, transitioning from a state-controlled economy to a market-oriented one. These reforms spurred rapid growth, particularly in the IT and service sectors, though challenges like economic inequality, environmental concerns, and infrastructure gaps remain.

Demographically, India is characterized by a youthful population, with a median age of 28.2 years and 65% of its population under 35. However, the fertility rate is near replacement level, signaling a slowing population growth. India’s healthcare system is a hybrid of public and private providers, with major government initiatives like Ayushman Bharat seeking to provide universal health coverage. While efforts to improve access and quality of healthcare are ongoing, issues such as chronic diseases, regional disparities, and the aging population persist.

India's medical device regulation is overseen by the Central Drugs Standard Control Organization (CDSCO), which classifies devices by risk. In line with international standards, India has improved its regulatory framework, streamlining device registration, ensuring safety, and enhancing post-market surveillance.

The medical device market in India has seen significant growth in recent years, with an estimated market size of around $11 billion as of 2022 (IBEF, 2023). This growth is projected to accelerate, driven by factors such as increasing healthcare expenditure, the rising prevalence of chronic diseases, and advancements in technology, which collectively contribute to a robust demand for innovative medical solutions (Saini et al., 2022). Furthermore, the Indian market presents compelling opportunities for global manufacturers due to its low per capita spending on medical devices compared to developed nations, suggesting significant potential for market expansion as the demand for advanced healthcare solutions rises among its large population (Saini et al., 2022). This growth is driven by several factors, including an aging population, increasing prevalence of chronic diseases, rising income levels, and government initiatives to improve healthcare infrastructure.

The medical device market in India is dominated by imports, with approximately 75% of the annual procurement of devices and diagnostics coming from abroad. This reliance on imports highlights the challenges faced by domestic manufacturers in establishing themselves within the competitive landscape, as many devices are designed for industrialized countries and may not cater effectively to the needs of low-resource settings, creating barriers to market access for innovative local products (Jarosławski & Saberwal, 2013). To address this, the government has implemented policies to promote local production, including tariffs on imported devices and incentives for domestic manufacturers. The market is expected to continue expanding, with a strong emphasis on locally manufactured devices, supported by government policies such as the "Make in India" initiative (IBEF, 2021). Moreover, to draw in foreign capital and promote technological breakthroughs, one of the main initiatives in India is to permit 100% Foreign Direct Investment (FDI) in the medical device industry (Jarosławski & Saberwal, 2013). Furthermore, India provides incentives to foreign enterprises wishing to transfer their manufacturing operations from China, making it a desirable substitute for companies searching for a more stable and welcoming environment (Shivagami & Prasad, 2021). In addition to these initiatives, the Production Linked Incentive (PLI) Scheme provides financial incentives to businesses that manufacture medical equipment domestically, fostering industry expansion and guaranteeing the nation's supply of reasonably priced, high-quality medical goods (Invest India, 2023).

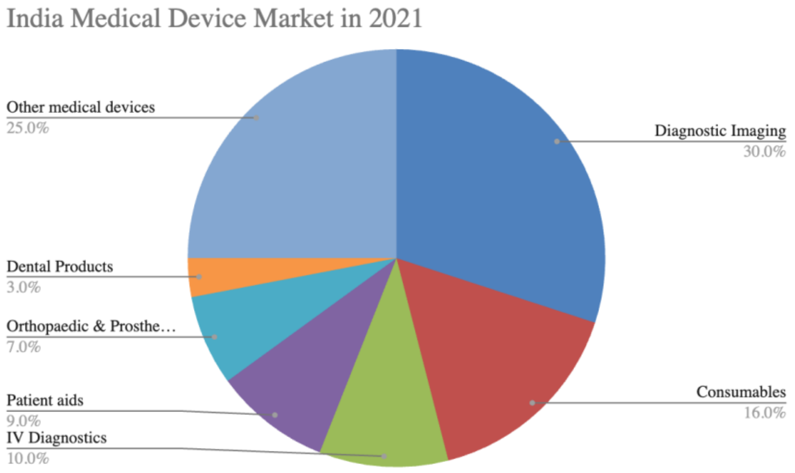

Figure 5. Medical Device Market Share - India (IKON Research, 2021).

India's MRI market is also expanding rapidly, reflecting broader trends in healthcare modernization and the adoption of advanced medical technologies. The market is projected to grow at a compound annual growth rate (CAGR) of over 8% in the coming years, driven by increased demand for diagnostic imaging services (Grand View Research, 2020). This surge in the MRI market is indicative of the broader trend toward modernization in India's healthcare sector, as the demand for timely and accurate diagnostic tools continues to rise, partly fueled by an increasing population that is becoming more aware of health issues and the available solutions. However, the accessibility and affordability of MRI services remain a challenge, particularly in rural areas, where infrastructure and resource constraints limit the widespread deployment of these advanced technologies.

3.3 Russia

Russia, the largest country in the world by land area (17.1 million square kilometers), spans both Northern Asia and Eastern Europe, with a population of approximately 144 million. Divided into 85 federal subjects, Russia has a significant resource base, including oil, natural gas, and minerals, which contributes to its standing as the eleventh-largest economy globally. Although Russia has a growing market for medical devices and substantial manufacturing capacity, it faces challenges in ensuring equitable access to healthcare, especially in rural areas. This mirrors disparities seen in other nations where advanced healthcare technologies are concentrated in urban centers.

Russia's transition from a centrally planned economy to a market economy after the Soviet Union's collapse in 1991 led to economic instability in the 1990s, but recovery began in the 2000s under President Vladimir Putin. While economic growth resumed due to rising oil prices and increased state control, the country still faces issues such as income inequality, corruption, and recent sanctions that have slowed growth.Demographically, Russia's population is aging, with a median age of 39.9 years and a fertility rate of 1.5, below the replacement level. The working-age population is shrinking, raising concerns about future labor force sustainability. The healthcare system, transitioning from state-run to a more privatized model, has struggled to deliver consistent care, particularly in rural areas, where infrastructure and qualified medical staff are often lacking.

Russia's medical device regulations, overseen by Roszdravnadzor, categorize devices by risk levels and require compliance with Russian standards and clinical evaluations. Efforts to align regulations with international standards are underway, and the government is promoting the localization of medical device production to reduce reliance on imports. However, the regulatory landscape remains complex, and challenges persist in ensuring equitable access to advanced medical technologies.

Russia represents a significant and growing medical device market, with an estimated market value of over $6 billion in 2024 (Mordor Intelligence, 2023). The market is driven by several factors, including an aging population, increasing prevalence of chronic diseases, and government initiatives to improve healthcare infrastructure. The market is expected to continue growing, particularly in areas such as diagnostic imaging, cardiovascular devices, and orthopedic implants. This growth presents both opportunities and challenges for domestic manufacturers and foreign investors alike, as understanding the regulatory landscape and local market dynamics will be crucial for capitalizing on this expanding market potential (Tsai et al., 2023).

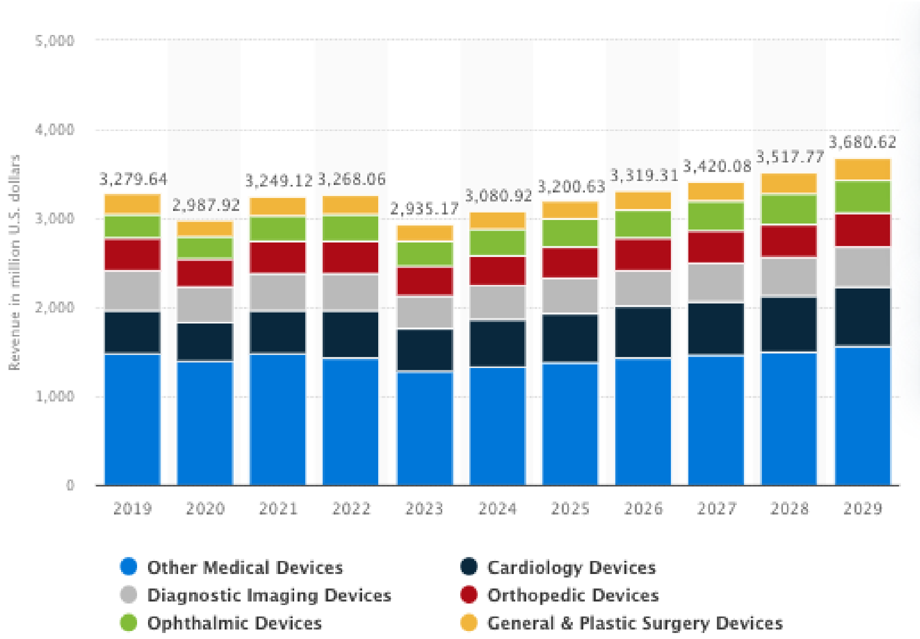

Figure 6. Russia Medical Device Market Share, 2023. Source: Statista.

Russia's MRI market is growing, which is consistent with larger trends in the country's healthcare modernization and sophisticated medical technology adoption.

The market is anticipated to expand in the next years at a compound annual growth rate (CAGR) of about 7% due to rising diagnostic service demand and government spending on healthcare (Mordor Intelligence, 2023).

The Russian medical device market is highly competitive, with several domestic manufacturers and multinational organizations as major players. While global players like Siemens Healthineers, GE Healthcare, and Philips Healthcare dominate the market, local companies are becoming more and more active as well, especially when it comes to producing affordable medical equipment that is specifically designed to meet the demands of the Russian healthcare system.

3.4 Brazil

Brazil is the largest country in South America and the fifth largest country in the world in terms of land area and population. Its total land area is approximately 8.5 million square kilometers. Brazil has 26 states and one federal district (which includes Brasília) and is divided into five regions: North, Northeast, Central-West, Southeast, and South. The country has over 213 million people, making it the sixth most populous country in the world. With most recent evaluations, Brazil has 5570 municipalities. (IBGE, 2024) Brazil also boasts one of the largest gross domestic product (GDP) outputs on Earth, fueled in part by Latin America's largest medical device market (and one of the largest device markets in the world) in terms of revenue, manufacturing output, and imports (Gouvea, 2004). The Brazilian medical device market is characterized by high local demand and a growing trend towards innovation, resulting in significant opportunities for both domestic and international manufacturers seeking to establish a foothold in this competitive landscape, with expectations for the sector to expand rapidly in response to demographic shifts, policy changes, and technological advancements.

In recent decades, Brazil has experienced substantial economic and social changes that have significantly impacted the quality of life and health indicators of its population. The nation has evolved from a military dictatorship with an unstable political economy and severe human rights abuses to a stable democracy characterized by pluralization and a presidential system. This transformation has been accompanied by the implementation of economic policies that have played a pivotal role in shaping the country's development trajectory. During the 1980s, Brazil experienced hyperinflation and a serious foreign debt crisis, leading to economic stagnation and recession, as well as a concentration of income among a small percentage of the population (Castro & Carvalho, 2003). However, in the 1990s, inflation was contained, although economic growth remained modest (Freeman et al., 2020). After the early 2000s, Brazil experienced more substantial but still modest economic growth, accompanied by large-scale social reforms that resulted in increases in school attendance and literacy rates (Freeman et al., 2020).

The country's health situation has also undergone significant changes. While there have been substantial improvements in recent decades, Brazil still exhibits an epidemiologic pattern where infectious and parasitic diseases remain prevalent (Baer et al., 2001). This is attributed to the lack of an adequate sanitary infrastructure, which is related to the high inequality of income. The Gini Coefficient of Brazil is currently 52.0 and the country ranks 38th by Gini Coefficient (World Bank, 2022).

Brazil's demographic structure is characterized by its large and diverse population, shaped by various social and economic factors. As of 2023, Brazil's population is estimated to be around 212 million, making it the most populous country in South America and the sixth most populous globally (IBGE, 2024). The country has a relatively young population, with a median age of approximately 34.4 years, reflecting a significant proportion of working-age individuals (Worldometer, 2024). Life expectancy in Brazil is 76 years for both sexes, 79.1 for women and 73.0 for males. However, Brazil is also experiencing a demographic transition, with a declining fertility rate that has reached around 1.7 births per woman, which is below the replacement level of 2.1 (World Bank, 2023). This decline signals a gradual aging of the population, which is expected to continue over the coming decades. About 24% of the population is under the age of 15, while the proportion of elderly citizens is steadily increasing. These demographic trends present both opportunities and challenges for Brazil, as the country navigates the implications of an aging population while still benefiting from a sizable youth demographic (IBGE, 2024).

Brazil is experiencing an epidemiological transition, with the proportion of the population aged 65 and over projected to reach 21.9% by 2050, an increase of 8.9% from 2017. This ageing population is expected to lead to a rise in chronic diseases driven by obesity and physical inactivity (Miranda et al., 2016).

3.4.1. Health System in Brazil

When the Brazilian healthcare system is examined, it is undoubtedly the Unified Health System (SUS) that first catches the eye and is an example to the world. The 1988 Constitution first enacted the decentralization of health services in Brazil (Sting et al., 2019). This led to the establishment of the Unified Health System, which granted local municipalities control over the provision and financing of most health services. The SUS system is structured around three core principles: universality, which ensures that every citizen has the right to healthcare; comprehensiveness, which covers all levels of care from preventive services to complex treatments; and equity, which aims to reduce health disparities by prioritizing those who are most in need. The SUS operates under a decentralized model, where federal, state, and municipal governments share responsibilities, ensuring that services are tailored to the needs of local populations while maintaining national standards.

The Unified Health System is one of the largest public healthcare systems globally, catering to over 210 million Brazilians (Menicucci, 2019). It offers a comprehensive range of services, including primary care, hospital treatments, emergency services, and preventive programs such as vaccinations and health education (Galvão et al., 2021). Additionally, the system manages the distribution of medications, regulates the private healthcare sector, and promotes public health initiatives to combat diseases and enhance overall community well-being(Galvão et al., 2021). The system's core is that everyone has equal opportunities health access and financial protection. Brazil's life expectancy increased from roughly 64.4 years in the 1990s to 75.3 years in 2017 after SUS was founded (OECD, 2021).

In Brazil, the organization and financing of the health system are mainly realized from two sources:

i) Out of pocket payments,

ii) SUS (Unified Social Assistance System)

SUS differs from other Latin American healthcare systems in its separation of healthcare and financing mechanisms. The Ministry of Health is integrated with the social security system, allowing public funds to finance any provider and enable more comprehensive healthcare. While the federal government finances healthcare, local governments provide services. Brazil has a large private insurance sector, with private companies offering additional services to high-income households (Toscas et al., 2023).

SUS operates through a decentralized structure involving federal, state, and municipal governments. The 26 states manage regional administration and strategic programs (e.g., high-priced drugs), while municipal health units oversee local SUS management, including co-financing, coordinating health programs, and delivering healthcare services. The Federal District combines state and municipal responsibilities. Key quasi-autonomous national health agencies include ANS, which defends public interest in private health insurance by regulating sector operators, and ANVISA, which focuses on health protection and promotion through surveillance of products and services, including pharmaceuticals (Menicucci, 2019).

3.4.2. Medical Device Market in Brazil

In 2023, the Brazilian medical device market was valued at approximately $9.7 billion, making it the largest in Latin America (IBGE, 2023). The market has experienced steady growth, driven by increased healthcare spending, a growing ageing population, and the expansion of both public and private healthcare sectors. The market is expected to continue its growth trajectory, particularly in sectors such as diagnostic imaging, cardiovascular devices, and orthopedic implants. This growth presents both opportunities and challenges for domestic manufacturers and foreign investors alike, as navigating Brazil's regulatory landscape and understanding local market dynamics will be crucial for successfully tapping into this expanding market potential (Rodriguez et al., 2023).

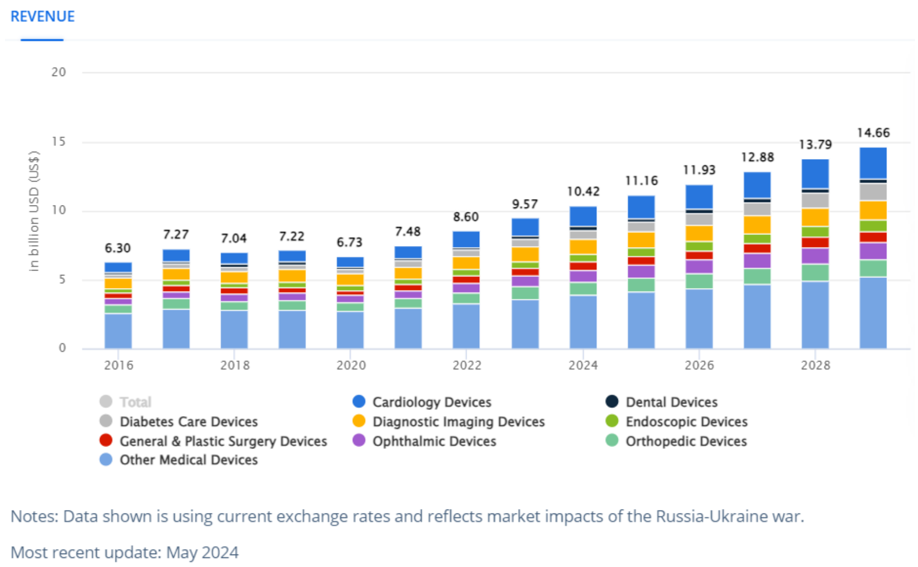

Figure 7. Medical Device Industry, Brazil 2023. (Source: Statista)

Brazil's medical device market highly depends on imports, with around 80% of devices coming from abroad (Gomes et al., 2020). The United States, China, and Germany are the top exporting countries to Brazil (Mordor Intelligence, 2023). Domestic production is limited, it is clustered in Sao Paulo and Rio De Janeiro (BRICS Medical Device Market Reports, 2023).

Table 2. Import share of Medical Devices, Brazil, 2022. Source: Brazil - Healthcare

Product Group	% Imported	Best Performing Sub-Groups
Consumables	40%	Syringes, needles & catheters are the largest segment of Brazil’s consumable market with an import share of 65% (40% supplied by US).
Diagnostic Imaging	75%	Electrodiagnostic Apparatus shows the highest growth. Philips Healthcare is a principal player in this field.
Dental Products	>25%	(Dental) Instruments & supplies are the largest segment and shows the highest growth. The import share is roughly 20% of the total market. Brazil’s MOH has announced to continue to invest in local production of this segment.
Orthopaedics & Prosthetics	>50%	Other Artificial Body Parts (excluding fixation devices and artificial joints) are the largest segment with the highest import share of roughly 50% as domestic production focuses on artificial joints and orthopaedic & fracture appliances.

Table 2. (continued)

Patient Aids	>75%	Portable aids (hearing aids, pacemakers etc) are the largest sector in the patient aids market, boasting a high import share of 90%/ Therapeutic appliances also show growth numbers and has an import share of around 50%.
Other Medical Devices	55%	Domestic production is strong for wheelchairs, hospital furniture and sterilizers, but under-developed for ophthalmic instruments and dialysis equipment which therefore are imported more than other products within this product group at around 60%.

In response to these high import rates, many policy tools are being used in Brazil to increase domestic production. The "localization work" in Brazil does not necessarily imply that a Brazilian company produces the product entirely with its own resources. Rather, the approach focuses on meeting the identified needs within Brazil, regardless of the company's origin or ownership structure. Even if the company is a global entity, the product is manufactured within the country's territory. There are successful policies implemented in this context. These policies are explained in detail in the results section, but to mention briefly, Brazil's local content policy is a key component of its Health Industry Economy Complex, designed to bolster domestic production and reduce dependency on imported medical goods. This policy mandates that a certain percentage of the components used in medical devices and pharmaceuticals must be sourced locally, thereby fostering the growth of domestic industries and ensuring that the country retains greater control over its healthcare supply chain. The local content policy is closely tied to the Productive Development Partnerships (PDP) strategy, which encourages collaborations between public and private entities to develop and manufacture essential health products within Brazil. The PDP strategy not only aligns with the goals of the local content policy by emphasizing domestic innovation and production but also aims to strengthen the country's technological capabilities and self-sufficiency in the health sector.

As an ecosystem, although industry-university collaborations are seen, mass production of complex technologies that could be described as high-tech is not encountered. Hence, the domestic production focuses on lower-complexity, laborintensive devices such as syringes, needles, and bandages.The medical device industry in Brazil is highly regulated, with the national health regulatory agency, ANVISA, overseeing the registration and approval processes (BMI, 2017; Caritá, 2018). In an effort to bolster local manufacturing and reduce reliance on imports, the government has also introduced programs aimed at fostering local innovation, facilitating access to investment capital, and providing continuous medical education, which are essential for improving knowledge and skills within the workforce that supports the sector.

Moreover, Brazil's medical device industry is highly regulated, with the National Health Surveillance Agency overseeing the registration and approval processes for medical devices (Gabriel & Lopes, 2021). Based on the potential risk that they may pose to patients and users, medical devices in Brazil are categorized into four classes (Class I to IV) according to the RDC No. 185/2001. Class I devices, such as surgical instruments and bandages, are considered low-risk, while Class IV devices, including implantable devices and life-supporting equipment, are classified as high-risk. The level of scrutiny a device undergoes during the registration process depends on its assigned class. Class IV devices, being high-risk, are subject to a more rigorous evaluation that involves a thorough review of their clinical data, manufacturing processes, and safety information.

Table 3. Summary of the Brazil Medical Device regulayory requirements.

National Regulatory Authority:	ANVISA
Medical Device Act:	RDC 751/2022
Registration requirements	● Technical Documentation based on the RDC 751/2022 Annex II. ● Free Sales Certificate from the manufacturer ● ISO 14971:2019 Risk Management Documentation
Certification process	● Work permit allowance required to market, sell and distribute products in Brazil
Quality Management System	● B-GMP certification from ANVISA, ● ISO 13485:2016 Standard Certificate

Medical devices and equipment in Brazil are regulated by the Brazilian National Health Supervision Agency, ANVISA. Coordinating ministerial decisions on the adoption and funding of health technologies in the public healthcare system is a complex process. This complexity leads to issues in coordinating the coverage of costs for health technologies adopted by public health institutions through ministerial decisions. While proper supervision prevents the use of unsafe and inefficient medical devices, ANVISA's authorization processes can drive public demand for certain products. Lawsuits are frequently filed against federal, state, and local authorities for using products not approved by ANVISA. (Gabriel & Lopes, 2021).

MRI technology is versatile and is used in a wide range of medical applications. It is a highly preferred technology, especially in the examination of cancer tissues, as it poses much less danger than CT and X-ray imaging (Vitor et al., 2017). Cancer is the second leading cause of death in Brazil after cardiovascular and cerebrovascular disorders. In 2020, the World Health Organization reported approximately 592,212 new cancer cases in Brazil, with 300,114 in males and 292,098 in females. The most common forms are prostate, lung, colon, and rectal cancer. Diagnostic imaging procedures performed in labs and hospitals play a crucial role in the early detection and primary treatment of these cancers. (Weiderpass et al., 2021)

The expansion and increased utilization of Magnetic Resonance Imaging technology in Brazil's public healthcare system has been a significant trend over the past two decades. This growth is evidenced by a substantial rise in the number of MRI procedures performed, which increased by an average of 19% annually from 2002 to 2014, signaling a heightened demand for advanced diagnostic imaging services among the Brazilian population (Dovales et al., 2019).

Table 4. Spatial distribution of MRI equipment in use in the public and private sectors in Brazil, by region, from 2015 to 2021. (NMH – DATASUS (https://datasus.saude.gov.br/)

Public Sector						
Year	**Southeast (n)**	**Northeast (n)**	**South (n)**	**North (n)**	**Central-west (n)**	**MRI Total (n)**
2015	58	16	10	11	4	99
2016	69	21	10	11	3	114
2017	70	33	12	14	5	134
2018	67	43	15	18	6	149

Table 4. (continued)

2019	70	50	14	19	6	159
2020	76	52	15	18	8	169
2021	77	60	16	20	9	182
Private Sector						
2015	803	247	267	84	148	1549
2016	832	280	288	93	151	1644
2017	928	319	311	109	193	1860
2018	996	346	336	121	211	2010
2019	1061	382	363	122	233	2161
2020	1083	393	388	130	274	2268
2021	1146	426	415	150	292	2429

Brazil has witnessed a steady rise in the availability and use of MRI technology within its healthcare system. We see that the use of MRI scans in Brazil has risen dramatically since 2006, though it still lags behind the rates seen in more developed nations (Dovales et al., 2019). This spike in MRI utilization has been matched by a growth in the number of MRI machines installed, especially within Brazil's public healthcare system. The continued investment and expansion of MRI infrastructure in the country underscores this technology's critical role in delivering modern, high-quality healthcare services to the Brazilian population.

It is worth to state that, as of 2022, Brazil was the country in Latin America with the highest density of magnetic resonance imaging scanners (MRI scanners), with a total of 14.52 units per million inhabitants.

During the initial months of the COVID-19 pandemic, the medical imaging market was significantly impacted. However, the importance of MRI scans in diagnosing neurological and cardiovascular conditions related to COVID-19 has led to their extensive use in Brazil during the pandemic. Studies have shown that some COVID-19 patients experience various neurological issues, including cerebral arteriopathy, acute ischemia infarction, hemorrhage, acute hemorrhagic necrotizing encephalopathy, and microhemorrhage. According to one Brazilian study, 8.6% of patients with restricted diffusion lesions and 22.9% of COVID-19 patients with bleeding or microhemorrhage had abnormal brain CT and MRI results. Given the high demand for MRI to diagnose neurological problems in recovered COVID-19 patients, the MRI market in Brazil has maintained a steady pace during the pandemic (Duarte et al., 2022).

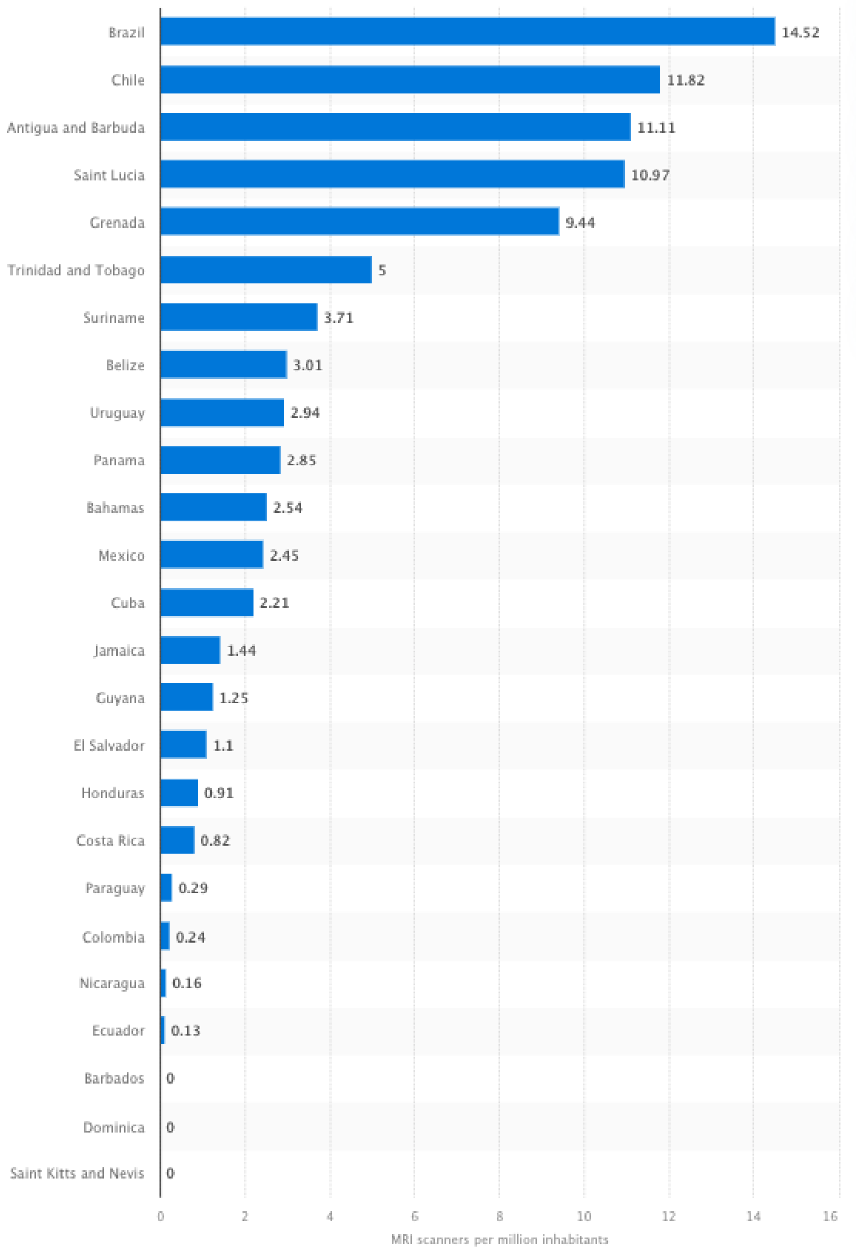

Figure 8. Number of magnetic resonance imaging scanners (MRI scanners) in Latin America and the Caribbean as of 2022, by country (per million inhabitants)

Source: Statista, 2023.

The Brazil Magnetic Resonance Imaging (MRI) Market size is estimated at USD 304.63 million in 2023 and is expected to reach USD 393.06 million by 2028, growing at a CAGR of 5.23% during the forecast period (2023-2028). Besides the growing demand for MRI scans, the Brazilian government's efforts to improve healthcare infrastructure and increase access to advanced medical technologies have also contributed to the market's growth.

Table 5. MRI Market data,2023. (Source: Mordor Intelligence)

Market Size (2023)	USD 304.63 Million
Market Size(2028 expected)	USD 393.06 Million
CAGR (2023-2028)	5.23%
Market Concentration	Medium
Major Players	Fujifilm, Siemens, GE Healthcare, Canon, Philips

There are several significant competitors in the fiercely competitive magnetic resonance imaging market in Brazil. Few of the big competitors now control the majority of the market in terms of market share. However, thanks to technological developments and the availability of excellent services, mid-sized and smaller businesses are expanding their market share by launching new items at lower rates. The magnetic resonance imaging market is dominated by businesses like Siemens Healthcareineers, GE Healthcare, Canon Medical Systems, and Philips Healthcare.

In summary, Brazil has made significant progress in expanding access to healthcare through SUS, its publicly funded Unified Health System. However, challenges remain in coordinating the adoption and funding of new health technologies, as well as aligning the incentives across the public and private healthcare sectors. Strengthening R&D collaboration between universities, public institutes, and industry is an ongoing priority to drive innovation in medical devices and pharmaceuticals. While Brazil has a robust regulatory framework and intellectual property system, the country continues to grapple with ensuring the availability of cost-effective and appropriate healthcare solutions to meet the diverse needs of its population (Viana et al., 2016; Morel et al., 2007; Rocha et al., 2012)

The health program implemented under Brazil's Unified Health System has stimulated economic development in numerous municipalities, expanded markets, and increased local production. Brazil has been successful in high-tech sectors, from maritime to aviation and aerospace. Technological advancements in these areas have led to innovation in medical devices. The development of science and technology in Brazil has also attracted foreign direct investments (Damiani, 2009).

Since the early 2000s, the Brazilian Association of the Medical, Dental, Hospital, and Laboratory Equipment Industry has supported these companies significantly, expanding their global reach. Consequently, the medical devices market in Brazil has grown significantly. It is estimated to reach $637.04 billion in 2024 and is projected to grow at a CAGR of 6.99% during the forecast period, reaching $893.07 billion by 2029 (Mordor Intelligence, 2023).

3.5. Türkiye

Türkiye is the 19th most populous country in the world, with about 85 million people living (ALNATOUR, 2020). Türkiye has a vibrant economy, ranking among the top 20 largest economies in the world, with a GDP of approximately US$ 906 billion (World Bank, 2022). The GDP value of Türkiye represents 0.40 percent of the world economy. The Turkish government operates a universal healthcare system known as "Universal Health Insurance" (Genel Sağlık Sigortası), which provides free or subsidized healthcare services to over 82 million people in the country.

Since the 2000s, the Turkish government has made significant investments to improve the country's healthcare infrastructure and access to medical technologies, including MRI scanners.

In 2003, the government launched the "Health Transformation Program" to restructure the healthcare system and increase access to advanced medical technologies like MRI. The program has led to a significant increase in the number of MRI machines in Türkiye.

Table 6. Health expenditures indicators btw 1999-2022. (TUİK, 2023)

Indicators on health expenditures, 1999-2022

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total health expenditure (Million TRY)	4 985	8 248	12 396	18 774	24 279	30 021	35 359	44 069	50 904	57 740	57 911	61 678	68 607	74 189	84 390	94 750	104 568	119 756	140 647	165 234	201 031	249 932	353 941	606 835
Health expenditure per capita (TRY)	79	128	190	284	363	444	517	636	726	813	804	843	924	987	1 108	1 228	1 337	1 511	1 751	2 030	2 434	2 997	4 206	7 141
Ratio of total health expenditure to gross domestic product (%)	4.6	4.8	5,0	5.2	5.1	5.2	5.2	5.5	5.7	5.8	5.8	5.3	4.9	4.7	4.6	4.6	4.4	4.6	4.5	4.4	4.7	5,0	4.9	4
Ratio of general government health expenditure to total health expenditure (%)	61.1	62.9	68.1	70.7	71.9	71.2	67.8	68.3	67.8	73	81	78.6	79.6	79.2	78.5	77.4	78.5	78.5	78	77.5	78	79.2	79.2	76.4
Ratio of private sector health expenditure to total health expenditure (%)	38.9	37.1	31.9	29.3	28.1	28.8	32.2	31.7	32.2	27	19	21.4	20.4	20.8	21.5	22.6	21.5	21.5	22	22.5	22	20.8	20.8	23.6

The aim of the Health Transformation Program is to organize, finance and provide health services in an effective, efficient and equitable manner. When we examine Table from this perspective, we see that the total health expenditure in Türkiye has increased significantly over the years. In 1999, the expenditure was 4,985 million TRY, and by 2022, it had risen to 606,835 million TRY. This substantial increase indicates a growing investment in the health sector. Moreover, There is a noticeable acceleration in health spending from 2018 onwards, with a sharp increase observed particularly from 2020 to 2022. This may reflect heightened spending due to the COVID-19 pandemic and efforts to strengthen the healthcare infrastructure. Additionally, the ratio of health expenditure to GDP has remained relatively stable, hovering around 4.4% to 5.8% over the years. This indicates that while health expenditure has increased in absolute terms, it has kept a steady proportion of the GDP. The slight increase in the ratio during certain years could be a response to economic conditions.

Türkiye's economy was primarily agrarian in the middle of the 20th century, while numerous state-led programs concentrated on industrialization and infrastructure development. But there were a number of political and economic crises throughout the 1950s and 1960s, including times of economic instability and military takeovers. Under Prime Minister Turgut Özal, who started a number of liberalization initiatives aimed at opening up Türkiye's economy to international markets, the 1980s marked a pivotal time of economic transformation. Türkiye's economic structure was modernized and became more tightly integrated with the global economy as a result of these changes, which included lowering governmental intrusion, fostering foreign investment, and supporting export-led growth (Ünal, 2018).

The 1990s saw Türkiye confront serious economic difficulties in spite of these reforms, including high inflation, unstable currency values, and recurrent financial crises. Political unrest and conflicts, notably those involving Kurdish autonomy and the emergence of political Islam, characterized this era socially. The pivotal moment occurred in the early 2000s when Türkiye responded to the terrible financial crisis of 2001 by implementing an extensive program of economic stabilization (Akyüz & Boratav, 2003).

Türkiye's social and economic fabric faced further difficulties in the 2010s, including as political turmoil, regional conflicts, and economic volatility. The 2016 coup attempt, geopolitical unrest, and poor economic management all played a part in the slowdown and inflation rise. Furthermore, Türkiye's current account deficit and reliance on foreign funding made it susceptible to changes in the world economy. Türkiye's strategic location, diverse economy, and expanding industrial and technological sectors enable it to maintain its prominent position in regional and global economic affairs despite these obstacles (Mahmood, 2023). In response to these ongoing challenges, the Turkish government has introduced targeted incentives and support initiatives specifically aimed at the medical device industry, with the intention of enhancing domestic production capabilities and fostering innovation within this crucial sector of the economy. These initiatives are designed to address the existing gaps in technological infrastructure and to promote local manufacturing, thereby reducing dependency on imports and improving the overall competitiveness of Turkish medical devices in the global marketplace (Güvercin, 2020).

The population of Türkiye is 86.4 million as of 2023 and the population growth rate is determined as 111%. According to the estimates of the Turkish Statistical Institute (TUIK), it is expected to be 100.3 million in 2040 and 107.1 million in 2060. In addition to population size, population structure is also of great importance. The country has a relatively young demographic profile, with a median age of about 33.1 years, indicating a substantial proportion of working-age individuals (TÜİK, 2023). Life expectancy in Türkiye has reached 78.3 years overall, with women having a higher life expectancy of 81.0 years compared to 75.6 years for men (TÜİK, 2023). However, Türkiye is also undergoing a demographic transition, with a declining fertility rate that has fallen to around 1.7 births per woman, below the replacement level of 2.1 (World Bank, 2023). This trend suggests a gradual aging of the population, which is projected to accelerate in the coming decades.

Currently, about 23% of the population is under the age of 15, while the proportion of elderly citizens is increasing steadily. According to TÜİK data, as of 2023, the population in the 15-64 age group constitutes 68.3% of the total population, while 21.4% of the population is between the ages of 0-14 and 10.2% is 65 years of age and older. These demographic shifts pose both opportunities and challenges for Türkiye, as the country must balance the needs of a growing older population while leveraging the economic benefits of a large, youthful workforce (TÜİK, 2023). Furthermore, it is estimated that the population in the 15-64 age group will decrease to 64.4% in 2040 and 58.7% in 2080, and the elderly population over the age of 65 will increase to 16.3% in 2040 and 25.6% in 2080 (TUİK, 2023). In OECD studies, if the share of people aged 65 and over is between 7 and 14% of the total population, the country is considered an "aging society", if this share is between 15 and 20%, it is considered an "old society", and if this share is 21% or higher, it is considered a "super-aged society". In this respect, while Türkiye is currently an aging society, according to TUİK's estimates, it will turn into a super-aged society after 2040.

3.5.1. Health System in Türkiye

The Turkish health system is characterized by a combination of public and private healthcare providers, with the government-run Universal Health Insurance system serving as the backbone of the system. This system ensures that a majority of the population has access to essential healthcare services, which in turn stimulates demand for medical devices, as healthcare providers seek to equip themselves with advanced technologies to improve service delivery and patient outcomes. (Uçak, 2016)

The Turkish health system is structured under the Ministry of Health, which is responsible for regulating, financing, and providing healthcare services. There are several key stakeholders involved in the governance and management of the Turkish health system (Akinci et al., 2012; Horton & Lo, 2013).

The Ministry of Health (MoH) is responsible for formulating health policies, regulations, and standards. It also oversees healthcare providers and ensures adherence to national health regulations. Subordinate to the MoH, the Turkish Medicines and Medical Devices Agency regulates the medical device industry, encompassing the approval, import, and distribution processes. Key stakeholders in the Turkish healthcare system comprise the MoH, Social Security Institution (SSI), healthcare providers, and professional organizations representing healthcare workers. Moreover, non-governmental organizations and patient advocacy groups play a pivotal role in shaping health policies and promoting public health initiatives.

The healthcare industry in Türkiye has undergone significant transformations over the past two decades. In 2003, the government launched the "Health Transformation Program" to restructure the healthcare system and improve access to advanced medical technologies. This program, implemented in the early 2000s, aimed to enhance the access, efficiency, and quality of healthcare services. Key reforms included the expansion of health insurance coverage, the establishment of family medicine practices, and the modernization of hospital infrastructure.

Table 7. Life Expentancy & infant mortality indicators, Türkiye.

	2015 2015	201620 2016	2017 2017	2018	2019	2020	2021 2021
Life expectancy	78	78	78.1	78.3	78.6	77.7	77.5
	80.7	80.7	80.8	81	81.3	80.5	80.3
	75.3	75.3	75.3	75.6	75.9	75	74.8
Infant mortality / Deaths per 1 000 live births	10	9.7	9	9.2	9	8.5	9

Source: OECD, 2023.

As seen in the Table 6, these efforts have led to substantial improvements in health indicators, such as increased life expectancy and reduced infant mortality rates.

While the Turkish health system has made important progress over the years, it still faces ongoing challenges that need to be addressed. With a strong commitment to reform and continuous improvements in health policies, Türkiye is actively working towards creating a more effective and sustainable health system. The country's approach, which views health services as a fundamental right for its citizens, has led to increased public investment in the healthcare sector. As demonstrated in Table 6, the ratio of general government health expenditure to total health expenditure has risen significantly from 61.1% to 76.4% over the past twenty-three years, reflecting the state's growing role in health financing.

On the other hand, when compared to OECD countries and Brazil, Türkiye's total health expenditures per capita remain below the OECD average. Despite a 5.4% compound annual growth in national income since the 2010s, health expenditures have only increased by 4.7% (OECD, 2021). This discrepancy highlights the need for further investment in the health sector to match economic growth. Additionally, Türkiye's demographic trends and lifestyle habits suggest that the demand for health services will continue to rise.

The decrease in health expenditures relative to the previous year has also led to an increase in out-of-pocket expenses for citizens. Moreover, the relatively low share of the budget allocated to health expenditures poses a challenge to prioritizing technology development and innovation in the healthcare sector. Nonetheless, the state's active involvement and focus on public health investments demonstrate a commitment to improving healthcare access and quality for all citizens.

3.5.2. Medıcal Device Market in Türkiye

Türkiye's medical equipment market has grown significantly in recent years, and as of 2022, it is expected to be worth about $2.8 billion (TÜSEB, 2023). It is anticipated that this expansion would continue to pick up speed, propelled by elements including rising healthcare costs, a prevalence of chronic illnesses on the rise, and technological developments that together create a strong need for unique medical treatments. Furthermore, because of Türkiye's advantageous location as a bridge connecting Europe and Asia and its comparatively lower per capita spending on medical devices in comparison to industrialized nations, the market offers global manufacturers enticing potential. This implies that there is a great deal of room for market growth as the country's population grows and the need for sophisticated healthcare solutions increases.

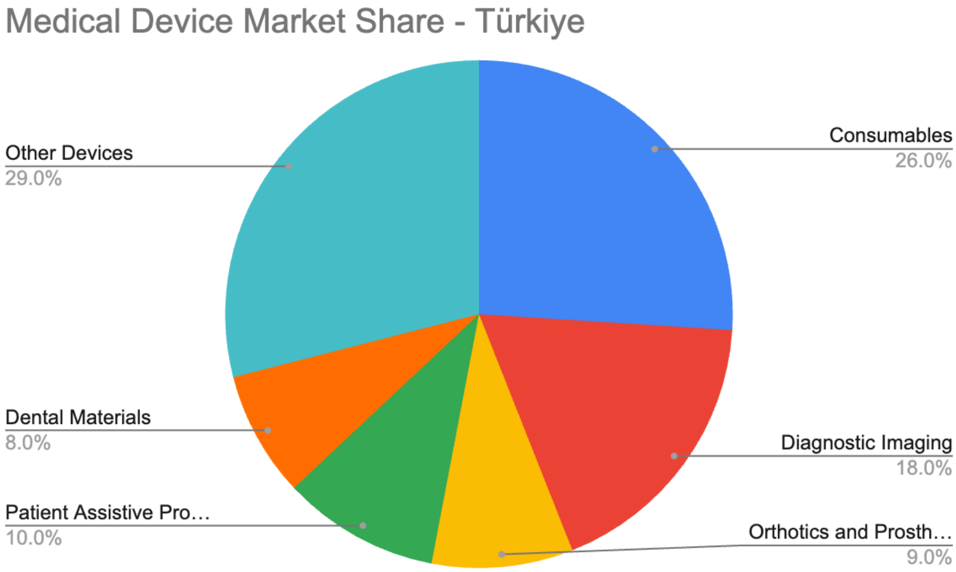

Figure 9. Medical Device Market Share, 2020. (Fitch Solutions, 2020)

The Turkish medical device market has grown approximately three-fold in the last five years and reached $2.4 billion in 2020 (Fitch Solutions, 2020). However, when we adjust the market growth for inflation, we see a market that has grown by half in the last 5 years. Unlike many sectors, the market grew by 50% in TL prices in 2020 due to new health needs arising from the Covid-19 pandemic; this growth was 31% and 22% when adjusted for inflation and exchange rate, respectively. There has been a significant increas in demand, especially for medical gloves, mechanotherapy devices and electronic diagnostic devices. It is estimated that the Turkish medical device market will grow by 6.7% CAGR in TL prices between 2020 and 2026 (Fitch Solutions, 2020). When we look at the import and export numbers, the medical device sector realized $933 million in exports and $2.1 billion in imports in 2020, resulting in a current account deficit of $1.1 billion. Compared to 2014, when the sector had its highest current account deficit in the last 10 years, the current account deficit decreased by 37% in 2020. The decrease in the current account deficit during this period was due to approximately 2.5 times increased exports and 6% decreased imports (Fitch Solutions, 2020). Nevertheless, the market is highly dependent on imports; for example, the ratio of sector imports to domestic demand was 85% on average in 2020. In 2020, exports of patient assistive devices and diagnostic imaging devices gained momentum due to the Covid-19 pandemic.

The Turkish medical device industry is relatively less developed compared to Brazil, with a greater reliance on imports. Türkiye's medical device market is dominated by multinational companies, which account for around 80% of the total market share (Aslan et al., 2014).

The Turkish government has recognized the need to strengthen the domestic medical device industry and has implemented various initiatives to promote local production and innovation. This includes measures to encourage investment in R&D, support technology transfer, and facilitate market access for local manufacturers (Lee, 2018). To address this, the Turkish government has implemented policies to promote local production, including tariffs on imported devices and incentives for domestic manufacturers. The market is expected to continue expanding, with a strong emphasis on locally manufactured devices, supported by government policies such as the "Domestic Product Priority" initiative (TÜSEB, 2021).The Strategic Investment Incentive Scheme also offers financial incentives to businesses that manufacture medical equipment domestically, fostering industry expansion and ensuring the nation's supply of affordable, high-quality medical goods (Invest in Türkiye, 2023). However, the Turkish medical device industry, including the MRI segment, still faces challenges in terms of technological capabilities, scale of production, and international competitiveness (Pilo, 2014). Developing specialized expertise and building a robust supply chain infrastructure remain critical priorities for the sector's growth and long-term sustainability.

Türkiye's medical device industry is highly regulated, with the Turkish Medicines and Medical Devices Agency (TİTCK) overseeing the registration and approval processes for medical devices (Koyuncu et al., 2020). Since Türkiye is a member of the European Customs Union, it has adopted the MDR (Medical Devices Regulations eu 745/2017) for Medical Devices, which is in force in the European Union. Accordingly, medical devices must obtain a CE certificate in order to circulate in the market.

The Regulation on Medical Devices (2017/745) divides medical devices into four classifications (Class I to IV) based on the possible risks they may provide to patients and users. Class IV devices, which include implantable devices and life-supporting equipment, are categorized as high-risk, whereas Class I devices, such surgical instruments and bandages, are regarded as low-risk. Depending on the class it is assigned, a medical device will go through different levels of inspection during the registration process. Due to their high risk, Class IV devices must pass a more stringent evaluation that includes a detailed examination of their clinical data, manufacturing procedures, and safety documentation.

Table 8. Summary of the Brazil Medical Device regulayory requirements.

National Regulatory Authority:	• TITCK Turkish Medicines and Medical Devices Agency
Medical Device Act:	• Regulation on Medical Devices (2017/745)
Registration requirements	• Technical Documentation based on Regulation on Medical Devices Annex II • CE Certificate • Free Sales Certificate from the manufacturer • ISO 14971:2019 Risk Management Documentation
Certification process	• Work permit allowance required to market, sell, and distribute products in Türkiye
Quality Management System	• ISO 13485:2016 Standard Certificate

In manners of administrative system, Türkiye has a comprehensive structure. The Turkish Medicines and Medical Devices Agency (TİTCK) is responsible for regulating medical equipment and devices in Türkiye. It is a complicated procedure to coordinate ministerial decisions about the acceptance and financing of health technology in the public healthcare system. Because of this intricacy, it becomes difficult to coordinate how ministerial decisions are made to cover the costs of health technologies that public health institutions employ. Although the use of risky and ineffective medical equipment is prevented by appropriate supervision, TİTCK's authorization procedures may increase consumer demand for particular goods. (Uçak, 2016).

The fast growth of the MRI market in Türkiye is indicative of broader trends in the modernization of healthcare and the use of cutting-edge medical technologies. The market is anticipated to expand in the upcoming years at a compound annual growth rate (CAGR) nearly 7%, mostly due to a rise in the demand for diagnostic imaging services (Fitch Solutions, 2020). The increasing need for prompt and precise diagnostic instruments is reflected in the MRI market's growth, which also reflects a broader trend toward modernization in Türkiye's healthcare system. Part of the reason for this demand is that people are growing more conscious of health problems and their options. Nonetheless, there are also issues with MRI services' pricing and accessibility, especially in rural areas where resource and infrastructure limitations prevent these technologies from being widely used.

With the spread of cardiovascular diseases and cancer, developments in cancer imaging processes, the increasing demand for high-tech imaging to the growing concept of private hospitals, and the increase in city hospitals, sales of diagnostic products is expected to expand. Figure 3 depicts the diagnostic imaging market size estimates till 2026.

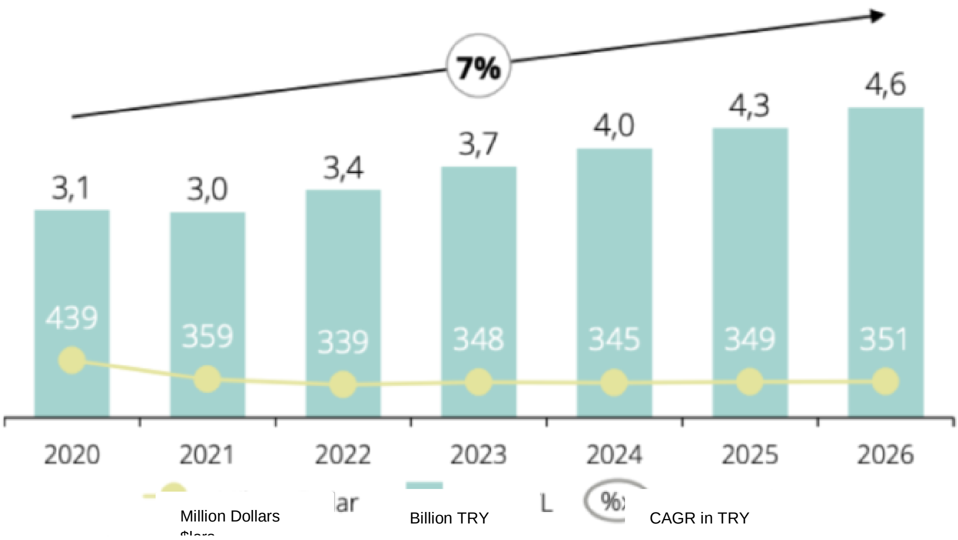

Figure 10. Diagnostic imaging market size estimate. (Fitch Solutions, 2020)

With the Health Transformation Program, an attempt was made to eliminate the numerical deficiency in the field of medical imaging after 2002. The number of MR devices, which was 58, reached 1048 in the last month of 2017 by renewing its existing technology.

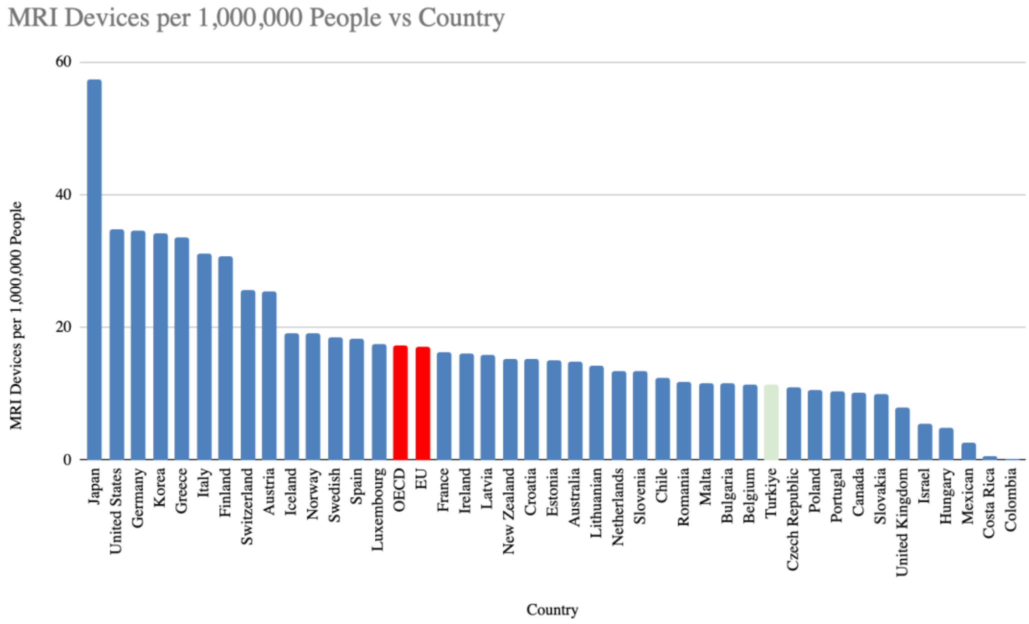

Figure 11. Distribution of the number of MRIs per 1,000,000 people OECD & non-OECD countriess, 2021 (OECD Database, 2021).

An important indicator of the state of healthcare service development is the number of MRI machines per person. Technologies for imaging play a major role in the processes of diagnosis and therapy. It is also worth to state that the MRI imaging data is considered crucial for raising the standard of healthcare. When we look at Table x, the average number of MRI devices per 1,000,000 people according to the OECD average is determined as 17.3. This number is 11.3 in Türkiye.

Table 9. Distribution of the number of MRIs per 1,000,000 people in hospitals, 2021 (General Directorate of Health Services).

Region	MoH	University	Private	Total
İstanbul	4.7	1.3	7.6	13.6
Batı Anadolu	5.6	2.7	4.8	13
Batı Marmara	4.6	1.4	5.9	11.9
Akdeniz	3.9	1.1	5.6	10.6
Ege	4.6	1.6	5.8	11.9
Doğu Karadeniz	6.3	0.7	4.3	11.3
Türkiye	4.4	1.3	5.6	11.3
Kuzeydoğu Anadolu	6	1.8	2.7	10.5
Ortadoğu Anadolu	3.8	2	2.6	8.4
Doğu Marmara	4.1	1.1	5	10.2

Table 9. (continued)

Orta Anadolu	3.7	1.5	3	8.2
Batı Karadeniz	4.9	1	2.7	8.6
Güneydoğu Anadolu	3.1	0.7	4.8	8.6

The availability of diagnostic imaging is one area where Türkiye's healthcare system excels, but there are also areas for improvement, as the table illustrates. Regional disparities in healthcare access can be shown in the fact that while some regions, like İstanbul and Batı Anadolu, have high MRI densities, others, like Güneydoğu Anadolu, lag behind. Furthermore, the prevalence of privatized healthcare in many areas raises the possibility that economic constraints could affect the capacity of individuals to acquire cutting-edge medical technology. Investing more in public healthcare infrastructure, especially in underprivileged areas, and making sure that resources are distributed more fairly nationwide could help address these inequities.

Last but not least, the number of MR devices increased at the highest rate during this period. From just 58 in 2002 to 1477 in 2018 and 915 in 2018, the number of MRI machines has grown considerably. Today, Türkiye has an MRI scanner density of 11.2 per million population, which is higher than the global average of 10 (Geethanath & Vaughan, 2019).

3.6 Comparatıve Analysis

The medical device industry has become an increasingly important economic sector, offering significant opportunities for growth and expansion, particularly in emerging markets (Wang & Giuffrida, 2016). As these countries continue to develop their healthcare infrastructures, the demand for innovative and cost-effective medical devices is on the rise, leading to a growing number of local manufacturers and enterprises focused on creating solutions tailored to their specific market needs. Moreover, the involvement of government investments in these markets is crucial, as it not only supports the sector's growth but also ensures that healthcare improvements are sustainable and aligned with local needs, thereby attracting further interest from investors and fostering successful partnerships with local stakeholders.

This study analyzes the MRI industry in Türkiye and Brazil and the role of the state in the formation of this industry. The reason for comparing Brazil and Türkiye is that, in addition to the information presented above about the BRIC countries, the two countries have similarities in terms of economic structure.

Brazil and Turkey exhibit notable parallels in their economic trajectories as developing countries that have undergone periods of rapid expansion and cyclical financial turbulence. Both nations have embraced neoliberal economic policies, particularly in the late 20th century, which has led to their deeper integration with the global marketplace. Brazil and Turkey have also grappled with inflationary pressures, currency fluctuations, and political instability, all of which have had similar impacts on their overall economic stability (Bozduman, ET., Erkan, B., 2018).

One of the primary similarities between Brazil and Türkiye lies in their reliance on commodity exports and foreign capital. Brazil's economy is primarily driven by agricultural products and mineral exports, while Türkiye has a more diversified portfolio but is still dependent on energy and hi-tech imports. Global market fluctuations, such as in commodity prices, have had direct impacts on both economies. As noted in research by FGV (2014), both countries also rely on foreign investment, and political turmoil has often led to capital flight and economic downturns.

Additionally, Brazil and Türkiye have both implemented significant economic reform programs in response to crises, such as Brazil's Real Plan and Türkiye’s IMF-backed reforms in the early 2000s (Ünal, E., 2013). These measures stabilized inflation and modernized their respective financial sectors, allowing for periods of economic growth. However, recent political instability in both countries has led to renewed concerns about their economic futures. According to the comparative analysis by Birol Erkan and Elif Tuğçe Bozduman (2018), despite their unique geopolitical and cultural contexts, Brazil and Türkiye’s economic policies and historical experiences demonstrate several points of convergence.

On the other hand, it is important to look at the two countries' National Innovation Systems in order to have a broader understanng of the current situation. The National Innovation Systems (NIS) of both **Türkiye** and **Brazil** are shaped by their unique historical, economic, and institutional contexts, but share several similarities and differences in terms of institutional frameworks, R&D investment, human capital, and international collaborations. While both nations have made substantial progress in fostering innovation, the structure and effectiveness of their NIS reveal distinct approaches and outcomes.

Türkiye's NIS is characterized by a strong government-driven approach, with public institutions playing a central role in funding and guiding innovation efforts. Key agencies like the Scientific and Technological Research Council of Türkiye (TÜBİTAK) and the Ministry of Industry and Technology are the primary drivers of research and development (R&D) across sectors (Ministry of Industry and Technology, 2020). Public sector-driven programs such as Vision 2023 and the 11th Development Plan aim to boost R&D spending and enhance technological capabilities across various industries (Directorate of Strategy and Budget, 2019). However, despite these efforts, Türkiye's NIS faces challenges related to its heavy reliance on external technology transfers and partnerships with international firms, which, while providing access to advanced technologies, limit the country's autonomy in developing indigenous innovation systems (TÜBİTAK, 2021).

In contrast, Brazil's NIS is distinguished by a more balanced interaction between public and private sectors. Institutions like the Ministry of Science, Technology, and Innovation (MCTI) and the National Development Bank (BNDES) have played pivotal roles in fostering innovation, particularly by supporting private sector R&D initiatives and regional innovation clusters (MCTI, 2020). Brazil's innovation framework benefits from a stable institutional infrastructure, with long-established organizations such as INPI (National Institute of Industrial Property) that work alongside private firms to support innovation (Cassiolato et al., 2002). Unlike Türkiye, Brazil has leveraged privatization and market-oriented reforms, particularly through the example of Embraer, to foster innovation autonomy and enhance global competitiveness (Marques & de Oliveira, 2009). The privatization of Embraer in the

1990s is a significant case where state-led innovation transitioned to a more dynamic private sector-driven approach, leading to global success in the aerospace industry (Goldstein, 2002).

In terms of R&D investment, Türkiye’s innovation system remains largely reliant on government funding. Public institutions, primarily TÜBİTAK, are responsible for the majority of R&D funding, which is concentrated in strategic sectors like defense, technology, and pharmaceuticals (TÜBİTAK, 2021). Despite efforts to increase R&D intensity to 1.8-2% of GDP by 2023, Türkiye still lags behind global averages, particularly in terms of private sector contributions (OECD, 2022). This is partly due to limited venture capital and insufficient private sector involvement in innovation activities, making it difficult for Türkiye to scale innovative solutions (Ministry of Industry and Technology, 2020).

Brazil, on the other hand, has developed a more diversified funding system for innovation. Both public institutions, such as CNPq (National Council for Scientific and Technological Development), and the private sector contribute to R&D investment. Brazil’s NIS also benefits from region-specific innovation policies, such as those in São Paulo, which help foster private sector participation and innovation in key sectors like agriculture, energy, and aerospace (Cassiolato et al., 2002). Brazil has also directed R&D spending towards niche industries, particularly the agricultural and aerospace sectors, where it has achieved global recognition (Goldstein, 2002). However, political instability and fluctuating financial resources have led to inconsistencies in Brazil's R&D funding, which sometimes hinder the long-term development of its innovation system (Vertesy & Szirmai, 2010).

Both countries have made strides in fostering entrepreneurship, though their ecosystems vary significantly in maturity. Türkiye’s entrepreneurial ecosystem is still in the emerging phase, with technoparks such as ODTÜ Teknokent and İstanbul Teknopark supporting startups and R&D activities. However, the lack of venture capital and the limited connection between academic research and market needs hinder the scaling of innovations in Türkiye (Ministry of Industry and Technology, 2020). Government programs like KOSGEB and TÜBİTAK BIGG aim to address these gaps, but the ecosystem still requires better integration and support (TÜBİTAK, 2021).

Brazil, on the other hand, boasts a more dynamic and established innovation ecosystem, especially in regions like São Paulo and Campinas, where innovation hubs and technology parks are well-developed (APTE, 2023). Brazil has benefited from a robust entrepreneurial culture, with international venture capital playing a significant role in supporting the country's growing fintech, biotech, and agricultural technology sectors (Cassiolato et al., 2002).

Both Türkiye and Brazil participate actively in international innovation networks, though their approaches differ. Türkiye's involvement in Horizon 2020, EUREKA, and bilateral agreements with countries like Japan and South Korea has facilitated technology transfer and increased funding for collaborative projects (TÜBİTAK, 2021). However, Türkiye's reliance on external partnerships often results in limited autonomy in innovation, as the country still depends on international collaborations for advanced technological expertise (Ministry of Industry and Technology, 2020).

Brazil, by comparison, has fostered stronger ties with international partners, particularly through its leadership within the BRICS nations and its involvement in South-South cooperation (Cassiolato et al., 2002). Brazil's sectors like agriculture and aerospace are integrated into global value chains, allowing for greater knowledge flows and technological collaboration with global players. Embrapa, Brazil's agricultural research corporation, is a prime example of how the country has built global partnerships to support innovation in vital sectors (Caliari & Ferreira, 2023).

In short, both Türkiye and Brazil have made significant progress in developing their National Innovation Systems, but their approaches differ in key areas. While Türkiye's NIS remains heavily government-driven, with challenges related to brain drain and private sector participation, Brazil has developed a more balanced system with strong public-private collaboration and a vibrant entrepreneurial ecosystem. Both countries face the challenge of retaining talent and increasing R&D investment but have leveraged international collaborations to boost their innovation capacity. By learning from Brazil's success in fostering a more market-oriented and diversified NIS, Türkiye can potentially address its current limitations and move toward a more sustainable and competitive innovation environment.

Table 10. Comparative table for Türkiye, Brazil, China, Russia, and India.

Parameter	Türkiye	Brazil	China	Russia	India
Number of Population	86.4 million (2024 est.)	215 million (2024 est.)	1.43 billion (2024 est.)	143 million (2024 est.)	1.43 billion (2024 est.)
Population Growth Pattern	Aging Population	Aging Population	Aging Population	Aging Population	Aging Population
Responsible Unit for Health Management	Ministry of Health (Sağlık Bakanlığı)	Ministry of Health (Ministério da Saúde)	National Health Commission (国家卫生健康委员会)	Ministry of Health of the Russian Federation	Ministry of Health and Family Welfare
Gini Coefficient	44.4 (2021)	52.0 (2022)	37.1 (2020)	36.0 (2020)	32.8 (2021)
Medical Device Law	Regulation on Medical Devices (2017/745)	RDC No. 185/2001, RDC 751/2022	Regulations by National Medical Products Administration (NMPA)	Federal Law No. 323-FZ on Public Health	Medical Devices Rules, 2017
Ratio of Health Expenditures to GDP	4.7% (2021)	9.6% (2021)	6.6% (2021)	5.3% (2021)	3.0% (2021)
Medical Device Market Size	$2.8 billion (2022 est.)	$11 billion (2022 est.)	$30 billion (2022 est.)	$7.5 billion (2022 est.)	$11 billion (2022 est.)
MRI Market Size	$100 million (2022 est.)	$350 million (2022 est.)	$1.5 billion (2022 est.)	$600 million (2022 est.)	$400 million (2022 est.)
Number of MRI Devices per 1,000,000 People	11.3 (2021)	14.0 (2021)	4.2 (2021)	9.4 (2021)	2.0 (2021)

In addition to the similarities in Brazil's and Türkiye's economic structures, another reason for choosing Brazil in the comparative study conducted among the BRIC countries is that the prevalence of MRI technology (number of MRI devices per 1,000,000 people), which is the main focus of the study, and the medical device market are the closest to Turkey among these countries.

Table 9 summarizes the information provided for the BRIC countries in the previous section. Based on this table, MRI market size and number of the MRI Devices per devices are critical indicators to evaluate.More information about the sector's proximity was revealed by the MRI rate per million people.

Aside from the aforementioned, Brazil and Türkiye were contrasted in this study because sectoral research is challenging to do in China and Russia due to the fact that governmental sources are mostly published in the native tongue, making information unobtainable.

Türkiye and Brazil are both emerging economies with quickly changing healthcare systems. This similarity offers a solid foundation for comparison because both nations are going through demographic changes, such aging populations, which have a big influence on healthcare needs. The healthcare and medical device industries will benefit from these changes, so it's important to know how each nation is responding to them.

Türkiye's medical equipment market, at $2.8 billion, is far smaller than Brazil's, at $11 billion. This distinction shows that Türkiye is a developing market in its own right and that Brazil is a significant force in the Latin American medical equipment sector. Moreover, Understanding the factors that influence these markets' sizes can help us better understand local demand, legal frameworks, and investment prospects. The fact that Brazil's MRI market is far bigger than Türkiye's may also point to a higher need for diagnostic imaging technologies brought on by increased health awareness or a higher prevalence of conditions that require for MRI diagnosis. Understanding this difference is essential to comprehending the function diagnostic technologies play in the provision of healthcare as well as how economic reasons propel market expansion in various nations.

It is worth to highlight that Brazil has a higher number of MRI devices per 1,000,000 people (14.0) compared to Türkiye (11.3), which suggests better access to advanced diagnostic tools in Brazil. This difference is essential for comparing how each country's healthcare infrastructure development affects patient care and diagnostic capabilities.

By comparing Brazil and Türkiye, this study aims to explore how two different emerging markets with varying healthcare expenditures, regulatory environments, and market sizes approach similar challenges. Understanding these differences and similarities will provide an opportunity to identify best practices and strategies that can be applied across different contexts.

CHAPTER 4

METHODOLOGY & METHODS

This study employs a comparative analysis of state strategies and their impact on technological learning in the MRI production industry in Brazil and Türkiye.

To begin, the research will review existing literature on the diffusion and utilization of MRI technology in both countries. This literature review will provide a broader context for understanding the current state of MRI production and adoption in Brazil and Türkiye.

The core of the study consists of in-depth case studies of the MRI production industries in Brazil and Türkiye. These case studies will involve analyzing specific state policies, incentives, and regulatory frameworks that have influenced the development of these industries in each country.

To conduct these case studies, the research will draw on a variety of data sources, including academic literature, industry reports, and government documents. The analysis will focus on identifying key differences in state strategies between the two countries and exploring how these differences have impacted technological learning, production capabilities, and the overall trajectory of the MRI industry.

The study aims to understand the role of the state in facilitating technological learning in the production of high-tech medical devices in developing countries. An assertion is developed based on the research questions is that the technological learning processes in MRI production differ significantly between Türkiye and Brazil, shaped by varying approaches to state intervention and industrial policy based on the different approaches for “nationalization” and “localization”. This research asserts that while state intervention is crucial in both cases, sustained and adaptive policy support is necessary to foster long-term technological growth and maintain local production in the high-tech medical device sector. MRI technology, chosen for its high level of complexity and technological sophistication among medical devices, serves as the focal point for this research. Accordingly, the study seeks to answer the following research questions:

1. How does the technological learning process differ in MRI production between Türkiye and Brazil?
2. What is the role of the state in enhancing the technological learning process in MRI production?

This study seeks to explore two critical aspects of technological learning in MRI production. First, it investigates how the technological learning process differs between Türkiye and Brazil, specifically focusing on the strategies and pathways each country adopts to foster innovation in this high-tech medical field. Second, it examines the role of state intervention in enhancing the technological learning process. These research questions are addressed through two hypotheses. The first hypothesis posits that the technological learning process in MRI production varies significantly between the two countries, with Brazil's approach relying more on state-led policies, while Türkiye emphasizes private sector-led technology transfer. The second hypothesis suggests that state involvement through policy incentives, such as Brazil's Local Content Policy, leads to more successful technological learning and domestic production outcomes compared to Türkiye, where state support is less extensive. Together, these hypotheses offer a framework for understanding the complex interplay between state policy and technological learning, and how different national strategies influence the development of high-tech industries.

To address these questions, the study utilizes a qualitative inductive approach based on the framework established by Eisenhardt (1989). This approach is particularly well-suited for exploring the opinions and experiences of stakeholders who have been directly involved in these processes. According to Meadows (2003), an inductive qualitative method is most effective for generating meaningful insights from the collected data. The primary objective of this approach is to condense the collected data into a coherent summary, establish clear connections between the research objectives and the findings, and develop a theoretical model or framework that captures the underlying structure of the experiences or processes identified in the textual data (Thomas, 2006). By facilitating an in-depth exploration of various themes, this inductive approach avoids the limitations often associated with quantitative methods, which may not fully capture the complexity of the subject matter (Browne et al., 2023). Semi-structured interviews with open-ended questions were conducted to explore the intricate nuances of stakeholders' subjective experiences within the medical device MRI industry.

4.1. Research Design

This study adopted a qualitative inductive approach to explore the role of the state in technological learning in the production of high-tech medical devices in emerging economies. The rationale for choosing this approach is that it allows for a comprehensive understanding of the complex and multifaceted phenomenon of technological learning and the state's role in this process (Vergara et al., 2023). The research design integrates multiple stages, including a comprehensive literature review, targeted participant selection, data collection through semi-structured interviews, and detailed qualitative data analysis. Each stage is carefully structured to provide an in-depth understanding of the role of state policies and market dynamics in shaping the MRI industries of these two countries.

The selection of MRI technology as the focal point for this case study is primarily justified by its status as a highly complex and advanced medical technology, representing the pinnacle of "state-of-the-art" innovation within the field of biomedical engineering. MRI systems involve sophisticated principles of physics, engineering, and software, making them exemplary models for examining technological learning and production capabilities. Moreover, both Türkiye and Brazil have undertaken significant initiatives in the domestic development and production of MRI technology, offering a valuable comparative context to assess the role of the state in fostering technological advancements in emerging economies. The intricate nature of MRI technology, coupled with these national efforts, makes it an ideal subject for exploring the dynamics of high-tech innovation and the impact of state-led strategies in technology-driven sectors.

The production of magnetic resonance imaging (MRI) in Brazil and Türkiye is investigated using a comparative case study method. This method was selected because it works well for investigating complicated phenomena in real-world settings, especially when the variables of interest have a complex relationship with unique regulatory and socioeconomic frameworks. The goal of the research is to determine how various state strategies and market dynamics affect technological learning and innovation in the manufacture of high-tech medical devices by comparing two nations with comparable economic standings but differing regulatory and market environments.

BRIC (Brazil, Russia, India, China, and Türkiye) countries' literature was thoroughly reviewed as part of the research's first phase (see Chapter 3). The objective of this research was to determine which nations, given their current economic situations, demographic compositions, regulatory environment, markets for medical devices, and unique characteristics of the MRI industry, would offer the most interesting and pertinent comparisons.

Brazil and Türkiye were chosen for a more in-depth comparison investigation after this initial analysis because of their similar economic circumstances and significant advancements in the MRI sector (see section 3.6). This descriptive comparision was then backed by the literature on technological learning and the role of the government. The MRI industry is highly specialized, dominated by large global companies, and presents high barriers to entry for new and small players. Factors such as access to raw materials, manufacturability, market share, and competition contribute to this. (Geethanath & Vaughan, 2019) The “nationalization” trend in Türkiye's technology and industry generated excitement for an MRI project, but it ultimately failed. In contrast, Brazil has met this need through a significant inflow of foreign direct investments. A key difference is that Brazil implements "localization" policies, whereas Türkiye's approach has been one of "nationalisation" in MRI technology.

4.2. Partıcıpant Selection

The study utilized purposive sampling to select participants who are directly involved in the MRI industry in Brazil and Türkiye. Criteria for participant selection were based on their expertise and experience in the field, including roles in policy-making, production, regulation, and utilization of MRI devices. This approach ensured that the study captured a diverse range of perspectives from key stakeholders who have firsthand knowledge of the technological learning processes and challenges within the MRI industry. Potential participants were identified through professional networks, industry directories, and academic publications, and were contacted through LinkedIn and professional email accounts to invite their participation in the study.

4.2.1. Sampling Method

A purposive sampling method was employed to select participants who have direct experience and expertise in the MRI industry both in Brazil and Türkiye. This method ensures that the participants are well-positioned to provide relevant and insightful information. (Palinkas et al., 2013) The purposive sampling approach ensures that the selected participants are well-equipped to provide relevant and valuable insights. The participants were identified through a combination of industry associations, professional networks, and snowball sampling. This sampling method allowed for selecting participants who could offer in-depth understanding and first-hand experiences related to the research objectives.

The sample size was determined based on the concept of saturation, where additional data collection yielded no new themes or information. In total, nineteen participants were selected from Brazil and Türkiye, including representatives from medical device manufacturers, policymakers, MRI technicians, and industry experts.

The participants for this study were selected based on their sectoral technical knowledge and practical experience in the technological learning process, to address the research questions "What factors influence the technological learning process in

MRI production?" and "What is the role of the state in enhancing the technological learning process in MRI production?"

A collection of questions as provided in the *Annex 2* was created to be posed to participants with MRI technology-related sectoral, technical, and political knowledge. The interview questions in this study were designed to explore the state's role in facilitating technological learning, specifically within the context of MRI technology. The development of these questions was guided by the theoretical framework established through a comprehensive review of the literature on the state's involvement in technological learning. Initially, the questions aimed to identify the institutional and organizational capacity, as well as the specific area of expertise, represented by each participant. Subsequently, the questions addressed both internal and external learning activities related to MRI technology, allowing for an assessment of the participants' technological learning capacity. Finally, the interview questions sought to gather insights into the state's three key roles in the development of MRI technology: the state as a priority setter, the state as an institution builder, and the state as an incentive provider. This structured approach ensured that the questions were aligned with the central themes of the study and allowed for a systematic analysis of how Accordingly, three groups of participant profiles were identified to perform interactive interviews: global company representatives who market or manufacture MRI technology in both nations, engineers employed by these multinational corporations and conversant with the product's technology, and small enterprises that either directly or indirectly contribute to the product's development, as well as state legislators.

In collaboration with my supervisor, the interview questions were carefully developed as an initial step. Following this, global companies actively operating in both Brazil and Turkey were identified, along with local manufacturers and businesses contributing to the MRI industry. The state’s role and structure within the industry were also examined to identify relevant stakeholders. These efforts guided the process of determining potential participants for the study.

Once the key topics and stakeholders were identified, interview requests were sent to individuals working in relevant fields via LinkedIn, outlining the purpose of the thesis. For those unreachable through LinkedIn, company email addresses were utilized. Additionally, my advisor leveraged his professional network to increase participation in Brazil. After confirming participants, online interviews were scheduled via Google Meet, according to their availability.

4.2.2. Participant Criteria

Participants were selected based on the following criteria:

- **Direct Involvement or Expertise in the Medical Device MRI Industry:** Participants are selected as if they have direct experience and expertise in the production, development, or regulation of the medical devices industry and the MRI technology.
- **Role Diversity:** Inclusion of policymakers, industry experts, business managers, union representatives, and technology end-users to capture a holistic view of technological learning in the MRI industry.

4.2.3 Participant Demographics

A total of nineteen participants were interviewed, comprising ten from Türkiye and nine from Brazil.

Table 11. Participant Demographics

Nr	Nick	Role	Institution / Organization	Country
1	INT1	MRI Field Engineer	Global MRI Manufacturer Firm	Türkiye
2	INT2	Project Coordinator	Local Private Firm	Türkiye
3	INT3	Health Techology Director	Local Private Firm	Türkiye
4	INT4	MRI Field Engineer	Local Private Firm	Brazil

Table 11. (continued)

5	INT5	MRI Field Engineer	Global MRI Manufacturer Firm	Brazil
6	INT6	Head of strategy development department	Policymaker	Türkiye
7	INT7	MRI technician	Global MRI Manufacturer Firm	Brazil
8	INT8	Professor, Electrics & Electronics Engineering Dept.	University Research Center	Türkiye
9	INT9	Board member	Sectoral association	Türkiye
10	INT10	Head of R&D projects	Policymaker	Türkiye
11	INT11	Chair of the Board	Union	Türkiye
12	INT12	Product Manager	Local Private Firm	Türkiye
13	INT13	Business Manager	Global MRI Manufacturer Firm	Brazil
14	INT14	Professor, Electrics & Electronics Engineering Dept.	University	Türkiye
15	INT15	Professor, Economics	University	Brazil
16	INT16	Manager	Government Bank	Brazil
17	INT17	Technical Specialist	Global MRI Manufacturer Firm	Brazil
18	INT18	Professor, Economics	University	Brazil
19	INT19	Electronics Engineer	Local Private Firm	Türkiye

4.3. Data Collection

Semi-structured interviews were used to collect data, allowing for a thorough examination of participant experiences and perspectives on the MRI markets in Türkiye and Brazil. In order to obtain comprehensive information on the technological learning processes, governmental regulations, and market dynamics in each nation, the interview questions were developed with consideration for the themes found in the literature review. Participants who accepted the invites and fulfilled the requirements were interviewed. With permission, every interview was videotaped in order to guarantee precise transcription and analysis.

Interviews were conducted between 15.03.2024 and 12.08.2024. Each interview lasted approximately 30 to 90 minutes. Interviews were conducted in English with the participants from Brazil and Turkish with the participants from Türkiye. All of the interviews are audio and video recorded with the participants' consent. The recordings were then transcribed verbatim to ensure accuracy. Transcriptions were reviewed and corrected for any errors or omissions.

Following an inductive research approach, I first sought to understand the current market conditions, strategic plans in the medical device industry, and ongoing significant project situations. After conducting an extensive literature review, I analyzed the transcripts of the interviews. An iterative process was then employed to examine the information captured in the interview transcripts and compare and contrast the analysis with the existing theoretical framework. This process was repeated until we were sure that the data in the transcripts that were important for the study were completely categorized. During this process, details that were not included in the coding system and were highlighted in the transcripts were also captured and new codings were developed.

4.4 Data Analysis

The MAXQDA program, a tool for qualitative data analysis, was used to examine the verbatim transcriptions of the interviews. A coding system that was created using the interview questions and the themes found in the literature study guided the analysis. The first coding procedure was guided by this framework, which made it possible to systematically classify the data using established codes as provided in the Annex 1.

After the first coding, the transcripts were examined twice more to guarantee the analysis's completeness. Iteratively reviewing the data allowed for the discovery of previously unanticipated themes as well as the identification of any that were missed in the initial study.

Thematic analysis was employed to analyze the qualitative data. (Khokhar et al., 2020) This analytical method involves identifying, examining, and reporting patterns within the data. Before starting the thematic analysis of the interview results, a thematic analysis of the interview questions was conducted. This analysis formed the framework of the code system for the qualitative data analysis. Then, the following steps were applied to analyze the transcripts:

- Familiarizing: Closely reading and re-reading the interview transcripts to become familiar with the data.
- Initial Coding: Generating preliminary codes from the data that capture important features relevant to the research questions.
- Identifying Themes: Grouping the codes into potential themes and compiling all pertinent data for each theme.
- Reviewing Themes: Refining the themes to ensure they accurately represent the data and are coherent.
- Defining and Naming Themes: Clearly defining and naming each theme to understand its scope and focus.
- Reporting: Integrating the themes into a narrative that addresses the research questions and objectives.

The qualitative data analysis followed an iterative process, moving back and forth between the data, codes, and themes to develop a rich, in-depth understanding of the questions that forms the basis of the study. This methodology offers a strong background for comprehending the technological learning processes in the Turkish and Brazilian MRI production businesses. Using a qualitative inductive methodology, the study attempts to provide a nuanced knowledge of the factors impacting technological advancement in these emerging economies by utilizing a thorough literature review, targeted participant selection, and rigorous data analysis.

Participants were provided with an e-mail outlining the study's purpose, procedures, and their rights. Informed consent was obtained prior to each interview. Confidentiality of participants was maintained by anonymizing the data. Pseudonyms were used in the transcripts and any identifying information was removed. The study received ethical approval from the Middle East Technical University Ethics Committee provided in the Annex 3. All research activities were conducted in accordance with the ethical guidelines and standards of Middle East Technical University. While the qualitative approach provides deep insights, it also has limitations. The findings may not be generalizable to all developing countries due to the limited sample size from Brazil and the specific contexts of the participants. Additionally, language barriers have influenced the depth and accuracy of the data collected.

CHAPTER 5

FINDINGS

The results of this study indicate that the state's role in technological learning in the MRI production industry can have significant implications for the industry's development in emerging economies like Brazil and Türkiye. Interviews help capture the outlook of the MRI industry and the outcomes of the technology development attempts, the nuanced differences in terms of policies, interaction among the main stakeholders' institutional structures, and the overall ecosystem fostering innovation. Semi-structured interviews with nineteen participants (ten from Türkiye and nine from Brazil) from diverse sectors, including field engineers, MRI technicians, Ministry of Health officials, academics, and industry representatives. The interview results are focused on identifying key differences in state strategies between the two countries and exploring how these differences have impacted technological learning, production capabilities, and the overall trajectory of the MRI industry. These filtered data then were evaluated using three main themes to understand the role of the state, which is the central focus of this thesis: i) priority setting, ii) institution building, and incentives.

This chapter is structured as follows:

- Sub-chapter 5.1. Expert Perspectives on MRI Technology: This section presents insights from experts regarding the technical aspects of MRI technology, with particular emphasis on the complexity of the production process.
- Sub-chapter 5.2. The MRI Project in Türkiye: This section provides a comprehensive overview of the historical context, key developments, and current status of the MRI project in Türkiye.
- Sub-chapter 5.3. The MRI Project in Brazil: This section examines the history, significant milestones, and present state of the MRI project in Brazil.

The key factors that appear to differentiate the technological learning processes in the two countries include the state's overall strategic orientation, the nature and extent of foreign direct investment, access to global value chains and knowledge networks, and the existence of complementary policies and institutions to support technological upgrading. To summarize the most striking outcome of the study, it can be stated that, in Brazil, the state has implemented a "localization" strategy, which has involved incentives and policies to attract foreign direct investment in MRI production. This has facilitated the transfer of technology and knowledge, enabling domestic firms to engage in deeper technological learning and build their production capabilities over time. (Şemin et al., 2007) (Gomes & Dalcol, 2007) In contrast, Türkiye has pursued a more nationalistic "localization" strategy, with the state seeking to develop domestic MRI production capabilities through state-backed initiatives. However, this approach has struggled to achieve the same level of technological learning and capability development as the Brazilian model.

5.1. Insights into MRI Technology And Manufacturability

Upon analyzing the interviews, several key technological components of MRI systems emerged as critical to the production process. I chose to present this section independently from the country comparisons because gaining a clear understanding of the complexity and advanced nature of MRI technologies is essential as a foundational step. This knowledge is critical for informing the development of appropriate policy instruments tailored to the unique challenges and demands of such high-tech innovations.

> INT8: “While I may sound a bit pessimistic, I feel that MRI systems are highly complex. It is not simply a device, but rather a sophisticated system involving various electronic and medical electronic components that humanity has ever developed and utilized. In fact, MRI systems may be more complicated than even a satellite receiver or a satellite itself, excluding the mechanical aspects required to launch and orbit the satellite. Even the mechanical components of the MRI system are not trivial.”

Each participant who provided technical input for the study began by highlighting the complexity of MRI technology. This topic is important since it requires a realistic presentation of what needs to be produced and completed. It is essential to be aware of all the specifics and advancements in MRI technology when making the decision to construct one, as this will enable more precise and methodical planning.I can say that the state's role in the local production of this complex technology is primarily as an environment creator. The environment creator is responsible not only for preparing the sector for the product and controlling competition, but also for developing the technical capacity required for this technology. This can be achieved through policies that encourage investment in high-tech industries and create an environment conducive to innovation. In addition to than that, the government can play a vital role in promoting international partnerships and collaborations, allowing local industries to learn from established global players. These collaborations can facilitate the transfer of knowledge and technology, accelerating the learning curve for domestic producers.

> INT14: “Therefore, it could be wiser to just purchase one of these superconducting magnets and attempt to create the remaining components, such as the software, coil, gradient coil, and RF coil. You know, a lot of power electronics that are hidden from view are present. So all you see when you walk into an MRI room is this device? However, there are a lot of activities going on within the space that require more than one megavolt for each power supply. Thus, we are discussing advanced technology there.”

In addition to the importance of planning when developing such a project, intervieews stated that it is more effective and reasonable to work in one or several areas rather than producing every point of MRI technology completely from scratch. Based on this, it can be suggested that a strategic approach for economically developing countries to focus on certain components of MRI systems while purchasing others. This approach reflects a pragmatic pathway to building domestic technological capabilities by initially concentrating on areas where there is potential for local innovation and expertise development. Here too, the role of the government is to strategically determine the orientation and facilitate this strategy by negotiating favorable terms for the acquisition of high-tech components and by supporting local manufacturers in developing complementary technologies.

> INT12: “Putting the system's parts together and getting it to function is one thing. Designing, producing, and marketing it are three different things entirely. The two are significantly dissimilar.”

The participants stressed the need for distinct research to be done on the technology's manufacturability and that MRI production is a completely different matter from technology development. A thorough understanding of both technological and market aspects is necessary for the design and production of MRI equipment. Government and academic institutions can work together to offer focused training programs that give engineers and business owners the skills and information they need. Moreover, proficiency in engineering, electronics, software development, and marketing is required for the successful creation of MRIs. Promoting cooperation between several disciplines can stimulate creativity and make it possible to create all-encompassing solutions that are suited to regional requirements.

To sum up, the analysis of the interviews highlights the intricate technological complexity of MRI systems and the vital role that targeted policies and strategic approaches play in their production. As participants underscored, MRI technology is more than just a collection of components; it represents one of the most advanced and sophisticated electronic systems in modern medical practice. A clear understanding of this complexity is essential for informed decision-making, particularly in developing countries aiming to build local capacities. The role of the government as an environment creator is crucial, not only in fostering innovation and technical capability but also in facilitating international partnerships that can accelerate technological development. Focusing on the production of specific MRI components, rather than attempting to create the entire system from scratch, provides a pragmatic pathway for economic development and local innovation. This strategic approach, supported by government policies and collaborations with academic institutions, can ensure that local industries develop the expertise needed to navigate both the technological and market challenges inherent in MRI production. Ultimately, this combination of focused production, international cooperation, and interdisciplinary collaboration will help bridge the gap between advanced technological systems and regional needs.

5.2. MRI Industry in Türkiye

In this section, the results obtained from the interviews are shared. The first attempts of the MRI studies conducted in Turkey are presented first. In the following sections, the MRI attempt with Aselsan and UMRAM project described based on the real world evidences.

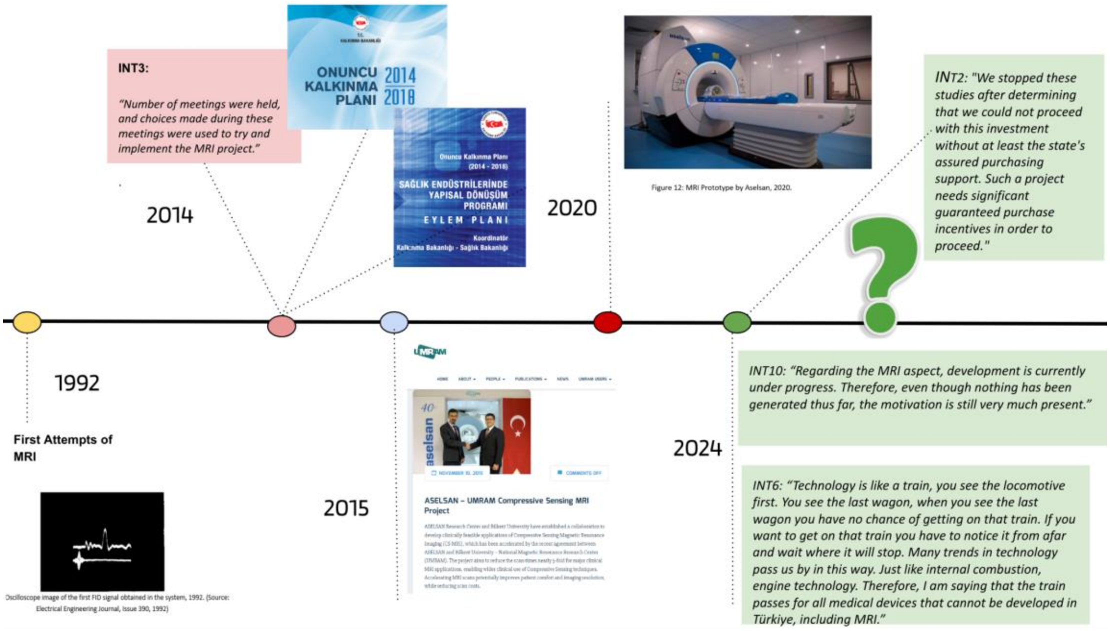

Figure 12. History of the MRI in Türkiye

Source: Author's representation.

Figure 12 shows the key milestones in the development of MRI technology in Türkiye. The first MRI device was developed through a project at Middle East Technical University (ODTÜ), leading to a functional prototype that was used at the ODTÜ Medico Center for 25 years. However, due to a lack of government support and incentives, the project did not move beyond the prototype stage.

In 2014, the importance of imaging technologies, including MRI, was formally recognized in Türkiye's 10th Development Plan. As part of this, the "Health Industries Structural Transformation Program Action Plan" emphasized the need to reduce reliance on foreign medical technologies and set strategic goals for domestic healthcare advancements.

In 2015, to pursue these goals, the University-Industry Collaboration incentive was launched. This involved a partnership between Bilkent University's National Magnetic Resonance Research Center (UMRAM) and Aselsan. Together, they aimed to produce MRI devices locally. By 2020, Aselsan announced the development of a working prototype. However, no further updates on the project have been made public since then.

This study focuses on MRI technology, driven by reports in 2020 that Türkiye would soon produce its own MRI devices (Aselsan, 2020). Figure 13 in the next section shows the MRI prototype from the latest 2020 update. Unfortunately, there has been no additional information on the project's current status.

As discussed earlier, MRI technology is a highly advanced system that integrates knowledge from various engineering disciplines. Recognizing the importance of local production of such a complex technology, I decided to investigate the development of MRI production in Türkiye. The lack of current information on this project highlights one of the main goals of this study: to uncover the true progress and status of MRI production in Türkiye.

5.2.1. History Of The MRI in Türkiye

During the course of the interviews, it became evident that Aselsan & UMRAM project was not Türkiye's first initiative in the development of MRI technology. This realization prompted a deeper investigation into a previous MRI project, which was initiated in 1992. As noted by INT 6, this project occurred during the early stages of Türkiye's technological advancement, when the country was beginning to make notable progress in the field of advanced engineering.

In the 1990s, MRI technology was still a nascent area of research, not yet dominated by global corporations. A research team, led by Prof. Dr. Ziya İder and Prof. Dr. Hayrettin Köymen from the Department of Electrical and Electronics Engineering at Middle East Technical University (METU), successfully developed Türkiye's first MRI device. This achievement, supported by the United Nations and TÜBİTAK, marked a significant milestone, as the team successfully captured their first images using the domestically developed device.

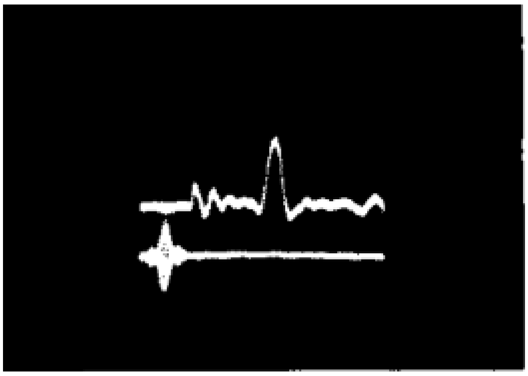

Figure 13. Oscilloscope image of the first FID signal obtained in the system, 1992. (Source: Electrical Engineering Journal, Issue 390, 1992)

The architecture of the first MRI system developed at METU was based on a resistive electromagnet with a fixed magnetic field of 0.15 Tesla. Acknowledging the need for future enhancements to a more sophisticated and higher-powered system, the project team ensured that all components, apart from the magnet, were selected for compatibility with more advanced systems. Key components such as the magnet and power supply, a VAX 3500 computer with a matrix processor, three gradient field amplifiers, an RF amplifier, and other hardware elements like a PC-AT and TMS320C25 processor card were procured externally.

In parallel, several critical components were developed internally by the research team, including a card for Analog-Digital and Digital-Analog conversion, an RF signal modulator and demodulator (MODEM), a preamplifier, and a directional coupler. The system's high-speed arithmetic processing was powered by a TMS320C25 card, with custom software developed in-house to manage its operation. The MRI system was installed within a dedicated space at METU's Health Center, which provided the necessary infrastructure, including a Faraday cage, a cooling system, and other essential facilities.

The project received financial support from TÜBİTAK for the procurement of electronic materials and fixed assets, while initial funding was provided by the United Nations. This initiative also opened doors for further research opportunities; two research assistants from METU and one from Bilkent University participated in a nine-week research program at KAIST in South Korea, a leading institute in the field. During this program, the team studied a similar MRI system and conducted successful experimental trials. This collaborative effort significantly advanced the technical expertise and development of MRI technology within Türkiye (Electrical Engineering Journal, Issue 390, 1992).

> INT14: "We finalized the research and got the first signal, after that they never showed interest again. About 15 years passed. 15 years later, TUBITAK, the undersecretary from the Ministry of Health, the rector of Gazi University, the head of the radiology clinic and some other guys came to visit us one day and asked why we did this."

A participant in this project disclosed that their team had successfully developed a system and was in the process of transitioning it to the production phase. However, they faced significant challenges due to the absence of a policy framework to facilitate their efforts. During our discussion,the interviewee emphasized the importance of commercializing such technology and the potential national benefits that could be realized if the technology were fully developed. At that time, the project was nearing completion, driven by a dedicated team of ten individuals. Despite the awareness and presence of state officials, there was a lack of political will to support the initiative. Consequently, the team, which had aimed to bring the technology to market using their own resources, was unable to advance due to the absence of a strategic vision. Nonetheless, they have continued their efforts in this field at a scientific level.

5.2.2. Current Situation Türkiye MRI Industry

As provided in the Figure 13, finalized prototype of the MRI project, is a study that started in 2015 with the partnership of UMRAM and Aselsan within the scope of "University-Industry Cooperation" and was implemented with the vision of "To have a say in the international market by producing high value-added advanced technological medical devices" included in the Tenth Development Plan. This study showed active development between 2015-2021, and no information about the fate of the project was shared in the press afterwards. The aim of this section is to explain the progress of the study chronologically.

Figure 14. MRI Prototype by Aselsan, 2020

Source: Anadolu Ajansı, 2020.

The inception of the MRI project in Türkiye can be traced back to the National Technology Initiative, a strategic effort aimed at enhancing the country's technological and industrial independence while boosting its global competitiveness. The National Technology Initiative seeks to elevate Türkiye's standing in the international arena by advancing its technological capabilities and reducing its dependence on foreign technologies (TÜBA, 2022). This initiative fosters innovation across various sectors, including information technology, energy, defense, health, and agriculture.

The core objectives of the National Technology Initiative include minimizing technological dependency, enhancing research and development (R&D) and innovation activities, cultivating a skilled workforce, increasing domestic production, and bolstering global competitive effectiveness (Coştu, Z., 2022). While the initiative spans a wide range of projects, its primary focus areas are information technology, energy, defense, health, and agriculture. In alignment with this initiative, significant localization and nationalization efforts have been initiated within the health sector to promote self-reliance and innovation.

> INT3: "By means of a Prime Ministry circular, a steering group for the health industry was formed in 2015. In brief, we call it TÜSEB. The

undersecretaries of the Ministry of Health, the undersecretaries of all pertinent ministries, the committee chairman, and TİTCK's committee secretariat were present when the committee was established. The goal of this committee was to localize the Turkish health industry. In order to accomplish this, a number of meetings were held, and choices made during these meetings were used to try and implement the MR project."

As Interviewee 3 mentioned, the prioritized sectors were specified in the "Health Industries Structural Transformation Program Action Plan" published by the Ministry of Health. Upon this, a university-industry collaboration project was initiated by the Ministry of Industry and Development. Approving the participant's statements, in the Turkish Medical Device Sector Strategy Document published in 2015, it was stated that the Tenth Development Plan, prepared in line with Türkiye's 2023 goals and covering the period 2014-2018, was prepared to include elements such as high, stable and inclusive economic growth as well as international competitive power, advanced manpower and sustainable use of resources.

INT19: "Regarding the tasks that needed to be done, there were explicit work packages. Aselsan was striving to learn as much as possible about the product at the system engineering level while UMRAM was providing technical and academic knowledge."

In alignment with the aforementioned goal, the MRI project was initiated through a collaboration between Aselsan and the Bilkent University UMRAM laboratory. The subsequent sections provide a detailed overview of the developmental stages of this project, along with the experiences and insights gained throughout these phases.

INT8: "On the hardware side, we were also writing a TUBITAK project to benefit from the support."

Within the project, UMRAM and Aselsan conducted their respective research independently to achieve their individual objectives. While some of these efforts were occasionally pursued under the auspices of TÜBİTAK-funded projects in both groups, they gradually lost momentum over time due to budget constraints and the overall uncertainty surrounding the project's future.

INT12: "I am not sure about the reasons behind it, but the decision was made not to continue the project."

The project continued actively between 2015-2021. Finally, news published in the press in by Aselsan states the following goals for 2021: “In the field of medical imaging; General Radiography Digital X-ray DevicesMagnetic Resonance Imaging Devices Product development studies are being carried out on the subjects. The first product to be launched to the market from the Digital X-Ray Devices family will be the Digital Mobile X-Ray Device. The product is planned to be launched to the market at the end of 2021. This product family is planned to be completed with floor/ceiling mounted devices and C-Arm Fluoroscopy devices. In the field of Magnetic Resonance Imaging, studies are ongoing to enter the market first with full body 1.5T MR imaging device models.”

After this statement, no any explanation or news was found regarding the status of the project. All participants who provided technical support to the study stated that the project was closed. When asked about the reasons for the closure of the study, I came across different explanations from different groups of participants. Assessing the study's conclusion is crucial to comprehending the boundaries of the implemented policy framework. Before discussing this matter, it was mentioned that TÜBİTAK funded the research within the framework of several initiatives. The research teams at Aselsan and UMRAM claimed that they were able to proceed with their work during the phase of study benefiting from TÜBİTAK supports.

> INT14: “In the end, Aselsan is a business focused on making money. It doesn't believe that producing MRI devices will help it become more competitive in the market.” , INT12: “As I said, it is impossible for us to continue without a strategic decision for products that have a very high market penetration and very high development costs.”

Aselsan participants stressed that they had finished the required system engineering-level study. MRI technology technology is expensive, though, and there are still some procedures that need to be done, such as the clinical validation study, which is quite expensive. The state was supposed to present a clear picture in order for the study on the Aselsan side to proceed, but because this expectation was not fulfilled, the project was put on hold. This is because Aselsan does not want to enter the market, and believes that the MRI equipment has a commercial profit edge. For this reason, Aselsan did not see it as advantageous to progress this study by allocating resources from its own budget.

> INT10: “Regarding the MRI aspect, development is currently under progress. Therefore, even though nothing has been generated thus far, the motivation is still very much present.”, INT6: “Technology is like a train, you see the locomotive first. You see the last wagon, when you see the last wagon you have no chance of getting on that train. If you want to get on that train you have to notice it from afar and wait where it will stop. Many trends in technology pass us by in this way. Just like internal combustion, engine technology. Therefore, I am saying that the train passes for all medical devices that cannot be developed in Türkiye, including MRI.”

Contraversionaly, some of the interviewees stated that they thought investing in MRI technology was not the right investment tool and that we should direct our target to artificial intelligence or different emerging technologies. When TÜSEB was asked why the project was closed, it was learned that they did not look into this project and were not informed about this issue. Based on this, it would not be wrong to say that there was a communication gap between the units of the Ministry of Health.
When asked why the project was terminated by UMRAM, they stated that the budget required for the continuity of the project was not provided and proper collaboration between stakeholders could not be achieved.

> INT2: "We stopped these studies after determining that we could not proceed with this investment without at least the state's assured purchasing support. Such a project needs significant guaranteed purchase incentives in order to proceed."

Based on this quote, it can be highlighted that a critical barrier to advancing MRI production is the necessity for government support, particularly through guaranteed purchase incentives. This issue underscores the challenges faced by local industries in initiating large-scale, high-risk technological projects like MRI production without assured demand and financial backing. By promising to buy a specific number of MRI systems made in the country, governments can play a crucial role in creating a steady demand that stimulates investment and production. To encourage initial investments, governments might also offer other financial incentives like subsidies, low-interest loans, or tax advantages in addition to purchase guarantees. These steps can assist in reducing the high expenses related to production, R&D, and research. Last but not least, it is critical to create regulations that are both supportive and explicit in order to ease entry into high-tech markets. Apart from this assertion, a further noteworthy discovery is that a tender was created specifically for public hospitals for this project; nevertheless, the high hurdle in this tender precluded the project's realization.

> INT3: “The 5-item medical equipment supply tender was released as part of the industrial cooperation initiative. Furthermore, it was anticipated that businesses like Aselsan would form a joint venture with a multinational corporation and submit a contract, or that Philips would provide instructions on how to form a joint venture with a local business and another business. The findings of the public tender could not be definitive in this regard.”

One final note regarding the conclusion of the MRI project in Türkiye: it has been suspended since the government and its partners were unable to come to a conscious decision to move forward with the project. The utopian specifications prepared for the state purchase guarantee required in the final stage, were prepared in a way that no company could contribute to, and as a result, they were postponed fifteen times before being closed on the grounds that no company would accept the tender.

As for the summary, the MRI project in Türkiye, initiated as part of the National Technology Initiative, aimed to reduce foreign dependency and boost technological capabilities in the health sector. Despite its initial promise, the project encountered numerous challenges, including insufficient government support, budgetary constraints, and a lack of collaboration between key stakeholders. While partnerships between Aselsan, UMRAM, and TÜBİTAK provided initial momentum, the project's ultimate suspension underscores the critical need for a strategic policy framework, including guaranteed purchasing incentives and financial backing from the state, to support the development of high-cost, high-tech innovations like MRI systems.

The inability to provide a clear strategic direction, coupled with the financial burden of clinical validation and market entry, left private partners like Aselsan unwilling to continue without substantial government commitment. The high entry barriers imposed by tenders and a lack of coherent communication between government bodies further contributed to the project's downfall.

This case highlights the importance of strong public-private partnerships and clear governmental policies to foster large-scale technological advancements. Without sufficient demand guarantees and comprehensive collaboration, local industries face significant risks in advancing high-tech production. Moving forward, it will be essential for Türkiye to develop more supportive policies, including financial incentives to successfully realize ambitious technological projects like MRI production.

5.2.3. Why Dıd It Fail?

During the interviews, important clues were obtained as to why the project failed. The most notable weaknesses were "planning" and "insufficient budget." This section was not initially included in the coding system. However, as stated in the method section, while the interview notes of the speakers were examined repeatedly, they persistently shared their predictions about the failure of the MRI project in Turkey, and these predictions were related to planning and budget. Therefore, I found these notes worth sharing in my thesis.

> INT1: “The main problem is not to produce technology. First, we need to create a commercial scenario.”

All participants actively working in the sector in Türkiye mentioned that one of the most important problems of this failed project was planning. We are talking about very detailed planning here. This planning could not have a high resolution planning both as a strategy and as a product management strategy. First of all, the lack of a clear commercial scenario is the main problem. The current picture in Türkiye is not drawn correctly, no effort was spent here and for this reason, a human resource and financial resource spent on this project has been suspended. Türkiye is usually around 1% of the world market in health technology products. The fate of this project had to be designed considering this situation. In fact, we expect it to be more. But the reason why this does not happen is that we do not produce the technology.

> INT9: "Every time Aselsan joins a project, it's considered a significant technological advancement. This job will be impossible to complete if it is

> not a massive white elephant like Aselsan. Conversely, when it's that big, everything gets really pricey since it takes ten people to carry each egg."

Collaborative planning was another issue. Information surfaced very slowly, according to a participant who works in the academy, because proper collaboration and collaboration could not be established at the level of scientific studies. An intriguing perspective on this topic was that the research processes were slowed considerably by the early participation of significant stakeholders.

Another overlooked and important issue in planning is real-world evidence and feedback data from the end users of the product.

> INT11:"A research can be conducted to determine the frequency, density, and vision of product designers entering the shooting rooms, perhaps checking the device for malfunctions, and determining root causes."

The end user of the product, its market should be determined and their needs should be analyzed. According to the information received from the participants, no real data has been obtained from the field and no attempt has been made for this.

> INT12: "We need to look at it with the logic of product management. In other words, we need to look at the strategic side of this business, for example. There are companies in the market, how many are there?" What kind of approach is there in the global conjuncture? It is very important to understand these.

Another deficiency emphasized in planning is competition analysis and product brand perception. At this point, the role of technological learning comes to the fore again. Learning not only the innovation and R&D information of the product but also its manufacturability is a very important issue. Issues such as technology analysis, current workforce potential, what kind of technologies to invest in gain great importance.

Participants working as R&D engineers in MRI emphasized that they have completed their research processes and that there is a gap in the transition to the next step. Based on this, in addition to learning the technology itself, it is very important to learn the manufacturability of high technology. At this point, if the state can establish the necessary externalities, it is possible for technological learning to accelerate.

When we approach with this logic, it is necessary to plan future developments as well as designing and putting the device on the market. INT9's comment on this issue is as follows:

> "The number and features of existing devices should be analyzed and the technology orientation in the next 5 years should be determined. Market size and value should be determined, and at the same time, it is essential to determine how much of this need we will provide with domestic solutions and how much economic gain we will make, and finally, what kind of strategy will be followed in the global market."

Government support, in the form of incentives and budgets, plays a crucial role in driving the progress of research and development studies, which are essential for technological advancements, scientific discoveries, and the overall economic and social development of a country. Moreover, such support can significantly reduce the financial risks associated with R&D activities, enabling firms to allocate resources towards innovative projects that they may have otherwise deemed too risky or financially burdensome, thereby enhancing their competitive edge in a rapidly evolving marketplace (Ngisau & Ibrahim, 2020).

> INT:8 “The cost of this tiny board is 200 euros, and we require two of them. These are features only found on specialized motherboards used to drive a single channel. However, this tiny thing's maximum capacity is only 30 amp; at most, it can hold 50 amp, or 800 amps. Since Siemens and Phillips manufacture similar products, you can calculate how much money you should spend to just purchase something similar. But in this case, we have to design it ourselves.”

The speaker highlights the challenges of working on projects under the TÜBİTAK budget, noting that the maximum funding has increased from 700,000 Turkish lira three years ago to about 1.5 to 2 million lira now. However, he emphasizes the high costs of specialized components, like a small power amplifier board costing €200, which is required in multiples for their work. They point out the significant financial burden of sourcing or designing such components, particularly for high-demand applications, since major manufacturers like Siemens or Philips do not readily supply them.

Additionally, government incentives can address market failures stemming from externalities and the principal-agent problem, which often hinder investment in long-term R&D projects, thus fostering a more conducive environment for innovation and collaboration between industries and research institutions (Yao, 2019).

> INT2: “We did not truly set out to create a product bearing the Aselsan brand and introduce it to the market. This study aimed to strengthen our own competencies so that we could contribute to projects that would support Türkiye's goal of creating high-tech medical devices and bringing technology to the country."

The MRI project in Türkiye, though initiated with promising collaborations between Aselsan and Bilkent University’s UMRAM, faced significant challenges due to inadequate planning, budgetary constraints, and a lack of strategic direction. The failure to create a clear commercial scenario and integrate a well-defined product management strategy played a critical role in the project's stagnation. Furthermore, insufficient collaboration among stakeholders, communication gaps within the Ministry of Health, and the absence of real-world feedback from end users hindered progress.

Budgetary limitations were a major barrier to the project's continuation. Although TÜBİTAK funding provided some initial support, it proved insufficient to cover the high costs of specialized components and the extensive R&D efforts required for such advanced technology. The lack of a government-backed purchasing guarantee further diminished the commercial viability of the project, discouraging private sector investment in high-risk, high-cost ventures like MRI production. As noted by interviewees, the absence of substantial financial incentives and a robust long-term funding model severely constrained the project's ability to move beyond the research phase.

The MRI project highlights the essential role of government intervention, not only in providing financial support but also in fostering a collaborative, innovation-driven environment. A strategic combination of incentives—such as subsidies, tax breaks, and R&D grants—coupled with a clear purchasing guarantee, could have mitigated the risks associated with the project and encouraged sustained investment. For future high-tech projects in Türkiye, a more structured approach to planning, budgeting, and collaboration is critical to ensure the success of initiatives aimed at reducing technological dependency and increasing domestic production capabilities.

In conclusion, the lessons learned from the MRI project underscore the need for more detailed planning, stronger government commitment, and improved coordination between all stakeholders to drive technological innovation in Türkiye. With the right support mechanisms in place, Türkiye can leverage its potential to compete in global markets and develop cutting-edge technologies that meet both domestic and international demands.

5.3. MRI Industry in Brazil

Like many emerging economies, Brazil has recognized the strategic importance of developing its domestic capacity to produce advanced medical devices, such as MRI machines, which are critical for modern healthcare diagnostics and treatment. This chapter explores the evolution of MRI manufacturing in Brazil, examining the various factors that have shaped its development, the role of government policies and incentives, and the collaborative efforts between industry, and public institutions.

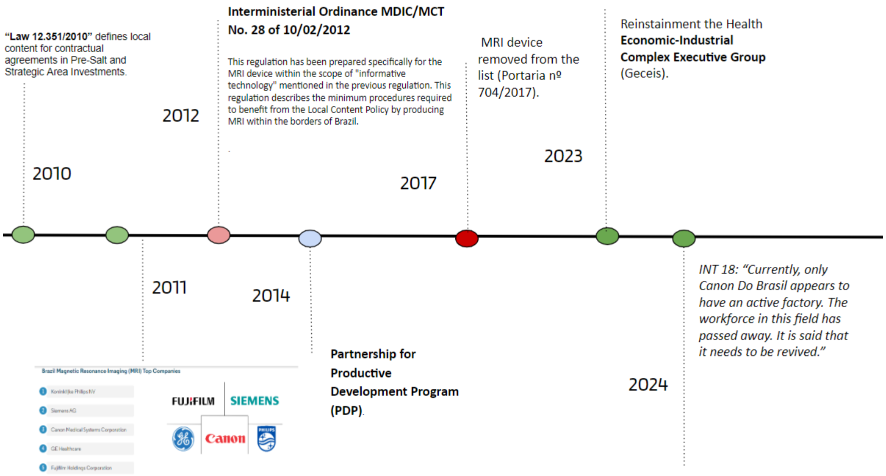

Figure 15. History of the MRI in Brazil

Source: Author's representation.

The journey of MRI manufacturing in Brazil is rooted in the country's efforts to reduce dependence on imported medical technology and foster local innovation. The Brazilian government has played a pivotal role in this process, implementing policies and providing incentives designed to stimulate the FDI(foreign direct investment) in the medical technology sector. By supporting domestic companies and research institutions, Brazil aims to create a sustainable ecosystem that can meet the growing demand for advanced medical imaging technology within the country and expand into Latin American markets.

The initial efforts toward promoting local production in Brazil began in the early 2010s with the implementation of the Local Content Policy. This policy framework combined financial instruments aimed at supporting both producers and end users, alongside partnership structures designed to enhance technological learning. A significant milestone occurred in 2012, when MRI devices were included in the SUS Priority Products list through a government circular. This inclusion created substantial opportunities for MRI manufacturers to benefit from the Local Content Policy, attracting major industry players to enter the Brazilian market during this period.

However, this positive trajectory was disrupted by administrative changes in 2017, which led to a revision of the policy. Notably, the MRI device was removed from the SUS Priority Products list, diminishing the support available to MRI manufacturers. In addition, low-interest credit programs offered by BNDES (Brazilian Development Bank), which had provided critical financial assistance, were also withdrawn. These changes significantly undermined the progress that had been achieved, leading to a gradual decline in momentum. As of today, it has been reported that only one of the originally established factories remains operational, reflecting the negative impact of these policy shifts on the local MRI manufacturing sector.

5.3.1 History Of The MRI in Brazil

The increasing demand for MRI facilities in Brazil, particularly within the public healthcare system, reflects a notable upward trend in the usage of advanced imaging technologies, significantly impacting patient care and diagnostic accuracy in a sector that has experienced considerable growth in recent years (Dovales et al., 2019).

The Brazilian government has implemented various policies and incentives aimed at promoting the domestic production of medical devices, which is particularly important for advanced technologies like MRI systems, as these efforts not only enhance local manufacturing capabilities but also contribute to job creation and skill development within the industry (Gomes & Dalcol, 2007). The study conducted by Dovales et al. (2019) revealed a significant increase in the use of MRI in Brazil between 2002-2014. This can be attributed to the improved image resolution and reduced health risks associated with the advancing MRI technology.

The initial efforts to produce MRI technology in Brazil were catalyzed by a government directive issued in 2010. This initiative arose from the growing need to address the significant costs associated with importing MRI devices and the logistical challenges posed by Brazil's geographical distance from the manufacturing facilities of global suppliers. The high demand for MRI equipment, coupled with Brazil's complex geographical landscape, led to frequent delays and inadequacies in the healthcare system.

As one interviewee INT5 noted, "It used to take eight months for an MRI device to arrive here from the head office in Japan, and this caused disruptions in our health system." These logistical delays underscored the urgency of developing a local production capability. To mitigate these issues, Brazil began exploring the transition to domestic production of MRI machines, primarily through strategies involving Foreign Direct Investment (FDI). This shift aimed to not only reduce dependence on imported technology but also enhance the country's ability to respond more swiftly to domestic healthcare needs.

As previously mentioned, the utilization of MRI technologies in Brazil saw a significant increase between 2002 and 2014. This rise is primarily attributed to the ability of MRI to provide high-quality images with minimal risk. However, despite its advantages, MRI technology is also associated with notable disadvantages, including its high cost and the logistical challenges of transporting such large equipment.

MRI devices were first included in the Strategic Products list of the Unified Health System (SUS) in 2010. To encourage the local production of these devices, the Brazilian government implemented a strategic policy mix aimed at attracting international companies to establish operations within the country. By requiring that the items on the Strategic Products list be manufactured domestically, the state offered various incentives to global companies willing to produce MRI devices within Brazil's borders.

An examination of the MRI-related activities of global companies in Brazil reveals a significant increase in activity between 2010 and 2014, reflecting the impact of these strategic policies.

> INT5: "When we look at the big players coming to Brazil and opening MRI factories, you see the years between 2010 and 2014. The reason for this is the success of the local content policy implemented to attract foreign players to the country.“

In Brazil, the concept of localization implies that the product or technology is manufactured within the country's borders. This leads to the consideration of the Local Content Policy, which are government strategy to promote the use of domestically produced goods and services. LCPs have been particularly influential in sectors like oil and gas, automotive, and information technology in Brazil. (Souza, 2013) These policies aim to enhance local industrial capabilities, create jobs, and stimulate economic development by requiring or incentivizing companies to source a certain percentage of their inputs locally. Brazil's local content policy has its origins in the mid-20th century, aligning with the country's broader industrialization strategy. Initially, the focus was on the automotive sector, with the goal of reducing reliance on imports and fostering the development of domestic industries. With the industrial trend shifts, information technology is included in the Local Content Policy. In this regard, the medical device sector, including MRI production, has begun to receive increased attention under this policy framework, emphasizing the need for a comprehensive industrial strategy that not only prioritizes local content but also addresses the technological advancements necessary for competitive manufacturing and innovation in Brazil's. In 2012, **Interministerial Ordinance MDIC/MCT No. 28 of 10/02/2012** was published. This regulation has been prepared specifically for the MRI device within the scope of "informative technology" mentioned in the previous regulation. This regulation describes the minimum procedures required to benefit from the Local Content Policy by producing MRI within the borders of Brazil. Moreover, the regulation establishes a framework for the inclusion of technological advancements that align with the national health priorities, thereby facilitating the development of a robust domestic manufacturing sector for MRI systems while underscoring the importance of fostering partnerships between government, academia, and industry.

Another point that needs to be emphasized here is the concept of "localization." In Brazil, the main goal is to meet health needs and, secondarily, to increase technology learning. The need for the MRI technology was driven by localized demands, unlike the approach seen in Türkiye. Furthermore, this growing trend necessitates a thorough evaluation of the implementation strategies employed by manufacturers. Local production not only mitigates reliance on imports but also stimulates innovation in MRI technology tailored to the specific healthcare needs of Brazil, enabling more efficient resource allocation and improved patient outcomes.

> INT18: “From the standpoint of international trade, local and, as far as Brazilian policy is concerned, distinct entities, we are unable to distinguish between companies based solely on the ownership of their capital; instead, we can compel them to engage in particular activities domestically, which is why we refer to this as local content rather than national content, since ownership by a Brazilian is not a prerequisite.”

Several policies arising from the health economic-industrial complex were introduced until 2015. One such policy was the List of Strategic Products, which served as a signal to the various players and institutions involved in the process of innovation and production in health about the demands of the universal health system. The health ministry led the interministerial governance body known as the

Executive body of the Health Economic-Industrial Complex, which defined this list on a regular basis with input from public and commercial organizations as well as civil society. The executive group assumed the role of a central hub for the institutional coordination of policies about the health economic–industrial complex. It facilitated connections between various entities and organizations involved in health innovation and production, such as funding and regulatory bodies. As a result, the executive group approved the development of an all-encompassing strategy driven by social objectives and national concerns. The strategic use of the state's purchasing power to subjugate industry and science, technology, and innovation policies to meet the requirements of the universal health system was another important undertaking. The public-private partnerships for domestic health goods manufacturing to meet requirements are the most inventive and persistent examples of the complex's actions. If there is a transfer of technology for the product in question, the health ministry ensures that partnerships can enter the public market. ((Temporão, & Gadelha, 2019)

> INT15: "One of the most powerful policies in the Health Economic - Industrial Complex is PDPs (Partnership for Productive Development). PDPs are aimed at encouraging the dissemination and adoption of new or existing products that have the potential to strengthen local production capacity and lead to innovation."

The productive development partnerships for domestic health goods manufacturing to meet requirements are the most inventive and persistent examples of the complex's actions. If there is a transfer of technology for the product in question, the health ministry ensures that partnerships are able to enter the public market. The technology complexity of the product being moved from the private sector to the local public partner institutions determines the market share and length of access, which varies from five to ten years. The products listed on the List of Strategic Products qualified for the collaborations.

The primary aim of PDPs is to systematically advance the Health Economic-Industrial Complex, ensuring that essential health products are produced within the country, which in turn reduces reliance on international suppliers and strengthens national health security.

A PDP agreement typically involves collaboration among three main entities: the Ministry of Health (MoH), private companies, and public laboratories. Under the agreement, the MoH commits to purchasing specific products for the Unified Health System (SUS) for a duration of up to ten years. In return, private companies agree to transfer the necessary production technology to a public laboratory over the same period. During the technology transfer, the private companies supply the products to the SUS. By the end of the partnership, the public laboratory is expected to be fully capable of producing the product independently and, if needed, can also transfer the technology to other public laboratories as directed by the federal government.

The implementation of a PDP is a complex and multi-phase process, structured as follows:

1. Phase I: Submission, Review, and Decision-Making
   In this initial phase, PDP proposals are submitted by interested parties. These proposals undergo a thorough review and decision-making process by the relevant government authorities to evaluate their alignment with national health priorities and their potential to enhance domestic production.
2. Phase II: Contractual Agreements and Product Development
   Once a proposal is approved, formal contracts are established, detailing the obligations of the MoH, private companies, and public laboratories. This phase also involves the early stages of product development, setting the groundwork for future technology transfer.
3. Phase III: Technology Transfer and Product Supply
   This phase is the central part of the PDP process, where the technology is transferred from the private company to the public laboratory. Simultaneously, the MoH procures the product from the private company for distribution within the SUS, ensuring that health system needs are met while building local production capacity.
4. Phase IV: Internalization of Technology
   In the final phase, the public laboratory completes the technology internalization process, gaining the ability to produce the product independently. This not only ensures a continuous supply to the MoH but also

allows the laboratory to share the technology with other public institutions if required.

Through these stages, PDPs are instrumental in building Brazil's capacity to produce critical health products domestically, aiming to create a robust, self-sustaining health sector that can address national needs and adapt to future challenges.

Additionally, the policy mix implemented in Brazil was designed not only to attract technology transfer to the country but also to provide higher quality and more imaging devices to healthcare centers and hospitals, which are the end users of this technology.

> *INT 16: "The local content policy implemented by the Brazilian government provided incentives for multinational companies like Siemens, Philips, and GE to manufacture MRI equipment within the country. These companies began producing MRI systems in Brazil to take advantage of the policy, which included financing mechanisms through the BNDES (The Brazilian Development Bank)to help hospitals and healthcare providers purchase the domestically manufactured equipment."*

The Local Content Policy has created an attractive incentive for the final consumer who will buy and generate low-interest rate loans, even as it supports the producing side. In this instance, hospitals that wish to buy the technology now have easier access to it, supporting local production. INT16 emphasizes that there has been stagnation in the sector since the government that changed in 2017 removed these low-credit purchase supports. Here, INT16 comments on the fact that many global companies were attracted to the country and that currently, only one company is actively producing.

In addition to this information, when we look at the current priority list for SUS, we see that MRI and imaging systems are not included here. In this case, we can assume that MRI devices do not currently have an active production process. This situation suggests that without sustained policy support and strategic focus on the MRI sector within the Brazilian healthcare framework, the momentum gained in local production and the associated benefits could decline, leaving unmet healthcare needs for effective diagnostic imaging services in the country.

5.3.2. Snapshot Of The MRI Technology in Brazil

While Brazil currently lacks specific incentives for MRI manufacturing projects, the introduction of the “Health Economic Industrial Complex” represents a significant step towards revitalizing the nation's expertise and capacity in the healthcare sector, including advanced medical technologies like MRI (Viana et al., 2016).

When the latest strategic product list published by the Ministry of Health in March 2017 was examined, it was seen that the MRI device was not on the list (Portaria nº 704/2017). Accordingly, at the moment, Brazil is not seeing any significant initiative or drive to produce MRI technology. This is because MRI is not listed among the necessary products that the Ministry has released. But when the need for MRI technology was recognized in the past during 2010s, substantial policy incentives were offered to boost domestic production.

According to the Health Economic-Industrial Complex, several incentives are offered. The **health economic–industrial complex** is an approach developed to integrate health care needs with industrial and innovation policies to enhance local production capabilities. This concept emphasizes the development of local production and innovation capacities to reduce dependency on global markets and improve health outcomes. In practice, it involves coordinating industrial, technological, and scientific strategies to support universal health access, particularly in response to public health crises like COVID-19. This approach was effectively applied in Brazil, enabling the country to rapidly scale up local vaccine production and ensure broad access to health care (Gadelha, et al., 2024). To achieve this goal, a technical committee was established. Originally known as GCIS, the group operated under the acronym from 2008 to 2019. Its objectives include fostering collaboration among government agencies, developing policies to support national R&D, production, and innovation, and satisfying the strategic needs of Brazil's Unified Health System (SUS).

Currently, Decree No. 11,464/2023, effective since April 24, has reinstated the Health Economic-Industrial Complex Executive Group (Geceis). Previously known as GCIS and active from 2008 to 2019, this group facilitates collaboration among government bodies and develops strategies to enhance national research, development, production, and innovation. It also aims to address the strategic needs of Brazil's Unified Health System (SUS).

This initiative aligns with the government's objective to achieve 70% local production of all essential inputs for the health sector, both industrial and services, by the conclusion of the current administration's term in 2027. This goal has been emphasized repeatedly by Health Minister Nisia Trindade since her appointment.

Under the new decree, the Health Economic-Industrial Complex is described as encompassing an economic, technological, and strategic foundation for the production of a wide range of health-related products. These include medicines, vaccines, active pharmaceutical ingredients, blood products, biotechnology products, medical equipment and devices, diagnostic products, materials for health use and personal protection, as well as goods and services related to information and connectivity in health, essential services and technologies, and other relevant products. Sector leaders believe that if MRI technology and imaging systems are deemed "needs" in this context, the appropriate policy tools in the health, economic, and industrial sectors will be triggered.

The guaranteed purchase initiatives that were previously put in place to draw foreign direct investment to the country and the policy mix that guarantees the incorporation of this information into state policy—both as a means of facilitating easier access to the technology the nation needs and as a secondary consideration to foster the development of an ecosystem—indicate that this policy tool is effective, even though we haven't seen an active strategy for MRI production at this time.

The reports that a participant working as an MRI field engineer in Brazil shared are shown in Figure 16. According to these claims, a local Brazilian company produces the Central Unit component of the MRI apparatus under the Philips name, which is under the engineer's responsibility. This scenario may potentially serve as proof that collaborative learning is the foundation of technology learning.

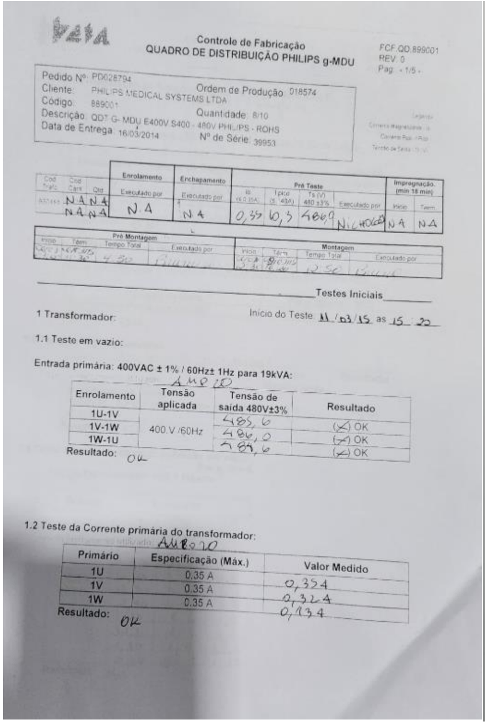

Figure 16. Brazilian Local Private Company Equipment used in the Philips MRI systems. *Source: Interviewee provided the related reports.*

The positive impact of the local content policy on MRI production in Brazil is further evidenced by the investment and expansion plans of major global medical device companies in the country. The participant's statement is also consistent with the literature. When we look at the top five MRI manufacturers in Brazil, we see Fujifilm, Siemens, GE Healthcare, Canon, and Philips. These companies' entry into the MRI market began with an agreement that Siemens made with an imaging laboratory in 2011. Within the scope of the Local Content Policy, policy mixes provided to global manufacturers to enable them to manufacture in Brazilian territory have created a cluster in parallel. INT4 from Brazil, which works with Philips MRI devices, emphasized that the equipment used as the central unit in Philips brand MRI devices is manufactured by a local Brazilian manufacturer, "Beta Electronics".

Additionally, the policy mix implemented in Brazil was designed not only to attract technology transfer to the country but also to provide higher quality and more imaging devices to healthcare centers and hospitals, which are the end users of this technology.

INT 16: "The local content policy implemented by the Brazilian government provided incentives for multinational companies like Siemens, Philips, and GE to manufacture MRI equipment within the country. These companies began producing MRI systems in Brazil to take advantage of the policy, which included financing mechanisms through the BNDES to help hospitals and healthcare providers purchase the domestically manufactured equipment."

The Local Content Policy has created an attractive incentive for the final consumer who will buy and generate low-interest rate loans, even as it supports the producing side. In this instance, hospitals that wish to buy the technology now have easier access to it, supporting local production. INT16 emphasizes that there has been stagnation in the sector since the government that changed in 2017 removed these low-credit purchase supports. Here, INT16 comments on the fact that many global companies were attracted to the country and that currently, only one company is actively producing. In addition to this information, when we look at the current priority list for SUS, we see that MRI and imaging systems are not included here. In this case, we can assume that MRI devices do not currently have an active production process. This situation suggests that without sustained policy support and strategic focus on the MRI sector within the Brazilian healthcare framework, the momentum gained in local production and the associated benefits could decline, leaving unmet healthcare needs for effective diagnostic imaging services in the country.

CHAPTER 6

CONCLUSION

The discussion section of this thesis aims to synthesize the findings from the study on MRI manufacturing in Türkiye and Brazil, providing a deeper understanding of the role of the state in technological learning and development. By analyzing the outcomes of the MRI projects in both countries through the theoretical framework of the state as a priority setter, institution builder, and incentive provider, this section explores the complexities and nuances of state intervention in fostering technological innovation in emerging economies.

In this chapter, it is examined how different state strategies and policies have influenced the trajectory of MRI technology development in Türkiye and Brazil, highlighting the successes and challenges encountered in each case. The discussion addresses key themes such as strategic priority setting, institutional frameworks for collaboration, and the provision of incentives to drive technological advancement. By comparing and contrasting the experiences of Türkiye and Brazil, this section seeks to uncover the underlying factors that contribute to the effective promotion of technological learning and innovation.

Furthermore, this discussion reflects on the broader implications of the findings for policy-making in emerging economies, offering insights into how governments can more effectively support the development of high-tech industries. The analysis also considers the limitations of the current study and suggest areas for future research, aiming to contribute to a more comprehensive understanding of the role of the state in technological development and to provide actionable recommendations for policy-makers seeking to enhance their countries' technological capabilities.

Ultimately, this chapter will integrate the empirical findings with the theoretical framework, providing a holistic perspective on the challenges and opportunities associated with state-led technological innovation in the context of MRI manufacturing. Through this analysis, the discussion aims to advance the academic discourse on state intervention in technological learning and to propose strategies for achieving sustainable technological development in emerging economies.

6.1 Analysis Of The Findings

Theoretical framework used in this study, focuses on the government's pivotal role in technological learning and innovation. It examines how state interventions can either enable or impede technological development, a critical driver of economic growth and competitiveness in emerging economies. The framework outlines three key functions of the government: as a priority setter, institution builder, and incentive provider. By analyzing these roles, the framework offers insights into how government policies and strategies can influence the trajectory of technological progress and support sustainable development.

As a priority setter, the government is pivotal in defining the nation's technological objectives and allocating resources toward strategic sectors (Hsu & Chiang, 2001). This entails identifying key areas for technological advancement, establishing long-term goals, and aligning public and private stakeholders to achieve these aims. By prioritizing specific technologies or industries, the government can catalyze innovation and direct the trajectory of technological progress. Nonetheless, setting these priorities demands not only a clear vision but also unwavering commitment and strategic planning to sustain momentum and ensure that initial efforts yield tangible outcomes. Lacking sustained focus and adaptability to evolving conditions, these initial priorities may falter, leading to missed opportunities for technological learning and growth (Anadón et al., 2016).

As an institution builder, the government is crucial in establishing Norganizational and regulatory frameworks that support technological learning and innovation. This entails creating institutions facilitating collaboration among diverse stakeholders, such as research institutions, universities, and private companies. Effective institution-building ensures the presence of robust systems for knowledge exchange, skill development, and technological transfer, all of which are essential for fostering innovation. The state's capacity to build strong institutions that promote cooperation and lower barriers to entry for new technologies can significantly influence the success of technological learning initiatives (Ahmedova, 2023).

Furthermore, the government can serve as an incentive provider, utilizing financial instruments such as subsidies, tax incentives, and grants to lower the barriers to innovation and encourage investment in high-risk, high-reward technological projects. By offering targeted incentives, the state can mitigate the financial risks of R&D activities and stimulate private sector participation in technological development. However, the effectiveness of these incentives depends on their design, consistency, and alignment with broader strategic objectives. A well-coordinated approach to incentive provision can catalyze technological learning, while a lack of strategic alignment or inconsistent policies may result in inefficiencies and stagnation (Ali et al., 2021).

6.1.1 Türkiye

The state's involvement in technical learning is condensed into three subsections in Chapter 2. The results are therefore assessed in light of this theoretical framework.

6.1.1.1. State as a Prıority Setter

The state’s role as a priority setter in the MRI project is evident in the initial strategic efforts to enhance technological and industrial independence under the National Technology Initiative. The inclusion of the MRI project in the Tenth Development Plan and the establishment of a steering group for the health industry (TÜSEB) demonstrate the state’s commitment to prioritizing advanced technological development in the health sector. However, despite these initial efforts to set priorities and provide direction, the project suffered from a lack of sustained strategic focus and commitment. The gradual loss of momentum and eventual suspension of the project highlight a failure in maintaining this priority over time, which was compounded by insufficient political support and a lack of a clear commercial strategy. This indicates a gap between the state's intention to set technological priorities and its ability to maintain and follow through on these priorities effectively. This suggests a disconnect between the state's purpose to establish technology goals and its capacity to successfully uphold and carry out these priorities. Furthermore, even after 32 years, it is evident that there is still a serious a shortage in this area given that the lack of progress in this area led to the termination of both the MRI project led by the Aselsan & UMRAM and the project completed in 1992.

6.1.1.2. State as an Institution Buılder

As an institution builder, the state's efforts were aimed at fostering collaboration between universities and industry, as seen in the partnership between Aselsan and the Bilkent University UMRAM laboratory. This collaboration was intended to leverage the technical and academic expertise of both entities to develop MRI technology. However, the findings suggest significant shortcomings in building effective institutional frameworks. The project encountered challenges related to poor coordination among stakeholders, slow information exchange, and communication gaps within the Ministry of Health. Additionally, the early involvement of significant stakeholders, such as large corporations, slowed down the research processes and created bureaucratic hurdles. The lack of a cohesive strategy and the absence of clear roles and responsibilities among the involved parties indicate that the state did not successfully build the necessary institutional infrastructure to support the project's progress and ensure effective technological learning.

6.1.1.3. State as an Incentive Provider

The role of the state as an incentive provider was crucial but inadequately fulfilled in the MRI project. While initial funding was provided through TÜBİTAK-supported projects, the lack of a government-backed purchasing guarantee emerged as a critical barrier to advancing local production of MRI technology. The absence of such guarantees, which are essential for creating a stable demand and reducing financial risks associated with high-cost, high-risk technologies, undermined the willingness of private firms like Aselsan to invest further in the project. Additionally, unrealistic tender requirements and a lack of supportive financial mechanisms, such as subsidies or tax incentives, further discouraged sustained investment and innovation. This failure to provide adequate incentives illustrates a significant gap in the state's role in encouraging technological development and market entry, ultimately contributing to the project's suspension.

In conclusion, there are serious shortcomings in each of the three areas of goal setting, institution building, and incentive providing that are revealed by analyzing the MRI project using the theoretical framework of the state's involvement in technical learning. While establishing institutional cooperation and making MRI technology development a strategic priority at first, the state was unable to maintain these initiatives over time. The project was unable to move past its infancy due to a number of factors, including a vague strategic plan, a lack of political backing, weak institutional frameworks, and insufficient funding. This instance emphasizes how crucial it is for the government to intervene in a way that is well-planned, strategically sound, and financially backed in order to promote technology innovation and successful technical learning and development.

6.1.2. Brazil

The analysis of MRI manufacturing in Brazil, when examined through the theoretical framework, presents a nuanced perspective on the state's involvement in technological learning. Initially, the Brazilian government exhibited a strong commitment to advancing medical technology by establishing institutional frameworks and offering incentives to foster local production. However, the lack of sustained support and strategic continuity over time has significantly weakened these initiatives. The shifting policy environment and changing priorities have introduced uncertainty, impeding the continuous development of MRI manufacturing in the country. For Brazil to achieve long-term success in technological learning and innovation, it is imperative for the state to adopt a more consistent and integrated approach. This approach should reinforce the state's roles as a priority setter, institution builder, and incentive provider, thereby ensuring the growth of domestic industries and the enhancement of technological capabilities.

6.1.2.1. State as a Priority Setter

As a priority setter, the Brazilian state recognized the strategic importance of developing domestic capacity for producing advanced medical devices, such as MRI machines. This recognition is reflected in the introduction of various policies aimed at reducing dependence on imported medical technology and fostering local innovation. The inclusion of MRI devices in the Strategic Products list of the Unified Health System (SUS) in 2010 and the subsequent government directive to promote local production demonstrate a clear prioritization of advanced medical technology. These actions were part of a broader initiative under the Health Economic-Industrial Complex, which aligns with Brazil's goal of achieving greater technological self-sufficiency in the healthcare sector. However, the findings also indicate that this priority has not been consistently maintained over time. The removal of MRI devices from the SUS priority list in 2017 and the lack of specific incentives for MRI manufacturing in recent years suggest a shift in focus or a deprioritization of this sector. This inconsistency in prioritization highlights a potential gap in the state's strategic commitment to sustaining long-term development in MRI technology.

6.1.2.2. State as an Insitution Buılder

In terms of institution building, the Brazilian government has made efforts to create a collaborative environment conducive to technological learning and innovation in the medical device sector. The establishment of the Health Economic-Industrial Complex Executive Group (Geceis) and the implementation of policies such as the Local Content Policy (LCP) and Productive Development Partnerships (PDPs) reflect the state's role in fostering institutional frameworks that promote cooperation between government agencies, industry, and research institutions. These initiatives aim to build a robust ecosystem for the development and production of health technologies, including MRI machines. By facilitating technology transfer through PDPs and encouraging multinational companies to manufacture domestically via the LCP, the state has contributed to enhancing local production capabilities and knowledge exchange. However, the findings also suggest that the effectiveness of these institutional frameworks can be limited by shifts in government policy and support, as seen with the discontinuation of certain incentives and the lack of a sustained strategic focus on MRI production. This underscores the need for stable and consistent institutional support to ensure the successful development of technological capabilities.

6.1.2.3. State as an Incentive Provider

As an incentive provider, the Brazilian state has implemented a variety of measures to stimulate investment in MRI manufacturing and broader health technology innovation. The Local Content Policy and the financing mechanisms provided by the Brazilian Development Bank (BNDES) to support the purchase of domestically manufactured MRI equipment are examples of how the state has incentivized both production and consumption within the country. These policies not only aimed to attract Foreign Direct Investment (FDI) but also sought to enhance local manufacturing capacity and reduce reliance on imports. The strategic use of government purchasing power and financial incentives, such as low-interest loans, played a crucial role in driving initial investments and encouraging multinational companies to establish production facilities in Brazil. However, the removal of these supports in 2017 and the absence of current incentives for MRI manufacturing indicate a withdrawal of state support, which has led to stagnation in the sector. This highlights the importance of sustained government incentives to maintain momentum and foster long-term technological development and innovation.

6.1.3. Brazil vs Türkiye

A comprehensive study was conducted on the MRI industry, focusing on its use and production in Brazil and Türkiye. This research integrated information from existing literature and news sources with real-world evidence gathered from experts and industry leaders in MRI technology. The study explored the history of MRI technology in both countries, aiming to provide a detailed depiction of the current state of the industry. Additionally, the investigation examined state policies that initiated, sustained, and concluded these projects. The purpose of collecting this data was to analyze the role of the state in technological learning during the development of such complex and advanced technologies. In the following section, the findings will be analyzed within the context of the theoretical framework, with the outcomes serving as a basis for the policy discussion in the subsequent chapter.

6.1.3.1. State as a Priority Setter

In Türkiye, the state's role as a priority setter for the MRI project was initially robust, marked by strategic efforts under the National Technology Initiative and the inclusion of the MRI project in the Tenth Development Plan. This initiative was intended to enhance technological and industrial independence, demonstrating a commitment to advancing the country's capabilities in high-value medical technologies. The establishment of a steering group for the health industry (TÜSEB) further underscored the state's intention to prioritize the development of MRI technology. However, despite these initial strategic priorities, the project suffered from a lack of sustained focus and commitment. Over time, this resulted in a gradual loss of momentum, which was compounded by insufficient political support and an absence of a clear commercial strategy to drive the initiative forward. This disconnect between the initial strategic objectives and the long-term commitment to these goals illustrates a significant gap in Türkiye's ability to maintain its priorities in the technological domain. Moreover, my personal perspective on the reasons behind this disconnect is that the intricate nature of this technology was not fully comprehended from a technical standpoint. Additionally, the absence of comprehensive feasibility studies contributed to the overall failure of the project. Despite the stakeholders fulfilling their responsibilities, the initiative ultimately faltered due to a top-down directive, coupled with insufficient time and financial resources for thorough and precise planning.

Conversely, in Brazil, the state's role as a priority setter was similarly evident in the initial stages, with a clear recognition of the strategic importance of developing domestic capacity for producing advanced medical devices, such as MRI machines. This was reflected in the inclusion of MRI devices in the Strategic Products list of the Unified Health System (SUS) in 2010 and the government's directive to promote local production. These actions were part of a broader strategy under the Health Economic-Industrial Complex, aimed at achieving technological self-sufficiency in the healthcare sector. However, like in Türkiye, Brazil’s commitment to these priorities was not consistently maintained over time. The removal of MRI devices from the SUS priority list in 2017 and the lack of specific incentives for MRI manufacturing in recent years suggest a shift in focus and a potential deprioritization of this sector. This inconsistency indicates a lapse in strategic continuity, undermining the long-term development of MRI technology in Brazil. Additionally, the low-interest loans and tax incentives offered to attract global companies played a crucial role. Hospitals often require financial assistance to acquire costly equipment like MRI machines. The low-interest loans provided to hospitals for purchases under the SUS Strategic Products framework significantly enhanced their purchasing power, thereby boosting demand for these products. This surge in demand, in turn, stimulated increased production. However, the discontinuation of these supports following the change of government in 2017 has had a substantial negative impact on both purchasing power and the production sector. Consequently, there is now only one global company (Canon Do Brasil) actively engaged in production of the MRI in Brazil.

6.1.3.2. State as an Institution Builder

In Türkiye, the state's role as an institution builder aimed to foster collaboration between academic and industrial entities, exemplified by the partnership between Aselsan and Bilkent University’s UMRAM laboratory. This collaboration was intended to combine technical and academic expertise to advance MRI technology. However, significant shortcomings were observed in the state's capacity to build effective institutional frameworks. The project faced numerous challenges, including poor coordination among stakeholders, slow information exchange, and communication gaps within the Ministry of Health. Additionally, the early involvement of large corporations without a clear strategic framework slowed down research processes and created bureaucratic obstacles. These issues highlight a failure to establish a cohesive institutional structure that could support the project's progress and ensure effective technological learning and development.

In contrast, Brazil's efforts as an institution builder were more structured, focusing on creating a collaborative environment conducive to technological innovation. The establishment of the Health Economic-Industrial Complex Executive Group (Geceis) and the implementation of policies such as the Local Content Policy (LCP) and Productive Development Partnerships (PDPs) demonstrate Brazil's commitment to fostering robust institutional frameworks. These policies were designed to promote cooperation between government agencies, industry, and research institutions, thereby enhancing local production capabilities and facilitating knowledge transfer. Despite these efforts, the effectiveness of these institutional frameworks was still subject to fluctuations in government policy and support. The discontinuation of certain incentives and the lack of a sustained strategic focus on MRI production have limited the long-term effectiveness of these institutions, highlighting the need for stable and consistent support to ensure the successful development of technological capabilities.

6.1.3.3. State as an Incentive Provider

In Türkiye, the state's role as an incentive provider in the MRI project was crucial but ultimately inadequate. While initial funding support was partially available through TÜBİTAK-funded projects, the absence of a government-backed purchasing guarantee posed a significant barrier to advancing local production of MRI technology. Such guarantees are vital for creating stable demand and mitigating financial risks associated with high-cost, high-risk technologies. The lack of these guarantees, coupled with unrealistic tender requirements and an absence of supportive financial mechanisms like subsidies or tax incentives, discouraged sustained investment and innovation. This failure to provide adequate incentives illustrates a significant gap in the state's role in promoting technological development and facilitating market entry, which ultimately led to the project's suspension.

In Brazil, the state initially played a more active role as an incentive provider. Policies like the Local Content Policy and financing mechanisms provided by the Brazilian Development Bank (BNDES) were implemented to stimulate investment in

MRI manufacturing and broader health technology innovation. These policies aimed to attract Foreign Direct Investment (FDI), enhance local manufacturing capacity, and reduce reliance on imports. The strategic use of government purchasing power and financial incentives, such as low-interest loans, was crucial in driving initial investments and encouraging multinational companies to establish production facilities in Brazil. However, the removal of these supports in 2017 and the absence of current incentives for MRI manufacturing have resulted in stagnation within the sector. This withdrawal of state support underscores the importance of sustained government incentives to maintain momentum and foster long-term technological development and innovation.

6.1.3.4. Concludıng Remarks

In comparing the MRI manufacturing efforts in Türkiye and Brazil through the lens of the theoretical framework, it is evident that both countries faced significant challenges in effectively leveraging the state's role as a priority setter, institution builder, and incentive provider. In Türkiye, initial strategic priorities and institutional collaborations were undermined by a lack of sustained commitment, strategic focus, and adequate incentives, resulting in the project's eventual suspension. Brazil, on the other hand, demonstrated more structured efforts in institution building and initial incentivization but similarly suffered from inconsistent prioritization and a withdrawal of incentives, leading to stagnation in the sector. These cases underscore the critical need for a cohesive, consistent, and well-supported state intervention to foster technological innovation and successful technological learning and development. To achieve long-term success, both countries must adopt a more integrated approach that reinforces the state's roles in setting priorities, building institutions, and providing incentives, ensuring the growth of domestic industries and the enhancement of technological capabilities.

The aim of this study is to compile the MRI story in Brazil and Turkey and the lessons to be learned from this story and to draw a lesson for Turkey. In Chapter 6, the past and current situation in both countries is reflected in great detail with all its reality. When the current situation is evaluated with the lens of the theoretical framework in this chapter, the following propositions emerge as very striking: The localization approach applied in Brazil is completely different from the one applied in Turkey. While in Brazil, it is enough for a product to be considered "local" to be produced in that land, in Turkey there is a "nationalization" approach. The main reason here is to reduce external dependency. It is thought that this approach comes from the success in the defense industry. However, this thesis reveals the following truth for Turkey: The technological development in the defense industry and the approaches developed with this development could not be adapted to a complex medical device. In this case, I foresee that the first suggestion that can be made for Turkey is that this technology can be realized in a way that is suitable for its own nature and with the right ecosystem by correctly understanding the nature of the technology and the need in the market.

6.2. Policy Recommendations

This study makes significant contributions to the existing literature in several ways. First, it provides a comprehensive explanation of a previously opaque failed MRI project, shedding light on the factors that led to its collapse. It then delves into an in-depth analysis of the reasons behind the failure to develop such a critical and costly technology. Through the lens of the MRI case study, the research underscores the indispensable role of the state in fostering technological learning and innovation.

Moreover, the study employs the case of Brazil as a comparative example to demonstrate how incremental production can be successfully executed in a similar economic structure and MRI market. Actually, the lack of a well-established MRI industry in Brazil is another indication that the country has made mistakes. However, after being taken off the SUS Strategic Product List, the MRI device lost its place inside the Brazilian system. Up to now, significant steps have been taken, and when we compare "nothing" at the end, they did have "something". Thus, this comparison offers a valuable contrast to the often-cited success stories that are difficult to replicate in the context of developing countries. The Brazilian case serves as a practical illustration for emerging economies, including Türkiye, of how local technological capabilities can be built through state intervention and strategic policy-making.

This analysis yields important policy lessons for Türkiye and other emerging economies aiming to cultivate domestic technological expertise. It emphasizes the necessity of recognizing the state’s multifaceted roles as a priority-setter, institution-builder, and provider of incentives in formulating strategies that promote sustainable technological learning and innovation. Additiınally, As a result of this inquiry, several observations about Türkiye has been made, one of which was that the lessons learned from the Defense Industry did not apply to the MRI project. From this point on, it is recognized that the high-tech medical device industry has additional needs that are still unmet due to the nature of these technologies and their development plans.

In the preceding section, the findings were critically evaluated through the theoretical framework, addressing the research questions posed by the study. To reiterate, this research sought to answer the questions: "How does the technological learning process in MRI production differ between Türkiye and Brazil?" and "What role does the state play in enhancing the technological learning process in MRI production?" Based on the responses to these questions, the conclusion was drawn that the failure of the MRI project in Türkiye was an outcome of the broader technological learning process. From this conclusion, a set of recommendations for improvement for Türkiye was proposed, incorporating the lessons learned from this analysis.

6.2.1. State as a Priority Setter

When compared, one of the key takeaways from Brazil's approach is the importance of consistent prioritization in state policy. Brazil initially identified MRI technology as a strategic priority and included it in the Strategic Products list of the Unified Health System (SUS), which helped focus efforts and resources on local production. Türkiye could benefit from a similar sustained prioritization strategy, where high-tech industries like MRI production are consistently highlighted as national priorities. This would involve not only setting clear initial goals but also maintaining them through long-term strategic planning and policy continuity, ensuring that projects receive ongoing support and are shielded from political and administrative changes. Initially, the MRI project in Türkiye had strong strategic intentions defined by the National Technology Initiative and the Tenth Development Plan. However, over time, the lack of sustained focus and strategic commitment led to project's stagnation and eventual suspension. In order to enhance effectiveness of the state as a priority setter, the government could:

- **Elaborate a Long-term Strategic Plan:**

In order to develop such a complex and high technology, a long-term strategy plan must be prepared in a very specific and detailed manner. Designing a detailed roadmap for development of advanced medical technologies like MRI, with clearly defined goals, milestones, timelines and budgets is crucial. This plan should be kept alive and followed through political transitions to guarantee continuity and focus. This plan should be evaluated not only in terms of policy but also from the perspective of product development and implementation.

First, the current situation and adequacy of existing MRI devices in the country should be assessed. The urgency and necessity of the technological need until the project's deadline should be determined. Additionally, it is crucial to evaluate the technological trends and future trajectory of MRI technology. Considering that the project may take five years to bring a product to market, the current technology may become outdated by then. Therefore, it is essential to closely monitor and adapt to the evolving technological landscape.

Furthermore, the key stakeholders should be identified based on their competencies, and their collaboration should be facilitated regularly. Once the project details are finalized, a comprehensive budget analysis should be conducted and closely monitored. Planning is a critical step for successfully completing such a complex project. Every aspect, including product management, incentives, human resources, budget, and technological advancements, should be carefully considered and reviewed at regular intervals. Failure to break down the high-level objectives into realistic sub-goals can lead to deviations from the desired path, emphasizing the importance of thorough planning.

Additionally, carrying out regular assessments of strategic plans in order to gauge progress made so far as well as make adjustments based on technological advancements or market demands are critical. Such reviews will help maintain relevance and efficacy towards achieving stated objectives. As briefly mentioned in the previous section, developments are progressing very rapidly in the technological age we are in. For this reason, in large projects, it is extremely important to review the plan and design at regular intervals to ensure that it meets the demand.

- **Enhance Understanding of Complex Technologies**

Another key factor contributing to the project's failure was the insufficient planning, which stemmed from decision-makers' limited familiarity with the intricate details of the technology. The absence of a comprehensive understanding of both the technological and commercial dimensions of MRI production posed a significant challenge in Türkiye.

Investing in thorough feasibility studies and market analysis to understand the technical requirements, potential challenges, and market dynamics of producing MRI machines domestically with the sectoral experts would increase the ability to create more effective roadmap. There should be a top-down approach here. The boundaries of the "nationalization" approach need to be drawn. In such a large technology, making all the hardware and all the software domestic is not an easy and achievable goal. For this reason, it was necessary to understand the technological importance of the issue and to make a detailed analysis of which parts would be produced domestically and which parts should be purchased.

On the other hand, encouraging partnerships with international experts, academic institutions, and industry stakeholders provides an opportunity to gain insights into the latest technological developments and global market trends. One such example of a collaboration that needs to be formed is the research that the scholarship holders did at the KAIST research center in South Korea during the MRI project processes that began in 1992. Additionally, strategies for ensuring the transfer of technological knowledge should be studied and utilized, such as the Productive Development Partnership used in Brazil.

Moreover, launching specialized training programs and workshops for policymakers and industry leaders to deepen their understanding of MRI technology and other complex medical devices, ensuring that strategic decisions are well-informed. The necessary information must be gathered in order for all project stakeholders—from technical participants to budget planners—to be in agreement. In order to ensure that strategic decisions are well-informed, technical trainings across committees can be arranged as well as an understanding of MRI technology and other complex medical devices.

6.2.2. State as an Institution Builder

Brazil’s establishment of institutional frameworks such as the Health Economic-Industrial Complex Executive Group (Geceis) and the implementation of policies like the Local Content Policy (LCP) and Productive Development Partnerships (PDPs) facilitated collaboration among government agencies, industry, and research institutions. These initiatives provided structured environments for technological learning and innovation. Türkiye can enhance its institutional frameworks by formalizing collaborative mechanisms that involve multiple stakeholders, including universities, research institutions, and private companies, to foster a culture of innovation and technological advancement. Strengthening institutional support structures, particularly those that encourage public-private partnerships and promote knowledge exchange, would be essential for developing domestic capabilities in high-tech sectors.

- **Strengthen Institutional Frameworks for Collaboration**

The partnership started as a project of the Ministry of Industry and Technology between Aselsan and Bilkent University’s UMRAM highlighted the importance of collaboration between academia and industry. However, the project faced challenges due to inadequate institutional support and coordination. To strengthen technological learning and innovation in the medical technology sector, it is essential to formalize collaborative mechanisms by establishing public-private partnerships and research consortia that facilitate structured cooperation between universities, research institutions, and industry players. Such formalized partnerships will enhance knowledge exchange and promote joint innovation efforts, driving technological advancements in high-tech industries. Additionally, supporting the creation of specialized research and development centers dedicated to high-tech industries, including medical technologies, is crucial for fostering a culture of innovation and continuous learning. Additionally, engaging small and medium-sized enterprises (SMEs) in these collaborative efforts is also vital, as their involvement can contribute significantly to innovation and diversification within the sector, enriching the overall ecosystem of medical technology development.

- **Improve Coordination and Communication**

The communication challenges and insufficient stakeholder coordination was another problem significantly impacted the project's failure. Participants highlighted the lack of effective information exchange and collaboration within the current ecosystem, which does not foster a conducive environment for cooperation. Ideally, the state should have proactively monitored these dynamics during the planning phase and intervened with collaborative measures as necessary.

To enhance coordination and effectiveness in technological initiatives, it is essential to establish clear communication protocols through the development of standardized channels and procedures, facilitating efficient information sharing and collaboration among stakeholders. This approach will help minimize misunderstandings and delays. Additionally, appointing dedicated project coordinators to oversee the execution of such initiatives would ensure effective task delegation and adherence to timelines. Promoting transparency and accountability within government agencies and institutions is also crucial; fostering a culture of openness and responsibility encourages constructive dialogue and feedback, ultimately helping to address challenges and improve project outcomes.

6.2.3. State as an Incentive Provıder

The role of incentives in Brazil’s strategy was significant in attracting foreign direct investment (FDI) and encouraging local production. Policies such as low-interest loans from the Brazilian Development Bank (BNDES) and government-backed purchasing guarantees helped reduce financial risks and create a stable demand for domestically produced MRI machines. Türkiye could incorporate similar financial incentives to stimulate investment in high-tech industries. Introducing targeted grants, subsidies, and tax breaks specifically designed for research and development in advanced medical technologies, as well as establishing government-backed purchasing guarantees, could provide the necessary financial security to encourage both domestic and international players to invest in local production. Additionally, creating low-interest loan programs to support healthcare providers in acquiring high-tech medical equipment would further bolster demand and drive innovation.

- **Developing Targeted Incentive Programs**

In Türkiye, the lack of a government-backed purchasing guarantee and inadequate financial support were major barriers to advancing local MRI production. To stimulate growth and innovation in high-tech medical technologies, including MRI manufacturing, it is essential to introduce targeted financial incentives such as grants, subsidies, and tax breaks specifically designed to support research and development (R&D). Establishing government-backed purchasing guarantees for domestically produced MRI machines and other medical technologies can create stable demand, reduce financial risks for manufacturers, and encourage investment in the sector. Additionally, creating low-interest loan programs to assist hospitals and healthcare providers in purchasing high-tech medical equipment will further stimulate demand and support local production, fostering a robust domestic market for advanced medical technologies.

- **Facilitating Technology Transfer and Localization**

Türkiye's approach to MRI production would benefit from a more strategic focus on technology transfer and localization in addition to the a "nationalization" approach. To strengthen the domestic production of MRI machines and other medical technologies, it is crucial to develop a comprehensive "localization" strategy that identifies key components that can be manufactured locally while allowing for the import of critical parts that are not yet feasible to produce domestically. Encouraging international partnerships with leading global companies and research institutions is also essential to facilitate technology transfer and knowledge exchange, thereby accelerating the development of local capabilities. Additionally, supporting capacity-building initiatives through training programs and workshops will enhance the skills and knowledge of the local workforce, ensuring they are well-equipped to engage in high-tech industries and drive technological innovation.

In order to effectively promote technological innovation and education in high-tech sectors such as MRI manufacturing, the Turkish government must take a more comprehensive and deliberate approach. Enhancing technological capabilities and fostering the growth of domestic companies can be achieved by the government through the reinforcement of its functions as an institution builder, priority setter, and incentive supplier.

REFERENCES

1. Bell, M., & Pavitt, K. (1993, January 1). Technological Accumulation and Industrial Growth: Contrasts Between Developed and Developing Countries. Oxford University Press, 2(2), 157-210. https://doi.org/10.1093/icc/2.2.157

2. Murray, A. J., & Sekella, M. E. (2007, June 26). Building the enterprise of the future. Emerald Publishing Limited, 37(2), 91-99. https://doi.org/10.1108/03055720710759883

3. Gans, J. S., Kearney, M., Scott, E. L., & Stern, S. (2021, March 1). Choosing Technology: An Entrepreneurial Strategy Approach. Institute for Operations Research and the Management Sciences, 6(1), 39-53. https://doi.org/10.1287/stsc.2020.0115

4. Steenhuis, H., & Bruijn, E. D. (2012, October 1). TECHNOLOGY AND ECONOMIC DEVELOPMENT: A LITERATURE REVIEW. World Scientific, 09(05), 1250033-1250033. https://doi.org/10.1142/s0219877012500332

5. Hatowska-Zycka, D., Kluczek, A., & Baginski, J. P. (2022, July 1). A Proposal of a Multi-Faced Approach for Building a Knowledge Management-Based Strategy in Small and Medium Companies. Society of Polish Mechanical Engineers and Technicians, 16(3), 245-257. [https://doi.org/10.12913/22998624/150238](https://doi.org/10.12913/22998624/15023

6. Al-Qdah, M. S., & Salim, J. (2013, November 20). Managing Tacit Knowledge in MNCs and the Role of ICT: Review Paper. Maxwell Scientific Publications, 6(21), 4110-4120. [https://doi.org/10.19026/rjaset.6.3519](https://doi.org/10.19026/rjaset.6.3519

7. Kornienko, A. A. (2015, January 1). The Concept of Knowledge Society in the Ontology of Modern Society. Elsevier BV, 166, 378-386. https://doi.org/10.1016/j.sbspro.2014.12.540

8. Reger, G. (2002, November 13). Strategic management of technology in a global perspective: differences between European, Japanese and US companies. https://doi.org/10.1109/picmet.2001.951715

9. Johannessen, J., & Olsen, B. (2006, February 27). Information and Communication Technology: Tacit Knowledge and Innovation. Springer Science+Business Media, 565-570. https://doi.org/10.1007/0-306-47467-0_95

10. Farooq, S., Ahmad, I., Gilal, M. A., & Nizamani, A. R. (2018, December 31). Absorptive Capacity in Optimum Internal Utilization of Foreign Direct Investment in Pakistan. Journal of Independent Studies and Research-Management, Social Sciences and Economics, 16(2), 85-96. https://doi.org/10.31384/jisrmsse/(2018).16.2.6

11. Farhadikhah, Z., & Husseini, S. M. H. (2015, October 1). A Review of Methods and Models of Technology Transfer. SciPress Ltd., 62, 173-181. https://doi.org/10.18052/www.scipress.com/ilshs.62.173

12. Lai, K., Chen, H., Chang, Y., Kumar, V., & Bhatt, P. C. (2020, June 19). A structured MPA approach to explore technological core competence, knowledge flow, and technology development through social network patentometrics. Emerald Publishing Limited, 25(2), 402-432. https://doi.org/10.1108/jkm-01-2020-0037

13. Chen, J., & Qu, W. (2003, November 1). A new technological learning in China. Elsevier BV, 23(11), 861-867. https://doi.org/10.1016/s0166-4972(02)00038-x

14. Lee, K. (2005, January 1). Making a Technological Catch-up: Barriers and opportunities. Taylor & Francis, 13(2), 97-131.

https://doi.org/10.1080/19761597.2005.9668610

15. Buchowicz, B. (1991, January 1). A process model of make-vs.-buy decision-making. The case of manufacturing software. Institute of Electrical and Electronics Engineers, 38(1), 24-32. https://doi.org/10.1109/17.65757

16. Lipsey, R. G. (2009, October 23). Economic growth related to mutually interdependent institutions and technology. Cambridge University Press, 5(3), 259-288. https://doi.org/10.1017/s1744137409990014

17. Phaal, R., Farrukh, C., & Probert, D. (2002, November 7). Practical frameworks for technology management and planning. https://doi.org/10.1109/ems.2000.872476

18. Jemala, M. (2013, September 30). Systemic Introduction to Technology Planning in the Context of Technology Competitiveness. Tomas Bata University in Zlín, 5(3), 101-113. https://doi.org/10.7441/joc.2013.03.08

19. Greitemann, J., Christ, E., Matzat, A. C., & Reinhart, G. (2014, January 1). Strategic Evaluation of Technological Capabilities, Competencies and Core-Competencies of Manufacturing Companies. Elsevier BV, 19, 57-62. https://doi.org/10.1016/j.procir.2014.05.017

20. Jin, Z., Si-zong, W., & Li, J. (2008, October 1). Organizational Attributes and Learning beyond the Boundaries. SAGE Publishing, 22(5), 297-304. https://doi.org/10.5367/000000008786102035

21. Arora, A., Cohen, W. M., & Walsh, J. P. (2016, July 1). The acquisition and commercialization of invention in American manufacturing: Incidence and impact. Elsevier BV, 45(6), 1113-1128.

https://doi.org/10.1016/j.respol.2016.02.005

22. Ghassim, B., & Foss, L. (2021, December 1). Understanding the micro-foundations of internal capabilities for open innovation in the minerals industry: a holistic sustainability perspective. Elsevier BV, 74, 101271-101271. https://doi.org/10.1016/j.resourpol.2018.09.011

23. Merchant, J. E. (1997, October 1). The role of governments in a market economy: Future strategies for the high-tech industry in America. Elsevier BV, 52(1-2), 117-131. https://doi.org/10.1016/s0925-5273(96)00072-2

24. Schuh, G., Latz, T., & Lorenz, J. (2022, December 9). Governmental Support Options for the Technology Transfer of Deep Tech Innovations. De Gruyter Open, 25, 24-36. https://doi.org/10.7250/itms-2022-0004

25. Lai, H. C., Chang, S., & Shyu, J. Z. (2004, January 1). The innovation policy priorities in industry evolution: the case of Taiwan's semiconductor industry. Inderscience Publishers, 1(1/2), 106-106. https://doi.org/10.1504/ijfip.2004.004617

26. Kim, C. (2005, January 1). An Industrial Development Strategy for Indonesia: Lessons from the South Korean Experience. Routledge, 10(3), 312-338. https://doi.org/10.1080/13547860500163589

27. Lall, S., & Pietrobelli, C. (2005, January 1). National Technology Systems in Sub-Saharan Africa. Inderscience Publishers, 1(3/4), 311-311. https://doi.org/10.1504/ijtg.2005.008746

28. Sharif, M. (1989, August 1). Technological leapfrogging: Implications for developing countries. Elsevier BV, 36(1-2), 201-208. https://doi.org/10.1016/0040-1625(89)90024-3

29. Park, E., Kim, K. J., Kwon, S. J., Ohm, J. Y., Pobil, Á. P. D., & Yoo, K. (2016, July 11). Determinants for the success of regional ICT ventures: a close examination of South Korea. Springer International Publishing, 5(1). https://doi.org/10.1186/s40064-016-2712-5

30. Mazzucato, M. (2015, January 1). From Market Fixing to Market-Creating: A New Framework for Economic Policy. RELX Group (Netherlands). https://doi.org/10.2139/ssrn.2744593

31. Chang, H., Cheema, A., & Mises, L. V. (2002, January 1). Conditions For Successful Technology Policy In Developing Countries—Learning Rents, State Structures, And Institutions. Taylor & Francis, 11(4-5), 369-398. https://doi.org/10.1080/10438590200000005

32. Jinji, N., & Toshimitsu, T. (2013, October 3). Strategic R&D policy in a quality-differentiated industry with three exporting countries. ScienceDirect. https://www.sciencedirect.com/science/article/pii/S0922142513000479

33. French-Mowat, E., & Burnett, J. (2012, April 1). How are medical devices regulated in the European Union?. SAGE Publishing, 105(1_suppl), 22-28. https://doi.org/10.1258/jrsm.2012.120036

34. Andrews, D., & Criscuolo, C. (2013, May 24). Knowledge-Based Capital, Innovation and Resource Allocation. OECD. https://doi.org/10.1787/5k46bj546kzs-en

35. Shenkar, O., Liang, G., & Shenkar, R. (2021, May 17). The last frontier of globalization: Trade and foreign direct investment in healthcare. Palgrave Macmillan, 53(2), 362-374. https://doi.org/10.1057/s41267-021-00439-w

36. Chang, H. (1998, November 5). Globalization, transnational corporations, and economic development: can the developing countries pursue strategic industrial policy in a globalizing world economy?. Cambridge University Press, 97-113.

https://doi.org/10.1017/cbo9780511599095.006

37. Chandra, V. (2006, January 1). Technology, Adaptation, and Exports: How Some Developing Countries Got It Right. World Bank Publications. https://ideas.repec.org/b/wbk/wbpubs/7118.html

38. Lee, C. (n.d). The role of the government and R&D infrastructure for technology development. ScienceDirect. https://www.sciencedirect.com/science/article/pii/0040162588900546

39. Wang, J., & Giuffrida, A. (2016, January 1). The Development of Medical Devices in Foreign Markets. OMICS Publishing Group, 05(02). https://doi.org/10.4172/2167-7689.1000167

40. Jing, Y., & Besharov, D. J. (2014, May 9). COLLABORATION AMONG GOVERNMENT, MARKET, AND SOCIETY: FORGING PARTNERSHIPS AND ENCOURAGING COMPETITION. Wiley-Blackwell, 33(3), 835-842. https://doi.org/10.1002/pam.21772

41. Riederer, S. J. (2000, January 1). Current technical development of magnetic resonance imaging. IEEE Engineering in Medicine and Biology Society, 19(5), 34-41. https://doi.org/10.1109/51.870229

42. Börnert, P., & Norris, D. G. (2020, July 1). A half-century of innovation in technology—preparing MRI for the 21st century. Wiley, 93(1111), 20200113-20200113. https://doi.org/10.1259/bjr.20200113

43. Hailey, D., & Marshall, D. A. (1995, January 1). The place of magnetic resonance imaging in health care. Elsevier BV, 31(1), 43-52. https://doi.org/10.1016/0168-8510(94)00673-3

44. Miranda, G. M. D., Mendes, A. D. C. G., & Silva, A. L. A. D. (2016, June 1). Population aging in Brazil: current and future social challenges and consequences. Federal University of Rio de Janeiro, 19(3), 507-519. https://doi.org/10.1590/1809-98232016019.150140

45. Viana, A. L. D., Silva, H. P. D., Ibañez, N., & Iozzi, F. L. (2016, January 1). La política de desarrollo productivo en salud en Brasil y la cualificación de los laboratorios públicos nacionales. Ciência & Saúde Coletiva, 32, 2557-2564.

46. Melo, R. C., & Miranda, A. S. D. (2022, April 1). Incremento decenal de estabelecimentos assistenciais no Brasil e vinculações com o Sistema Único de Saúde. Centro Brasileiro de Estudos de Saúde, 46(133), 346-357. https://doi.org/10.1590/0103-1104202213307

47. Weiderpass, E., Colombet, M., Soerjomataram, I., Parkin, D. M., Piñeros, M., Znaor, A., & Bray, F. (2021, April 22). Cancer statistics for the year 2020: An overview. Wiley, 149(4), 778-789. https://doi.org/10.1002/ijc.33588

48. Duarte, A., Fujiki, R. H. M., Gloria, L. F. P., Fragoso, D. C., Pacheco, F. T., Calvi, C., Júnior, M. R., Maia, A. C. M., & Rocha, A. J. D. (2022, May 1). Neurological imaging findings in hospitalized COVID-19 patients: a retrospective observational study in two Brazilian reference centers. Thieme Medical Publishers (Germany), 80(5), 490-496. https://doi.org/10.1590/0004-282x-anp-2021-0103

49. Geethanath, S., & Vaughan, J. T. (2019, January 14). Accessible magnetic resonance imaging: A review. Wiley-Blackwell, 49(7). https://doi.org/10.1002/jmri.26638

50. Akinci, F., Mollahaliloğlu, S., Gürsöz, H., & Öğücü, F. (2012, September 1). Assessment of the Turkish health care system reforms: A stakeholder analysis. Elsevier BV, 107(1), 21-30. https://doi.org/10.1016/j.healthpol.2012.05.002

51. Horton, R., & Lo, S. (2013, July 1). Türkiye's democratic transition to universal health coverage. Elsevier BV, 382(9886), 3-3. https://doi.org/10.1016/s0140-6736(13)61181-2

52. Cruz, J. A. W., Cunha, M. A., Moraes, T. P. D., Marques, S., Tuon, F. F., Gomide, A. L., & Linhares, G. D. P. (2022, January 10). Brazilian private health system: history, scenarios, and trends. BioMed Central, 22(1). [https://doi.org/10.1186/s12913-021-07376-2](https://doi.org/10.1186/s12913-021-07376)

53. Xiao, H., & Liu, S. (2020, January 1). Research on the Path of Reverse Innovation: A Case Study of High-tech Industry Latecomer Firms in China. Science Publishing Group, 8(4), 138-138. [https://doi.org/10.11648/j.ijefm.20200804.12](https://doi.org/10.11648/j.ijefm.20200804.1)

54. Gomes, M. A. S., Kovaleski, J. L., Pagani, R., & Zammar, G. (2020, October 1). Technology transfer and investments in brazilian public healthcare. São Paulo Federal Institute of Education, Science and Technology, 11(6), 1883-1898. https://doi.org/10.14807/ijmp.v11i6.1176

55. Ngisau, N., & Ibrahim, N. A. (2020, January 1). Technological Innovation Adoption in Manufacturing Sector: The Moderator Role of Government Support. Journal of Economics, Business, and Management, 8(3), 200-205. [https://doi.org/10.18178/joebm.2020.8.3.637](https://doi.org/10.18178/joebm.2020.8.3.6)

56. Yao, X. (2019, January 1). Do Innovation Subsidies Policy Improve the Innovation Performance of Enterprises?. Scientific Research Publishing, 07(02), 1-12. https://doi.org/10.4236/jss.2019.72001

57. Kasule, F., Li, Z., & Sun, K. (2018, August 2). Government IT related Hi-Tech company’s incentives and subsidies role on industries in Hebei province, China. Journal of Advanced Manufacturing Systems, 4(4). https://doi.org/10.20474/jabs-4.4.4

58. Xiong, H., & Shen, Y. (2020, December 1). Influence of Government Subsidies for Green Technology Development on the Performance of Chinese New-Energy Automobile Enterprises. Nature Environment and Pollution Technology, 19(4), 1593-1598. https://doi.org/10.46488/nept.2020.v19i04.026

59. Bloom, N., Reenen, J. V., & Williams, H. (2019, August 1). A Toolkit of Policies to Promote Innovation. American Economic Association, 33(3), 163-184. https://doi.org/10.1257/jep.33.3.163

60. Rehman, N. U. (2016, January 1). Does Internal and External Research and Development Affect Innovation of Small and Medium-Sized Enterprises? Evidence from India and Pakistan. RELX Group (Netherlands). https://doi.org/10.2139/ssrn.2800101

61. Goñi, E., & Maloney, W. F. (2017, February 28). Why don’t poor countries do R&D?. ScienceDirect. https://www.sciencedirect.com/science/article/pii/S0014292117300247

62. Kumar, P., & Kumar, R. (2018, January 1). Rural Health Scenario – Role of family medicine: Academy of Family Physicians of India Position Paper. Medknow, 7(6), 1157-1157. https://doi.org/10.4103/jfmpc.jfmpc_254_18

63. Taqi, M., Bidhuri, S., Sarkar, S., Ahmad, W. S., & Wangchok, P. (2017, April 10). Rural Healthcare Infrastructural Disparities in India: a Critical Analysis of Availability and Accessibility. Journal of Medical Research and Health Sciences, 3(2), 125-149. https://doi.org/10.15415/jmrh.2017.32011

64. Arakeri, S., & Hazarika, D. (2023, October 26). An Analysis of Demographic Features in India. Imperial Publications. https://www.imperialpublications.com/image/catalog/JAMAR211.pdf

65. Aghion, P., & Howitt, P. (1998). Endogenous Growth Theory. MIT Press.

66. Cohen, W. M., & Levinthal, D. A. (1989). Innovation and Learning: The Two Faces of R&D. The Economic Journal, 99(397), 569-596.

67. Lall, S. (1992). Technological Capabilities and Industrialization. World Development, 20(2), 165-186.

68. Mazzucato, M. (2013). The Entrepreneurial State: Debunking Public vs. Private Sector Myths. Anthem Press.

69. Nelson, R. R., & Winter, S. G. (1982). An Evolutionary Theory of Economic Change. Harvard University Press.

70. Rodrik, D. (2004). Industrial Policy for the Twenty-First Century. International Economic Journal, 20(4), 1-44.

71. Heifetz, R. A. (2009, June 30). Leadership Without Easy Answers. Harvard University Press. https://doi.org/10.2307/j.ctv1pncrt0

72. Baskaran, A. (2000, October 1). Duality in national innovation systems: the case of India. Oxford University Press, 27(5), 367-374. https://doi.org/10.3152/147154300781781850

73. Viana, A. L. D., Silva, H. P. D., Ibañez, N., & Iozzi, F. L. (2016, November 3). A política de desenvolvimento produtivo da saúde e a capacitação dos laboratórios públicos nacionais. Ciência & Saúde Coletiva, 21(8), 2533-2543.

74. Hsu, C., & Chiang, H. (2001, February 1). The government strategy for the upgrading of industrial technology in Taiwan. Elsevier BV, 21(2), 123-132. https://doi.org/10.1016/s0166-4972(00)00029-8

75. Anadón, L. D., Chan, G., Harley, A. G., Matus, K., Moon, S., Murthy, S. L., & Clark, W. C. (2016, August 12). Making technological innovation work for sustainable development. National Academy of Sciences, 113(35), 9682-9690.

https://doi.org/10.1073/pnas.1525004113

76. Ahmedova, S. (2023, January 1). The role of universities in the development of technological entrepreneurship and innovation. EDP Sciences, 420, 10002-10002. https://doi.org/10.1051/e3sconf/202342010002

77. Ali, A., Ilahi, I., Qayyum, A., Mohammed, I., Al-Fuqaha, A., & Qadir, J. (2021, July 14). Incentive-Driven Federated Learning and Associated Security Challenges: A Systematic Review. TechRxiv. https://doi.org/10.36227/techrxiv.14945433

78. Dovales, A. C. M., Harbron, R. W., Souza, A. A. D., Rosa, L. A. R. D., González, A. B. D., Pearce, M. S., & Veiga, L. H. (2019, September 1). Patterns and trends in outpatient diagnostic imaging studies of the Brazilian public healthcare system, 2002–2014. Elsevier BV, 8(3), 254-260. https://doi.org/10.1016/j.hlpt.2019.07.001

79. Gomes, L. C. N., & Dalcol, P. R. T. (2007, October 24). ESTRATÉGIAS DE PRODUÇÃO NA INDÚSTRIA DE EQUIPAMENTOS MÉDICOS DE DIAGNÓSTICO POR IMAGEM: UMA ANÁLISE DA RESSON NCIA. Universidade Federal de Santa Catarina, 7(1). https://doi.org/10.14488/1676-1901.v7i1.94

80. Şemin, S., Güldal, D., & Demıral, Y. (2007, May 1). Globalization and the trends of medical technology trade in Turkey. Elsevier BV, 81(2-3), 320-327. https://doi.org/10.1016/j.healthpol.2006.07.002

81. Guimarães, M. D., Schuch, A., Hochhegger, B., Gross, J. L., Chojniak, R., & Marchiori, E. (2014, April 1). Functional magnetic resonance imaging in oncology: state of the art. Colégio Brasileiro de Radiologia e Diagnóstico por Imagem, 47(2), 101-111. https://doi.org/10.1590/s0100-39842014000200013

82. Pal, A., & Rathi, Y. (2021, January 1). A review and experimental evaluation of deep learning methods for MRI reconstruction. Cornell University. https://doi.org/10.48550/arxiv.2109.08618

83. Azad, R., Khosravi, N., Dehghanmanshadi, M., Cohen-Adad, J., & Merhof, D. (2022, January 1). Medical Image Segmentation on MRI Images with Missing Modalities: A Review. Cornell University. https://doi.org/10.48550/arXiv.2203

84. Kabasawa, H. (2022, January 1). MR Imaging in the 21st Century: Technical Innovation over the First Two Decades. Japan Society of Magnetic Resonance in Medicine, 21(1), 71-82. https://doi.org/10.2463/mrms.rev.2021-0011

85. Alzola-Aldamizetxebarria, S., Fernández-Méndez, L., Padró, D., Ruíz-Cabello, J., & Ramos-Cabrer, P. (2022, October 13). A Comprehensive Introduction to Magnetic Resonance Imaging Relaxometry and Contrast Agents. American Chemical Society, 7(42), 36905-36917. https://doi.org/10.1021/acsomega.2c03549

86. Grover, V. P., Tognarelli, J. M., Crossey, M. M., Cox, I. J., Taylor-Robinson, S. D., & McPhail, M. (2015, September 1). Magnetic Resonance Imaging: Principles and Techniques: Lessons for Clinicians. Elsevier BV, 5(3), 246-255. https://doi.org/10.1016/j.jceh.2015.08.001

87. ALNATOUR, D. (2020, January 1). A REVIEW ON EFFORTS OF HEALTH TOURISM IN TURKEY. Research Hub, 7(59), 2739-2744. https://doi.org/10.26450/jshsr.2066

88. Ünal, E. (2018, January 16). An institutional approach and input–output analysis for explaining the transformation of the Turkish economy. Springer Nature, 7(1).[https://doi.org/10.1186/s40008-017-0101-z](https://doi.org/10.1186/s40008-017-010-z)

89. Akyüz, Y., & Boratav, K. (2003, September 1). The Making of the Turkish Financial Crisis. Elsevier BV, 31(9), 1549-1566. https://doi.org/10.1016/s0305-750x(03)00108-6

90. Mahmood, A. (2023, January 1). Turkish Inflation, Private Debt & how to overcome it. Cornell University. https://doi.org/10.48550/arxiv.2301.07064

91. Güvercin, D. (2020, July 6). Boundaries on Turkish export-oriented industrialization. Springer Nature, 9(1). [https://doi.org/10.1186/s40008-020-00221-5](https://doi.org/10.1186/s40008-020-00221)

92. Uçak, H. (2016, September 29). The relationship between the growth in the health sector and inbound health tourism: the case of Turkey. Springer International Publishing, 5(1). https://doi.org/10.1186/s40064-016-3341-8

93. Kaya, S., Karsavuran, S., & Yıldız, A. (2015, June 26). Medical tourism developments within Turkey. Edward Elgar Publishing. https://doi.org/10.4337/9781783471195.00044

94. Koyuncu, O., Gürsöz, H., Alkan, A., Çetintaş, H. C., Pasaoglu, T., Ceyhan, E. M., & Walker, S. (2020, February 3). Evaluation of the Performance of the Turkish Regulatory Agency: Recommendations for Improved Patients' Access to Medicines. Frontiers Media, 10. https://doi.org/10.3389/fphar.2019.01557

95. Guimarães, R. (2022, October 1). Towards an industrial policy for expanding access to health. Associação Brasileira de Saúde Coletiva, 27(10), 3987-3992. https://doi.org/10.1590/1413-812320222710.10282022en

96. Dovales, A. C. M., Harbron, R. W., Souza, A. A. D., Rosa, L. A. R. D., González, A. B. D., Pearce, M. S., & Veiga, L. H. (2019, September 1). Patterns and trends in outpatient diagnostic imaging studies of the Brazilian

public healthcare system, 2002–2014. Elsevier BV, 8(3), 254-260.https://doi.org/10.1016/j.hlpt.2019.07.001

97. Souza, R. D. (2013, October 29). Original View on Brazilian Local Content Regulatory Environment. Offshore Technology Conference. https://doi.org/10.4043/24363-ms

98. Vitor, T., Martins, K. M., Ionescu, T. M., Cunha, M. L. D., Baroni, R. H., Garcia, M. R. T., Wagner, J., Neto, G. D. C. C., Nogueira, S. A., Guerra, E. G., & Amaro, E. (2017, March 1). PET/MRI: a novel hybrid imaging technique. Major clinical indications and preliminary experience in Brazil. Instituto Israelita de Ensino e Pesquisa Albert Einstein, 15(1), 115-118. https://doi.org/10.1590/s1679-45082017md3793

99. Serbest, A. (2007, November 1). Education and Human Resources Strategy for the Vision 2023 Technological Foresight Study of Turkey. IEEE Engineering in Medicine and Biology Society. https://doi.org/10.1109/mgdete.2007.4760359

100. Coates, W. C., Jordan, J., & Clarke, S. (2021, September 22). A practical guide for conducting qualitative research in medical education: Part 2—Coding and thematic analysis. Wiley, 5(4). https://doi.org/10.1002/aet2.10645

101. Meadows, K. (2003, October 1). So you want to do research? 3. An introduction to qualitative methods. MA Healthcare, 8(10), 464-469. https://doi.org/10.12968/bjcn.2003.8.10.11700

102. Thomas, D. R. (2006, June 1). A General Inductive Approach for Analyzing Qualitative Evaluation Data. SAGE Publishing, 27(2), 237-246. https://doi.org/10.1177/1098214005283748

103. Browne, I., Sutton, A., & Zhang, W. (2023, May 30). Perceptions and Attitudes Regarding Medical Device Development in Canada Among Canadian Innovators: A Qualitative Study. Adis, Springer Healthcare, 7(5), 793-809.

https://doi.org/10.1007/s41669-023-00422-1

104. Vergara, F. A., Fischer, A., Seuring, T., Beaufort, C. D., Fagherazzi, G., & Aguayo, G. (2023, September 1). Mixed-methods study protocol to identify expectations of people with type 1 diabetes and their caregivers about voice-based digital health solutions to support the management of diabetes distress: the PsyVoice study. BMJ, 13(9), e068264-e068264. https://doi.org/10.1136/bmjopen-2022-068264

105. Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2013, November 6). Purposeful Sampling for Qualitative Data Collection and Analysis in Mixed Method Implementation Research. Springer Science+Business Media, 42(5), 533-544. https://doi.org/10.1007/s10488-013-0528-y

106. Bittencourt, B. A., & Figueiró, P. S. (2019, October 1). Innovation ecosystems articulation and shared value creation. Fundação Getulio Vargas, Escola Brasileira de Administração Pública e de Empresas, 17(4), 1002-1015. https://doi.org/10.1590/1679-395174403x

107. Khokhar, S., Pathan, H., Raheem, A., & Abbasi, A. M. (2020, December 31). Theory Development in Thematic Analysis: Procedure and Practice. Journal of Advanced Manufacturing Systems, 3(3), 423-433. https://doi.org/10.47067/ramss.v3i3.79

108. Adak, M. (2015, July 1). Technological Progress, Innovation and Economic Growth; the Case of Turkey. Elsevier BV, 195, 776-782. https://doi.org/10.1016/j.sbspro.2015.06.478

109. Kılcı, E. N. (2021, April 21). A study on financial sustainability of healthcare indicators for Turkey under the health transformation program. Wiley, 36(4), 1287-1307. https://doi.org/10.1002/hpm.3182

110. Sülkü, S. N., & Caner, A. (2010, February 12). Health care expenditures and gross domestic product: the Turkish case. Springer Science+Business Media, 12(1), 29-38. https://doi.org/10.1007/s10198-010-0221-y

111. Esen, E., & KEÇİLİ, M. Ç. (2021, April 15). Economic Growth and Health Expenditure Analysis for Turkey: Evidence from Time Series. Springer Science+Business Media, 13(3), 1786-1800. https://doi.org/10.1007/s13132-021-00789-8

112. Atalan, A. (2020, April 2). Forecasting for Healthcare Expenditure of Turkey Covering the Years of 2018-2050. Gümüşhane Üniversitesi Sağlık Bilimleri Dergisi, 9(1), 8-16. https://doi.org/10.37989/gumussagbil.538111

113. India Brand Equity Foundation. (n.d.). Make in India: A global manufacturing hub. India Brand Equity Foundation. https://www.ibef.org/economy/make-in-india

114. Imperial Publications. (2021). Journal of advanced medical and radiology (JAMAR) 2021 issue. Imperial Publications. https://www.imperialpublications.com/image/catalog/JAMAR211.pdf

115. Mordor Intelligence. (2022). China magnetic resonance imaging (MRI) market report. Mordor Intelligence. https://www.mordorintelligence.com/industry-reports/china-magnetic-resonance-imaging-mri-market

116. Liu, Y. (2020). Advances in MRI techniques. Journal of Advances in Medical Science, 3(4). https://journals.bilpubgroup.com/index.php/jams/article/view/1030

117. National Bureau of Statistics of China. (n.d.). Homepage. National Bureau of Statistics of China. https://www.stats.gov.cn/english/

118. Brahmachary, R. L., Silva, S., & Lahiri, R. (2019). How does the brain control blood sugar levels? Frontiers for Young Minds. https://kids.frontiersin.org/articles/10.3389/frym.2019.00023

APPENDICES

A. CODING SYSTEM

Below, coding table is provided.

Table 12. Coding System.

Category	Theme	Code	Example quote
Knowledge Types	**Internal Knowledge**	Gap between commercialization and technology	The biggest obstacle is the gap between the commercialization of know-how and the transformation of science into technology.
		Engineering capabilities and collaboration	Brazil, especially São Paulo, has significant engineering capacities with talent from hospitals and universities. The projects involved hardware development and learning.
		Hardware development focus	Our main focus in these projects was hardware development—designing, prototyping, and producing.
		Reverse Engineering for Knowledge Acquisition	"You either need to buy something and secretly reverse-engineer it or contribute to the project by purchasing components.
	External Knowledge	University partnerships and feedback	Partnerships with universities are important for developing technologies, gathering feedback, and enhancing product development.
		Collaboration with Specialized Companies	"We also explored production technologies, like composites, with specialized companies
		University Partnerships for Technology Development	We have partnerships with universities to develop technologies, not in MRI, but in other devices like Synapse 3D and for Ultrasound imaging.

		Multidisciplinary Expertise Requirement	It involves various fields like machinery, electrical engineering, electromagnetics, and even antennas.
		Collaboration with European Manufacturers	Our engineers could start this process by collaborating with or even transferring engineers from other European manufacturers.
		Importance of Fieldwork and Feedback	Feedback from the field is crucial—understanding how the devices are used and the feedback from users is key.
Government Role	**Priority Setting**	Government priority setting	The Ministry of Health plays a crucial role in setting product priorities and collaborating with different public institutions for policy implementation.
		Public Health Priority List	Ministry of Health used to prepare a list of products that were their priorities. I believe it's something important also for public policy implementation.
		Policy Focus on Health System Vulnerabilities	Since 2003, we've implemented policies aimed at reducing the vulnerabilities of the Brazilian health system extended to include medical devices.
		Short-Lived Device Development Effort	The effort to develop a device for that purpose wasn't actually a long process for Aselsan but in the end, they likely didn't see a financial advantage, and the project was closed.
		Focus on Domestic Medical Device Development	I believe we must focus on developing a domestic and national MRI, X-ray, or CT device... because we currently buy devices like MRI from companies abroad.
		Analysis of MRI Replacement Needs	We need to analyze how many of our MRI machines will need to be replaced over the next 5 years with new technologies and how much we can develop with our own resources.
		Investment and Global	We should assess the required

		Market Entry	investment and, if successful, how we could enter the global market."
		Customer Satisfaction as a Key to International Success	The key to having a product preferred internationally lies in customer satisfaction... producing a competitively priced, high-performance system.
		Leveraging expertise for joint ventures	China has developed key industries by leveraging expertise through joint ventures and knowledge-sharing initiatives. Brazil could adopt a similar strategy.
		Deep-Rooted Global Market Network	One of the big reasons why investment is not enough is that there is a deep-rooted market network in the world.
		Leveraging expertise for joint ventures	China has developed key industries by leveraging expertise through joint ventures and knowledge-sharing initiatives. Brazil could adopt a similar strategy.
		University and Industry Collaboration	We have partnerships with universities to develop technologies, not in MRI, but in other devices like Synapse 3D and post-processing products.
		Multi-Disciplinary Expertise Requirement	A lot of knowledge and experience is required... It involves various fields like machinery, electrical engineering, electromagnetics, and even antennas.
		Collaboration Abroad to Gain Expertise	Send scientists from a company or university abroad, to places like Philips or China, to establish collaborations and learn.
		Managing Collaboration and Resources	The issue, as I see it, is not just about planning but managing—managing the budget, the project, the collaboration, and human resources.
		Lack of Collaboration in High-Tech Development	We have very good artificial intelligence professors here, but no collaboration.
	Institution Building	Government-led Health Industries	n 2015, a Health Industries Steering Committee (TÜSEB) was established

		Steering Committee	through a Prime Ministry circular to localize the health industries in Turkey.
		Ongoing Discussion at a High Level of the Government	These matters are already being discussed at a high level. I know that talks have taken place between the ministers and Aselsan's top management.
		Health as an Industrial Complex	We understand health as an industrial complex that encompasses the pharmaceutical and medical device sectors, as well as healthcare providers.
		Local Assembly Incentives	Brazil supports companies in setting up assembly operations locally for MRI systems, this can reduce taxes by almost 14%
		High Taxes and Import Challenges	High taxes in Brazil can add 30 to 40% to the end-user price. Importing takes a lot of time shipment is by sea, taking almost 60 days.
		Encouraging Domestic Production	We need to start producing all of our own medical devices, from syringes to large devices like PET-CT and MRI machines... imported medical equipment comes at a high cost.
		Aselsan and Public Health Goals	Aselsan is a company with profit-driven goals, whereas the Ministry of Health's policy is to protect public health, not to pursue profit.
		Defining Local Manufacturing	The second layer of this policy is defining what it means for a manufacturer to be manufacturing in Brazil. We have the local content policy, and there are different types.
		Sector-Specific Local Content Policies	The federal government may define specific local content manufacturer policies.
	Incentives	Incentives for MRI Manufacturers	There was a local content policy related to MRI equipment, and a some of the multinational companies started manufacturing MRI equipment in

			Brazil.
		BNDES Financing and Below-Inflation Loans	BNDES had access to interest rates that were below inflation. This meant hospitals could purchase equipment with long-term contracts and finance these purchases at favorable rates.
-		Engineering Talent from Universities and Hospitals	In Brazil, especially São Paulo, has significant engineering capacities, with talent coming from hospitals and universities, which offer strong health-related programs.
-		Lack of Knowledge and Infrastructure for MRI	We don't yet have the deep knowledge or infrastructure to develop a new Brazilian MRI system. Many of our highly skilled engineers leave because salaries here are too low.
-		Need for Experienced Experts	If you're thinking of making such a device, it's not enough to just say 'let's do it, we have engineers.' You need highly experienced experts in the field.
-		Initiative and Expertise in Superconductors	There isn't much initiative being shown. I'm not very familiar with the superconductor part, but I'm unsure if they have the capability to wind an MRI magnet.
-		Integration and Component Manufacturing	It's about integration, and the value comes from making some key components yourself. You won't succeed just by assembly.
-	**Human Resources**	Criticism of Assembly-Only Approach	What E**** refers to as making an MRI involved Chinese workers at UMRAM assembling parts—magnet from one place, electronics from another.
-		High Initial Investment	Let's say $200 million... how much sales I'll make in the coming years and how long it will take to break even on that $200 million investment.
-	**Budget**	TÜBİTAK-Supported Projects	The work started with TÜBİTAK-supported projects... Two of these

			were focused on the transmit coil of the MRI device, and one was related to the gradient system.
-		Limited Resources and Borrowed Infrastructure	Our work was done with very limited resources... we borrowed or rented infrastructure meant for other purposes.
-		Higher Development Cost Compared to Purchasing	The cost of developing something may be 10 times higher than just buying an MRI device from a company.
-		Long-Term Investment in Knowledge and Infrastructure	When governments or organizations want to start something new, they have to invest heavily... Little by little, they gain expertise.
-		The Importance of Dedicated Resources	A talented individual might emerge with a breakthrough idea, but how can they do that without access to a lab or the necessary resources?
-		Canon manufacturing MRI in Brazil	Canon is currently the only company manufacturing MRI equipment in Brazil. Others have left since the change in government policies in 2017.
-		Shift from Total Dependence on Imports	We use to have nothing. We had to import everything. The outcome was that Canon is established in Brazil. So we have something.
-		Local Content Stamp and Market Exit	I checked the system to see which MRI equipment had the local content stamp, and currently only Canon is manufacturing in Brazil. Other companies that were once established have since left.
-		Government Policy Impact on Interest Rates	Since 2017, after a change in government and a new law, BNDS could no longer offer interest rates below inflation.
-	**Current Situation**	Focus on Magnetic Particle Imaging (MPI)	Teams are working on a subject called magnetic particle imaging, but this is a different system than the current MRI device.

-		Lack of MRI Production in Southern Brazil	In particular MRI we don't have here in the South of Brazil. We don't have firms in the South of Brazil that produce this kind of equipment.
-		Government's Industrial Cooperation Initiative (SP)	This initiative started with the government's industrial cooperation project, abbreviated as SP. Without the investment, it didn't fully develop.
-	**Origins of the project**	Focus on Magnetic Particle Imaging (MPI)	Teams are working on a subject called magnetic particle imaging, but this is a different system than the current MRI device.
-		Missed Opportunities for Medical Device Development	The train for all medical devices that could not be developed in Turkey, including MRI, has passed.
-		Hybrid Manufacturing Approach	I believe they sourced the magnet from Korea, and some electronic circuits were imported, while others were made locally.
-		Unequal Regional Distribution of Medical Devices	We have good numbers, but the distribution in all region is not enough in this case.
-		Continued Motivation for MRI Production	As for MRI, the work is still ongoing—nothing has been produced yet, but the motivation on that front remains strong.
-	**Shall we do MRI?**	Lack of Support for Commercialization	The project never received the support needed for commercialization and remained as an open prototype that served its purpose.
-		Business Cycle Beyond Technology Discovery	Discovering MRI technology or completing its production does not create this technology. There is a large business cycle.
-		Product Management and Strategic Business Focus	In Turkey, we need to approach this with a product management mindset, focusing on the strategic side of the business.
-	**Planning**	Need for Experienced Experts	If you're thinking of making such a device, it's not enough to just say 'let's

			do it, we have engineers.' You need highly experienced experts in the field.
-		Sales and Marketing Strategy	You need to consider the sales channel strategy, marketing communication strategy, and other aspects separately when drafting strategies.
-		Market Potential Segmentation	Starting with market potential segmentation—how customers are divided—is the right approach for this analysis.
-		Challenges of a Small Domestic Market	Let me say this: as a country, if you say 'I will make an MRI,' Turkey is less than 1% of the world market.
-		Inspiration from China's Example	Turkey needs to follow China's example because Turkey has a large domestic market... Today China likely holds around 20% of the global medical technology market.
-		Project Discontinuation	At some point, for reasons I'm not fully aware of, it was decided not to continue with the project.
-		Local Content Policy as a Tool	The local content policy is an instrument for the health industry complex concept.
-		Decentralized Health System and Local Content	The Brazilian health system is designed for in those cases where the purchases are decentralized... a local content policy within the BNDES.
-		Industrial Policy Successes	We had industrial policies... that really worked, that brought added value, brought employment, qualified employment to Brazil.
-		Policy Evaluation for Attracting Companies	We had a policy that attracted a lot of companies and now, only one of them stayed. We need to evaluate what went wrong.
-	**Public Policies**	Local Content vs. National Content	We cannot differentiate companies by their ownership structure. Instead, we require them to carry out specific activities within the country

-		Production Capacities for Medicine and Equipment	The idea is to develop capacities to produce medicine or equipments.
-		Economic Crisis and Focus on Production	There is a serious economic crisis in the country, and this outcome has been clear for some time. If we don't produce, this is what happens.
-		Turkey’s Small Share in the Global Market	The global market that those companies serve is vast, and Turkey's share is only 1%.
-		Definition of "National"	When you say national, you are thinking of property of capital... private national companies plus the organizations established by the government directly.
-		Trust from Hospital and Doctors	Will the doctor trust the device we produce? Would the doctor really want to use something unproven, or would they prefer a device that has already established its reliability?
-	**Perception**	Motivation to Produce New Devices	It could be done if there were enough motivation... but you also need to look at it from the hospital's perspective.

B. QUESTIONNAIRE LIST

Questions for Brazil

1- Questions for the local manufacturers and subcontractors:

Introductory Questions

1. Can you give brief information about your company? How many people work in your company? What percentage of your workers are technical staff? What percentage is R&D staff?

Knowledge Types

1. I want you to think of the MRI product that you are developing/selling. Which part of the product do you design/manufacture?

Internal Knowledge

1. What is the extent of R&D and technology development efforts in your company specific to MRI?

External Knowledge

1. Do you use reverse engineering strategies to gain technological knowledge?
2. What are your knowledge sources outside the company (can be patent databases, scientific research etc.)? Who do you cooperate and collaborate with?
3. What did you learn about MRI technology during these interactions? How useful was this interaction? How did you benefit from these interactions? How do you feel about using this information in your MRI technology development projects?

Government

1. What do you think about the role of the state in MRI technology production? Does the government strategically affect the direction of technology development ? Is it any different from government support to any other technology? If yes in what sense? What kind of policy tools are available that affect MRI (technology) production.
2. What can be improved in government policy toward MRI production?

2- Questions for the global companies in Brazil

Introductory Questions

1. Can you briefly tell us about your company's story in Brazil ? When did you come to Brazil? Why? How many people work in your company? What percentage of your workers are technical staff? What percentage is R&D staff?

2. What were your initial thoughts on Brazil's technological potential when you started operating in the country?

Knowledge Types

NA

Government

1. What was the most important incentive for you to produce MRI here? Can you describe the pros and cons of the incentives and regulations you benefited from?
2. Who is your customer?
3. What is your perspective on the capabilities and skills of the local workforce in Brazil regarding the production of technological products like MRI?

Interaction with locals

1. Do you invest in and support local start-ups, research centers, tech-based companies in Brazil? What is your rationale in doing these?
2. How is your relations with the local universities? Do you collaborate with universities in technology development and R&D? Do you cooperate with universities in training and education?

3- Questions for the Brazil Government:

Introductory Questions

1. Where does MRI technology stand in the government strategies to develop technology? What do you think is the biggest problem with MRI use, distribution and production, and what policy tools are you using to solve this problem?

Knowledge Types

Internal Knowledge

1. How do global firms' strategies on MRI R&D affect the local firms?
2. What do you think about the localization of MRI technology? What would be the positive and negative aspects of this strategy? Does Brazil have sufficient technological capabilities to design and produce MRI? How do these capabilities be built?

External Knowledge

1. How do you consider the evolution of the technological learning of the MRI industry within the years?
2. What are the boundaries of the global firms manufacturing in Brazil?

Government

1. Why do you support the production of MRI by the global companies in Brazil?

2. Do you think that the government policies implemented in MRI production and technology production are successful? Why or why not? What are the future strategies of the government in MRI specific technological capabilities? Will benefiting from the global firms continue? Are there attempts to localise MRI technology?
3. Who are the customers of MRI devices in the market? Is the state a customer? Do you run a support program regarding the purchase of MRI products?

Questions for Türkiye

1- Questions for the local manufacturers and subcontractors:

Introductory Questions

1. Can you give brief information about your company? How many people work in your company? What percentage of your workers are technical staff? What percentage is R&D staff?

Knowledge Types

Internal Knowledge

1. I want you to think of the MRI product that you are developing/selling. Which part of the product do you design/manufacture?

External Knowledge

1. Do you use reverse engineering strategies to gain technological knowledge?
2. What are your knowledge sources outside the company (can be patent databases, science etc. as well)? Who do you cooperate and collaborate with?
3. What did you learn about MRI technology during these interactions? How useful was this interaction? How did you benefit from these interactions? How do you feel about using this info in your MRI technology development projects?

Government

1. What do you think about the role of the state in MRI technology production? Does the government strategically affect the direction of technology development ? Is it any different from government support to any other technology? What kind of policy tools are available that affect MRI (technology) production.
2. What can be improved in government policy toward MRI production?

2- Questions for the Aselsan

Introductory Questions

1. What is the current status of the MRI project that has been ongoing for a while? At what stage is the product? When do you plan to enter the market?

2. What triggered the MRI production project?

Intenal Knowledge

1. What is the extent of R&D and technology development efforts specific to MRI? Can you give a rough estimate of the local content ratio of the prototype/product? Which parts of an MRI do you think Türkiye is capable of producing?

External Knowledge

1. Do you use reverse engineering strategies to gain technological knowledge?
2. What are your knowledge sources outside the company (can be patent databases, scientific papers, etc.)? Who do you cooperate and collaborate with?
3. What did you learn about MRI technology during these interactions? How useful was this interaction? How did you benefit from these interactions? How do you feel about using this information in your MRI technology development projects?

Government

1. What do you think about the role of the state in MRI technology production? Does the government strategically affect the direction of technology development ? Is it any different from government support to any other technology? What kind of policy tools are available that affect MRI (technology) production?
2. What can be improved in the government policy toward MRI production?
3. Who do you think is the customer of this technology? Are you planning to be in the local market only?

Local Manufacturers

1. Have you worked with subcontractors? Or are you planning to work? Is developing a local supplier network viable in Türkiye? Are we capable? If not, what do you think the government should do? 3- Questions for the Türkiye Government

3- Questions for the Turkish Government:

Introductory Questions

1. Where does MRI technology stand in the strategies of the government in technological development? What do you think is the biggest problem with MRI use, distribution and production, and what policy tools are you using to solve these problems?

Internal Knowledge

1. How do global firms' strategies on MRI R&D affect the local firms and the strategies of the government?
2. What do you think about the localization of MRI technology? What would be the positive and negative aspects of this strategy? Does Türkiye have

sufficient technological capabilities to design and produce MRI? How could these capabilities be built?

External Knowledge

1. How is the evolution of technological learning in the MRI industry over the years? What are the global firms capable of? How far is Türkiye from the global knowledge frontier on MRI? Does Türkiye's position change over the years in MRI specific technology and production compared to the global leaders?
2. What are the boundaries of the global firms manufacturing in Turkey?

Government

1. What are the reasons of supporting the production of MRI by Aselsan?
2. Do you think that the government policies implemented in MRI production and technology production are successful? Why or why not? What are the future strategies of the government in MRI specific technological capabilities? Is there a localization of MRI production strategy?
3. Who are the customers of MRI devices in the market? Is the state a customer? Do you run a support program regarding the purchase of MRI products?

4- Questions for UMRAM

4. What are the key components involved in manufacturing an MRI machine?
5. In what ways can universities contribute to advancing MRI manufacturing capabilities in economically developing countries?
6. Are there any specific technological or infrastructural barriers that hinder the manufacturing of MRI machines in developing countries?
7. What strategies or approaches can be employed to overcome these challenges and enhance MRI manufacturing capabilities in developing countries?
8. Are there any successful examples of MRI manufacturing initiatives in economically developing countries that we can learn from?
9. In what ways can universities contribute to advancing MRI manufacturing capabilities in economically developing countries?
10. Looking ahead, what do you envision for the future of MRI manufacturing in developing countries, and what steps can be taken to realize these goals?

C. ETHICAL APPROVAL

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
APPLIED ETHICS RESEARCH CENTER

ORTA DOĞU TEKNİK ÜNİVERSİTESİ
MIDDLE EAST TECHNICAL UNIVERSITY

DUMLUPINAR BULVARI 06800
ÇANKAYA ANKARA/TURKEY
T: +90 312 210 22 91
F: +90 312 210 79 59
ueam@metu.edu.tr
www.ueam.metu.edu.tr

13 MART 2024

Konu: Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın **Prof. Dr. Semih Akçomak**

Danışmanlığını yürüttüğünüz Ceren Yavuz'un "***MRI Production in Brazil and Turkey: How do different state strategies affect technological learning?*** " başlıklı araştırmanız İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek 0145-ODTUİAEK-2024 protokol numarası ile onaylanmıştır

Bilgilerinize saygılarımla sunarım.

Prof. Dr. Ş. Halil TURAN
Başkan

Prof.Dr. İ. Semih AKÇOMAK
Üye

Doç. Dr. Ali Emre Turgut
Üye

Doç. Dr. Şerife SEVİNÇ
Üye

Doç.Dr. Murat Perit ÇAKIR
Üye

Dr. Öğretim Üyesi Süreyya ÖZCAN KABASAKAL
Üye

Dr. Öğretim Üyesi Müge GÜNDÜZ
Üye

D. CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: Yavuz, Ceren.

EDUCATION

Degree	Institution	Year of Graduation
BS	Ankara University Biomedical Engineering	2020
High School	Polatpşa High School, KKTC	2015

E. TURKISH SUMMARY

Günümüzde hızla ilerleyen teknolojik gelişmelerle birlikte, teknoloji, ekonomik büyümenin önemli bir itici gücü haline gelmiştir. Ülkeler ve işletmeler, rekabetçi kalmak ve sürdürülebilir kalkınmayı sağlamak için sürekli yenilik yapmak ve yeni teknolojileri benimsemek zorundadır. Teknolojik öğrenme, yani teknolojik bilgi ve becerilerin edinilmesi ve biriktirilmesi, özellikle gelişmekte olan ülkelerin, ekonomik katkılarını artırmaları ve gelişmiş ekonomilerle aralarındaki farkı kapatmaları için kritik bir mekanizma haline gelmiştir (Bell & Pavitt, 1993; Koçoğlu ve ark., 2012).

Artan küreselleşme ve dijital dönüşüm eğilimiyle, teknolojik öğrenmenin gelişmekte olan ekonomilerdeki önemini daha da artırmıştır. Bu ülkeler, teknolojik yeteneklerini geliştirmek için teknoloji transferi, taklit, ortak girişimler, lisanslama ve yerli yenilik gibi stratejilere sıklıkla başvurmaktadır (Steenhuis & Bruijn, 2012; Chen & Qu, 2003; Lee, 2005). Bu tez, gelişmekte olan ekonomilerde teknolojik öğrenmenin dinamiklerini incelemek amacıyla, yüksek teknolojili tıbbi cihazlar, özellikle Manyetik Rezonans Görüntüleme (MR) teknolojisinin üretim ve gelişim süreçlerini ele almaktadır. Çalışma, Brezilya ve Türkiye'deki MR üretimi girişimlerini inceleyerek, devlet politikaları ve teknolojik öğrenme süreçleri arasındaki karmaşık etkileşimi anlamaya çalışmaktadır.

Çalışmanın üç temel amacı vardır:

1. Gelişmekte olan ekonomilerde devletin, tıbbi cihaz sektöründe teknolojik öğrenme ve yeniliği nasıl teşvik ettiğini değerlendirmek.
2. Brezilya ve Türkiye'nin, yerli MR üretimi girişimlerinde karşılaştıkları başarı faktörlerini ve engelleri analiz etmek.
3. Benzer bağlamlarda teknolojik öğrenmeyi ve endüstriyel rekabet gücünü artırabilecek politika önerileri geliştirmek.

Araştırma, iki ülkeyi karşılaştırarak sektör raporları, devlet politikaları ve yarı yapılandırılmış görüşmelere dayanmakta ve Türkiye ile Brezilya arasındaki teknolojik öğrenme süreçlerinin nasıl farklılaştığını, devlet müdahalesinin MR üretiminde nasıl bir rol oynadığını incelemektedir. Çalışma iki önemli varsayım öne sürmektedir:

1. Brezilya, daha çok devlet odaklı politikalara yönelirken, Türkiye savunma sanayiinden elde ettiği deneyimlerle özel sektör tarafından yönlendirilen teknoloji transferine daha fazla önem vermektedir.
2. Brezilya'nın Yerli İçerik Politikası, Türkiye'ye göre daha etkin teknolojik öğrenme sonuçları ve yerli üretim kapasitesi sağlamaktadır.

Bu çalışma, Brezilya ve Türkiye'deki MR üretimi girişimlerinin karşılaştırmalı bir analizini yaparak, gelişmekte olan ekonomilerde devlet politikalarının teknolojik öğrenme ve yeniliği nasıl teşvik ettiğine dair yeni bilgiler sunmayı amaçlamaktadır. Bulgular, bu ülkelerin yerli MR teknolojisi üretme çabalarında karşılaştıkları başarı faktörleri ve engellerin daha geniş bir şekilde anlaşılmasına katkıda bulunacaktır. Çalışmanın katkıları arasında, teknolojik öğrenme süreçlerini geliştirmek isteyen diğer gelişmekte olan ekonomiler için bir politika çerçevesi geliştirilmesi yer almaktadır. Ayrıca, yüksek teknoloji tıbbi cihaz sektörü üzerine odaklanarak, bu araştırma, ülkelerin yeniliği nasıl teşvik edebilecekleri, endüstriyel rekabet gücünü nasıl artırabilecekleri ve yabancı teknolojilere olan bağımlılığı nasıl azaltabileceklerine dair pratik bilgiler sunmaktadır. Bulgular, sadece politika yapıcılar için değil, aynı zamanda teknoloji yoğun sektörlerde faaliyet gösteren endüstriler için de önem arz etmektedir.

Çalışmanın teknolojik odağı olan Manyetik Rezonans Görüntüleme (MR), tanısal radyoloji alanında çığır açan, güçlü bir tıbbi görüntüleme yöntemidir. Günümüzde MR, hastalık tespiti, karakterizasyonu, evreleme, tedaviye yanıt değerlendirmesi ve tedavi sonrası izleme gibi birçok uygulama alanı ile tıp dünyasında vazgeçilmez bir araç haline gelmiştir (Guimarães vd., 2014). 1970'lerdeki gelişiminden bu yana, MR teknolojisi kayda değer ilerlemeler kaydederek klinisyenlerin ve araştırmacıların iyonize radyasyon kullanmadan, insan vücudunun yüksek kaliteli ve ayrıntılı görüntülerini elde etmelerine olanak tanımıştır (Guimarães vd., 2014; Pal ve Rathi, 2021). MR, olağanüstü yumuşak doku kontrastı sağlama kapasitesi ve iyonlaştırıcı radyasyonun kullanılmaması nedeniyle, kanser teşhisi ve yönetimi gibi çeşitli tıbbi uygulamalarda tercih edilen bir görüntüleme yöntemi olarak öne çıkmaktadır. Yumuşak dokuların detaylı görüntülerini üretme kabiliyeti ve radyasyon kullanmaması sebebiyle, katılımcılar açısından bilgisayarlı tomografi (BT) yöntemine göre daha az riskli bir seçenektir (Azad vd., 2022). Son dönemde MR teknolojisindeki gelişmeler büyük ölçüde yapay zeka (AI) ve makine öğrenimi (ML) ile şekillenmiştir. Bu teknolojiler, görüntü yeniden inşasını geliştirerek, teşhisleri otomatikleştirerek ve daha hızlı ve hassas görüntüleme çözümleri sunarak MR'nın yeteneklerini dönüştürmüştür.

Akademik çerçeve olarak kullanılan "teknolojik öğrenme" konsepti ise gelişmekte olan ekonomilerde, gelişmiş ülkelere kıyasla temel araştırma ve Ar-Ge kaynaklarına erişimin genellikle sınırlı olduğu durumlarda büyük bir öneme sahiptir. Bu nedenle, mevcut teknolojileri öğrenme ve benimseme yeteneği, gelişim sürecini hızlandırmak ve aradaki farkı kapatmak için kritik bir öneme sahiptir (Goñi& Maloney, 2017). İşletmelerin ayakta kalabilmek için teknolojik bilgi üretmeye, yenilikçi olmaya ve değişen koşullara kolay adapte olmaları gerekir. Bu bağlamda, teknolojik öğrenme, araştırma-geliştirme (Ar-Ge) gibi içsel çabalarla, işbirlikleri, teknoloji transferi gibi dış kaynaklarla mevcut teknolojilerin kazanılmasını ve yeni bilgilerin geliştirilmesini tarif etmektedir (Lei ve ark.,1996).

Teknolojik Bilgi, şirketler tarafından içsel olarak Ar-Ge ve yenilik yoluyla, dışsal olarak ise ortak girişimler ve lisanslama yoluyla elde edilir. Gelişmekte olan ekonomilerdeki firmalar genellikle ileri teknolojileri taklit ederek başlarlar ve zamanla yeniliğe yönelirler. Akademik kurumlarla yapılan işbirlikleri de teknolojik gelişim için önemlidir (Greitemann ve ark., 2014). Firmanın hedeflerine bağlı olarak yenilikçi (ofansif), savunmacı ya da taklitçi yaklaşımlarla farklı öğrenme stratejileri uygulanır. Bu stratejiler, firmanın içsel ve dışsal bilgiyi entegre etme becerisine bağlıdır. Üniversiteler ve araştırma enstitüleriyle yapılan ortaklıklar, teknolojik öğrenme ve yeniliği destekler.

Tüm bu süreçlerde de devlet, teknolojik öğrenmede teşvikler sağlamak ve sanayi politikaları, Ar-Ge fonlaması, işbirliklerini teşvik etmek yoluyla destek sunmaktır. Firmalar olgunlaştıkça, devlet teknoloji sağlayıcısı rolünden, yeniliği kolaylaştıran bir role geçer ve müdahalelerle inovasyona erişimi geliştirir. Devlet, ayrıca öncelikli sektörleri belirler, inovasyonu destekleyen kurumlar inşa eder ve teknolojik ilerlemeyi teşvik eden stratejik politikalar uygular. Özellikle, bu tezin temelini oluşturan "Teknolojik Öğrenmede Devletin Rolü" kavramı, gelişmekte olan ekonomiler için teknolojik ilerlemenin temel taşıdır. Bu ülkeler için teknolojik öğrenme ve devletin bu süreçteki rolünü doğru bir şekilde anlamak ve değerlendirmek, doğru adımları atmayı kolaylaştıracaktır. Gelişmekte olan ekonomilerde devlet politikalarının ve devlet liderliğindeki girişimlerin teknolojik yenilik ve kapasite oluşturma üzerindeki etkisi çeşitli çalışmalarda geniş çapta araştırılmıştır.

Bu tez, Brezilya ve Türkiye'de MR endüstrisine odaklanarak, tıbbi cihaz sektöründe devletin teknolojik öğrenmedeki rolünü incelemeyi hedeflemektedir. Bu bağlamda, devletin belirlediği öncelikler, inşa ettiği kurumlar ve sunduğu teşvikler incelenmektedir.

Bu çalışmada, Türkiye ve BRIC (ekonomisi büyümekte olan ülkelerden Brezilya, Rusya, Hindistan ve Çin) ülkeleri arasından Brezilya seçilmiştir. Brezilya ve Türkiye, ekonomik yapıları ve benzer sağlık sistemlerine sahip olmaları nedeniyle karşılaştırılmıştır. Yüksek teknolojili tıbbi cihazların gelişmekte olan ülkelerdeki üretimi, kaynak eksikliği ve düzenlemeler gibi birçok zorlukla karşı karşıya kalmaktadır. Bu nedenle, bu ülkeler için yerel ihtiyaçlara uygun stratejiler geliştirmek büyük önem taşımaktadır.

Brezilya, Latin Amerika'nın en büyük tıbbi cihaz pazarına sahiptir ve bu pazar 2023'te yaklaşık 9.7 milyar dolar olarak değerlendirilmiştir. Brezilya'nın MR pazarı 2023 itibariyle 304.63 milyon dolar büyüklüğünde olup 2028'de 393.06 milyon dolara ulaşması beklenmektedir. Brezilya'da MR cihazlarının büyük bir kısmı ithalat yoluyla temin edilmektedir ve bu alandaki önemli oyuncular Siemens, GE Healthcare ve Philips gibi uluslararası şirketlerdir.

Türkiye, yaklaşık 85 milyon nüfusuyla dünyanın 19. en kalabalık ülkesidir. Türkiye'de MR pazarı, 2022 itibariyle yaklaşık 100 milyon dolar büyüklüğündedir ve

2028'e kadar %7 yıllık bileşik büyüme oranıyla büyümesi beklenmektedir. Türkiye'de MR cihazlarının sayısı 2002'de 58 iken, 2021'de 1048'e ulaşmıştır. Türkiye'nin sağlık sistemi kamu ve özel sektör işbirliği ile yönetilmekte olup, MR cihazlarının %80'i ithal edilmektedir.

Brezilya ve Türkiye, tıbbi cihaz sektöründe benzer zorluklarla karşı karşıyadır. Her iki ülke de ekonomik yapıları, demografik değişiklikler ve sağlık sistemlerindeki reformlar açısından benzerlik göstermektedir. Brezilya ve Türkiye'de devletin sağlık sektörüne yaptığı yatırımlar, bu iki ülkenin tıbbi cihaz pazarlarının büyümesine katkı sağlamıştır. Ancak her iki ülkede de MR cihazlarının yaygınlaşması için daha fazla yatırım yapılması gerektiği vurgulanmaktadır.

Tablo 1: Türkiye ve Brezilya'nın MR Pazarı Karşılaştırması

Parametre	Türkiye	Brezilya
Nüfus (2024 tahmini)	86.4 milyon	215 milyon
Sağlık harcamalarının GSYH oranı	4.7% (2021)	9.6% (2021)
MR Pazarı Büyüklüğü	100 milyon $ (2022)	350 milyon $ (2022)
1 Milyon Kişi Başına MR Cihazı Sayısı	11.3	14.0

Bu çalışma, Brezilya ve Türkiye'deki MR üretim endüstrilerinde devlet stratejilerinin teknoloji öğrenimi üzerindeki etkilerini karşılaştırmalı olarak incelemektedir. Araştırmanın amacı, her iki ülkede yüksek teknoloji tıbbi cihazların üretiminde devletin rolünü anlamaktır.

Araştırma, Brezilya ve Türkiye'de MR teknolojisinin yayılımı ve kullanımına ilişkin mevcut literatürün incelenmesiyle başlamaktadır. Bu literatür, MR üretimi ve benimsenmesinin mevcut durumu hakkında geniş bir bağlam sunmaktadır.

Çalışmanın temelini, Brezilya ve Türkiye'deki MR üretim endüstrilerine dair derinlemesine vaka çalışmaları oluşturmaktadır. Bu süreçte uygulnan devlet politikaları, teşvikler ve düzenleyici çerçevelerin sektör üzerindeki etkilerini analiz etmektedir. Amaç, iki ülke arasındaki devlet stratejilerindeki farklılıkları ve bu farklılıkların teknoloji öğrenimi ve üretim kapasitesi üzerindeki etkilerini incelemektir.

Çalışma, Eisenhardt'ın (1989) çerçevesine dayalı nitel indüktif bir yaklaşım kullanmaktadır. Veriler, akademik literatür, sektör raporları ve devlet belgeleri gibi çeşitli kaynaklardan toplanmış ve yarı yapılandırılmış mülakatlar aracılığıyla analiz edilmiştir.

Brezilya ve Türkiye'deki MR endüstrisinde doğrudan yer alan 19 katılımcıdan veri toplanmıştır. Katılımcılar, sektör uzmanları, üreticiler, düzenleyiciler ve politika yapıcılar gibi farklı rollerdeki kişilerden oluşmaktadır. Mülakatlar, katılımcıların deneyimlerini ve sektörün mevcut dinamiklerini anlamak için yapılandırılmıştır.

Veriler, MAXQDA yazılımı kullanılarak tematik analiz yöntemiyle incelenmiştir. Mülakat transkriptleri, araştırma sorularına göre kodlanmış ve tematik analiz yoluyla ana temalar belirlenmiştir. Bu süreç, teknoloji öğrenimindeki temel faktörlerin ve devlet politikalarının rollerinin derinlemesine anlaşılmasını sağlamıştır.

Çalışma, devlet müdahalesinin Brezilya ve Türkiye'de MR üretimindeki teknoloji öğrenim sürecinde önemli bir rol oynadığını ortaya koymuştur. Brezilya'daki "yerelleştirme" politikalarının daha başarılı sonuçlar verdiği, Türkiye'nin ise "millileştirme" stratejilerinde zorluklar yaşadığı belirlenmiştir. Çalışma, devlet politikalarının sürdürülebilir teknoloji öğrenimi ve yerli üretim için kritik olduğunu vurgulamaktadır.

Yapılandırılmış görüşmeler, farklı sektörlerden 19 katılımcı ile gerçekleştirilmiştir (Türkiye'den 10, Brezilya'dan 9 katılımcı). Görüşmelerin odak noktası, iki ülke arasındaki devlet stratejilerinin temel farklılıklarını ve bu farklılıkların teknolojik öğrenme, üretim yetenekleri ve MR endüstrisinin genel gidişatı üzerindeki etkilerini keşfetmektir. Elde edilen veriler, devletin rolünü anlamak için üç ana tema üzerinden değerlendirilmiştir: i) öncelik belirleme, ii) kurum inşası ve teşvikler.

Çalışmanın sonuçlarını özetlemek gerekirse, Türkiye'de MR üretimi için ilk girişim ODTÜ'de gerçekleştirilmiştir. 1992 yılında TÜBİTAK ve Birleşmiş Milletler desteğiyle yerli bir MR cihazı geliştirilmiş, ancak devlet desteği yetersiz olduğu için bu proje prototip aşamasını geçememiştir. Daha sonra 2015 yılında, Aselsan ve UMRAM iş birliği ile Türkiye'nin ilk yerli MR cihazının üretilmesi amacıyla bir proje başlatılmış, ancak bu proje de yeterli devlet desteği ve stratejik yönlendirme eksikliği nedeniyle tamamlanamamıştır. Türkiye'nin MRI teknolojisini Ulusal Teknoloji Girişimi'nin bir parçası olarak başlangıçta önceliklendirmesi takdire şayan olsa da, sürdürülebilir bir taahhüt eksikliği gözlemlenmiştir. MRI üretiminin uzun vadeli bir öncelik olarak tutulmaması, stratejik odağın giderek yüksek teknoloji tıbbi cihazlardan uzaklaşmasına neden olmuş ve projelerin devamlılığını engellemiştir. Öte yandan, finansal teşvikler daha sınırlı kalmış, devlet destekli yeterli garanti sağlanmaması, yerli MR sistemlerinin talebini artırmakta yetersiz kalmıştır. Güçlü teşvik mekanizmalarının yokluğu, yerli üreticilerin daha yüksek finansal risklerle karşı karşıya kalmasına yol açmış ve bu durum, üretim kapasitesini genişletme ve Ar-Ge'ye yatırım yapma kapasitelerini sınırlamıştır.

Brezilya'da ise, ithal tıbbi teknolojilere bağımlılığı azaltma ve yerel inovasyonu teşvik etme çabalarıyla başlamıştır. Brezilya hükümeti, tıbbi teknoloji sektöründe yerli üretimi teşvik eden politikalar uygulayarak ve doğrudan yabancı yatırımları (FDI) destekleyerek, MR cihazlarının yerel üretimini artırmayı amaçlamıştır. Brezilya'nın teknolojik öğrenmeyi teşvik etmek için kurumsal çerçeveler oluşturması, özellikle Sağlık Ekonomik-Endüstriyel Kompleksi Yürütme Grubu (Geceis) ve Üretken Gelişim Ortaklıkları (PDP'ler) gibi girişimlerle, devlet, akademi ve sanayi arasında işbirliğini teşvik etmiştir. Bu işbirlikleri, teknolojik öğrenmeyi destekleyen bir ortam yaratmış ve yerel firmaların küresel değer zincirlerine dahil olarak kritik teknolojik uzmanlık kazanmalarını sağlamıştır. 2010 yılında MR cihazları, Brezilya'nın Kamu Sağlık Sistemi (SUS) kapsamında Stratejik Ürünler listesine eklenmiş, bu da yerli üretim için büyük bir fırsat yaratmıştır. Ancak 2017'deki yönetim değişikliği ile bu politika revize edilmiş ve MR cihazları listeden çıkarılmıştır. Ayrıca, BNDES tarafından sağlanan düşük faizli kredi programları da iptal edilmiştir. Bu değişiklikler, MR üretimindeki ilerlemeyi büyük ölçüde olumsuz etkilemiş ve yerel üretimin duraklamasına neden olmuştur. Günümüzde, başlangıçta açılan fabrikalardan yalnızca biri faaliyetine devam etmektedir.

Çalışmanın en çarpıcı sonucu, Brezilya'da devletin MR üretimi için "yerelleşme" stratejisi uyguladığı ve bunun yabancı doğrudan yatırımları çekerek teknoloji ve bilgi transferini kolaylaştırdığıdır. Bu süreç, yerel firmaların derinlemesine teknolojik öğrenme sürecine katılmalarını ve üretim kapasitelerini geliştirmelerini sağlamıştır. Türkiye ise daha milliyetçi bir "yerelleşme" stratejisi izlemiş, ancak bu yaklaşım Brezilya modeli kadar başarılı olamamıştır. Projede planlama ve bütçe yetersizliği en önemli zayıflıklar olarak öne çıkmaktadır. Yeterli bir ticari senaryo oluşturulmamış, rekabet analizi yapılmamış ve kullanıcı geri bildirimleri dikkate alınmamıştır. Ayrıca, devletin stratejik satın alma garantisi sunmaması da projenin devam etmesini engellemiştir. Aselsan, MR cihazının ticari olarak kârlı olmadığını düşündüğünden projeyi ilerletme kararı almamıştır.

Sonuç olarak iki ülkede, bulguları akademik çerçeveye göre analiz ettiğimizde, her iki ülkede de devlet, başlangıçta stratejik öncelikler belirlemiş, kurumsal iş birliğini teşvik etmiş ve teşvikler sağlamış olsa da, bu girişimlerin sürdürülebilirliği konusunda sorunlar yaşamıştır. Türkiye’de proje, stratejik odak eksikliği, yetersiz teşvikler ve koordinasyon sorunları nedeniyle başarısız olurken, Brezilya’da ise politik tutarsızlıklar ve teşviklerin sona erdirilmesi sektörü duraklatmıştır. Her iki projede de devletin tutarlı, stratejik ve sürdürülebilir müdahalelerinin teknolojik öğrenme ve gelişim için ne kadar önemli olduğunu göstermektedir.

Yukarıda da ifade edildiği gibi bu tez çalışmasının amacı, Türkiye için politika önerisi sunmaktır. Bu çalışma, başarısız olmuş bir MR projesine dair daha önce belirsiz olan faktörleri açıklayarak literatüre önemli katkılar sunmaktadır. Gelişmiş ve maliyetli bir teknolojinin neden geliştirilemediğini derinlemesine analiz etmektedir. MR projesi üzerinden, devletin teknolojik öğrenme ve inovasyonu teşvik etmedeki vazgeçilmez rolüne vurgu yapılmaktadır.

Ayrıca, Brezilya'nın durumu, benzer bir ekonomik yapı ve MR piyasasında kademeli üretimin nasıl başarılı bir şekilde uygulanabileceğini gösteren bir karşılaştırma örneği olarak kullanılmaktadır. Günümüzde Brezilya'da yerleşik bir MR sanayisinin olmaması, orada da bazı stratejik hatalar yapıldığını gösterse de, MR cihazının SUS Stratejik Ürünler Listesi'nden çıkarılmasından bu yana bazı önemli adımlar atılmıştır. Sonuç olarak, bu karşılaştırma, gelişmekte olan ülkelerde çoğunlukla tekrarı zor olan başarı hikayelerine kıyasla değerli bir tezat sunmaktadır. Brezilya, devlet müdahalesi ve stratejik politika yapımı yoluyla yerel teknolojik kapasitelerin nasıl inşa edilebileceğini gösteren pratik bir örnek olarak Türkiye gibi gelişmekte olan ülkeler için anlamlı bir ders niteliği taşımaktadır.

Bu analiz, Türkiye ve diğer gelişmekte olan ekonomilerin yerli teknolojik uzmanlık geliştirme hedeflerine yönelik önemli politika dersleri sunmaktadır. Devletin, sürdürülebilir teknolojik öğrenme ve yeniliği teşvik eden stratejiler geliştirmede bir öncelik belirleyici, kurum inşa edici ve teşvik sağlayıcı olarak çok yönlü rollerini tanımanın gerekliliğini vurgulamaktadır. Ayrıca, Türkiye'nin Savunma Sanayiinden öğrendiği derslerin MR projesine olan yansımalarının yetersiz olduğu gözlemlenmiştir. Bu noktadan itibaren, yüksek teknoloji tıbbi cihaz sektörünün, bu teknolojilerin doğası ve gelişim planları nedeniyle henüz karşılanmamış ek ihtiyaçları olduğu sonucuna varılabilir.

Öneki bölümde, araştırma bulguları teorik çerçeveye göre ele alınmış ve çalışmanın araştırma soruları değerlendirilmiştir: "Türkiye ve Brezilya'da MR üretimindeki teknolojik öğrenme süreci nasıl farklılık göstermektedir?" ve "Devlet, MR üretimindeki teknolojik öğrenme sürecini nasıl geliştirmektedir?" Bu sorulara verilen yanıtlar doğrultusunda, Türkiye'deki MR projesinin başarısızlığının daha geniş teknolojik öğrenme sürecinin bir sonucu olduğu sonucuna varılmıştır. Bu analizden yola çıkarak, Türkiye için iyileştirme önerileri sunulmuştur.

Devletin Öncelik Belirleyici Rolü

Brezilya'nın yaklaşımından çıkarılabilecek en önemli derslerden biri, devlet politikasında tutarlı önceliklendirme yapmanın önemidir. Brezilya, MR teknolojisini başlangıçta stratejik bir öncelik olarak belirlemiş ve Birleşik Sağlık Sistemi (SUS) Stratejik Ürünler listesine dahil etmiştir. Bu, yerel üretime yönelik çabaların ve kaynakların odaklanmasını sağlamıştır. Türkiye de benzer bir uzun vadeli önceliklendirme stratejisinden yararlanabilir; bu, MR üretimi gibi yüksek teknoloji endüstrilerinin ulusal öncelik olarak sürekli vurgulanmasını içerir. Bu yaklaşım, sadece başlangıçta net hedefler belirlemekle kalmayıp, uzun vadeli stratejik planlama ve politika sürekliliği ile bu hedefleri koruyarak, projelerin sürekli destek almasını sağlamalıdır.

Türkiye'deki MR projesi, başlangıçta Ulusal Teknoloji Girişimi ve Onuncu Kalkınma Planı ile güçlü stratejik amaçlar taşıyordu. Ancak zamanla, odak ve stratejik bağlılığın yetersiz kalması, projenin duraksamasına ve nihayetinde askıya alınmasına yol açtı. Devletin öncelik belirleyici rolünü daha etkili hale getirmek için şu adımlar atılabilir:

- **Uzun Vadeli Stratejik Plan Geliştirmek**: MR gibi karmaşık bir teknolojiyi geliştirmek için çok spesifik ve detaylı bir uzun vadeli stratejik plan hazırlanmalıdır. İleri tıbbi teknolojilerin gelişimi için net hedefler, kilometre taşları, zaman çizelgeleri ve bütçeleri içeren ayrıntılı bir yol haritası oluşturmak gereklidir. Bu planın politik geçişler sırasında devamlılığı sağlanmalı ve sürekli olarak gözden geçirilmelidir. Teknolojik trendler de izlenmeli ve projeler düzenli olarak güncellenmelidir.
- **Karmaşık Teknolojileri Anlamayı Artırmak**: MR teknolojisinin karmaşıklıklarının tam olarak anlaşılamaması, projenin başarısız olmasına yol açan faktörlerden biridir. Sektör uzmanlarıyla birlikte yapılacak kapsamlı fizibilite çalışmaları ve pazar analizleri, daha etkili yol haritaları oluşturmada yardımcı olacaktır.

Uluslararası uzmanlarla işbirliği yapılması ve teknik eğitim programlarının teşvik edilmesi de stratejik kararların teknoloji ve pazar hakkında derin bir anlayışa dayanarak alınmasını sağlar.

Devletin Kurum İnşa Edici Rolü

Brezilya'nın Sağlık Ekonomik-Endüstriyel Kompleksi Yürütme Grubu (Geceis) gibi kurumsal yapıları oluşturması, hükümet, endüstri ve araştırma kurumları arasında işbirliğini kolaylaştırmıştır. Türkiye, üniversiteler, araştırma kurumları ve özel şirketler arasındaki işbirliğini formalize ederek yenilik ve teknolojik ilerlemeyi teşvik eden kurumsal yapıları güçlendirebilir.

- **İşbirliği için Kurumsal Çerçeveleri Güçlendirmek**: Üniversiteler, araştırma kurumları ve sanayi oyuncuları arasında yapılandırılmış işbirliğini teşvik eden kamu-özel ortaklıkları ve araştırma konsorsiyumları oluşturarak, yüksek teknoloji endüstrilerinde bilgi paylaşımı ve ortak yenilik çabalarını desteklemek gerekmektedir.
- **Koordinasyonu ve İletişimi İyileştirmek**: Türkiye'nin MR projesinde, paydaşlar arasındaki etkili koordinasyon eksikliği projeyi olumsuz etkilemiştir. İletişim protokollerinin standartlaştırılması ve şeffaflığın teşvik edilmesi, işbirliği süreçlerini iyileştirebilir.

Devletin Teşvik Sağlayıcı Rolü

Brezilya'da düşük faizli krediler ve devlet destekli satın alma garantileri, finansal riskleri azaltarak yerli MR üretimini teşvik etmiştir. Türkiye de benzer teşvikleri, yüksek teknoloji endüstrileri için hibeler, sübvansiyonlar ve vergi indirimleri şeklinde uygulayabilir. Ayrıca, devlet destekli satın alma garantilerinin oluşturulması ve sağlık hizmeti sağlayıcıları için düşük faizli kredi programlarının geliştirilmesi, yerli tıbbi cihazlara olan talebi artırabilir.

- **Hedefe Yönelik Teşvik Programları Geliştirmek**: Gelişmiş tıbbi teknolojilerde Ar-Ge'yi destekleyen hibeler, vergi indirimleri ve devlet destekli satın alma garantileri gibi hedefe yönelik teşviklerin uygulanması, yerli MR üretimi gibi projelere yatırımları teşvik edebilir.
- **Teknoloji Transferi ve Yerelleştirmeyi Kolaylaştırmak**: MR üretiminde daha stratejik bir "yerelleştirme" yaklaşımı benimsenmeli ve uluslararası ortaklıklarla teknoloji transferi hızlandırılmalıdır. Ayrıca, eğitim programları ve atölye çalışmalarıyla yerel iş gücünün yetkinlikleri artırılmalıdır.

Bu çalışmanın bulguları, gelecekteki araştırmalar ve politika geliştirme için birkaç kilit alana işaret etmektedir. İlk olarak, devletlerin uzun vadeli stratejik önceliklerini hızla gelişen teknolojik manzarayla daha iyi uyumlu hale getirme mekanizmalarının daha fazla araştırılması gerekmektedir. MRI ve diğer tıbbi teknolojiler ilerlemeye devam ettikçe, devletlerin yapay zeka (AI) ve makine öğrenimi (ML) gibi yeni yenilikleri politikalarına dahil etme stratejileri geliştirmeleri gerekecektir.

İkincisi, uluslararası işbirliğinin gelişmekte olan ekonomilerde teknolojik öğrenmeyi nasıl teşvik ettiğinin araştırılması gerekmektedir. Brezilya'nın yerelleştirme modeli etkili olsa da, giderek artan sayıda yüksek teknoloji sektörü küresel yenilik ağlarına dayanmaktadır. Türkiye ve diğer gelişmekte olan ülkeler, uluslararası araştırma kurumları ve teknoloji merkezleri ile daha derin bir etkileşime girerek, daha hızlı teknolojik gelişim ve bilgi transferi sağlayabilir.

Ayrıca, kamu-özel ortaklıklarının teknolojik inovasyonu nasıl yönlendirdiği konusu da daha fazla incelenmelidir. MRI üretimi dışındaki sektörlerde bu işbirliklerinin etkinliği araştırıldığında, gelişmekte olan ekonomiler bu modeli biyoteknoloji, havacılık veya yenilenebilir enerji gibi diğer yüksek teknoloji sektörlerinde nasıl uygulayabileceklerine dair değerli içgörüler elde edebilirler.

Son olarak, bu çalışma devlet destekli teşviklerin yerli üretim kapasitelerini teşvik etmedeki kritik rolünü vurgulamaktadır. Gelecekteki araştırmalar, sübvansiyonlardan vergi indirimlerine ve devletin satın alma garantilerine kadar farklı teşvik türlerinin, yerel yüksek teknoloji endüstrilerinin büyümesi ve sürdürülebilirliği üzerindeki etkisini incelemelidir. Hangi teşviklerin hangi sektörlerde en etkili olduğunu daha iyi anlamak, daha hedefe yönelik ve etkili politika müdahalelerine olanak sağlayacaktır.
Sonuç olarak, bu çalışma Türkiye ve Brezilya'daki MRI sektörüne odaklansa da, bulguları çok daha geniş bir endüstri ve ülke yelpazesi için geçerlidir. Bu araştırmadan elde edilen içgörüler, yüksek teknoloji sektörlerinde teknolojik kapasiteler inşa etme çabalarına yön verebilir ve nihayetinde gelişmekte olan ekonomilerin küresel piyasada rekabetçi oyuncular olarak konumlanmasına yardımcı olabilir.

F. THESIS PERMISSION FORM / TEZ İZİN FORMU

(Please fill out this form on computer. Double click on the boxes to fill them)

ENSTİTÜ / INSTITUTE

Fen Bilimleri Enstitüsü / Graduate School of Natural and Applied Sciences ☐

Sosyal Bilimler Enstitüsü / Graduate School of Social Sciences ☒

Uygulamalı Matematik Enstitüsü / Graduate School of Applied Mathematics ☐

Enformatik Enstitüsü / Graduate School of Informatics ☐

Deniz Bilimleri Enstitüsü / Graduate School of Marine Sciences ☐

YAZARIN / AUTHOR

Soyadı / Surname : YAVUZ
Adı / Name : Ceren
Bölümü / Department : Bilim ve Teknoloji Politikası Çalışmaları / Science and Technology Policy Studies

TEZİN ADI / TITLE OF THE THESIS (**İngilizce** / English): MRI PRODUCTION IN BRAZIL & TÜRKİYE: HOW DO DIFFERENT STATE STRATEGIES AFFECT TECHNOLOGICAL LEARNING?

TEZİN TÜRÜ / DEGREE: **Yüksek Lisans** / Master ☒ **Doktora** / PhD ☐

1. **Tezin tamamı dünya çapında erişime açılacaktır. /** Release the entire work immediately for access worldwide. ☒

2. **Tez iki yıl süreyle erişime kapalı olacaktır.** / Secure the entire work for patent and/or proprietary purposes for a period of **two years**. * ☐

3. **Tez altı ay süreyle erişime kapalı olacaktır.** / Secure the entire work for period of **six months**. * ☐

***** *Enstitü Yönetim Kurulu kararının basılı kopyası tezle birlikte kütüphaneye teslim edilecektir. / A copy of the decision of the Institute Administrative Committee will be delivered to the library together with the printed thesis.*

Yazarın imzası / Signature .... **Tarih** / Date ....
(Kütüphaneye teslim ettiğiniz tarih. Elle doldurulacaktır.)
(Library submission date. Please fill out by hand.)

Tezin son sayfasıdır. / This is the last page of the thesis/dissertation.