The Dynamics of Technological Catching-up: The Case of Iran's Gas Turbine Industry

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I hereby declare that this thesis has not been, and will not be, submitted in whole or in part to another University for the award of any other degree.

Signature: ……………………………………….

Mehdi Majidpour

Are those who know equal with those who know not?

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The dynamics of technological catching-up: The case of Iran's gas turbine industry

Summary

Today, fostering gas-fired power plants is recognised as a significant step towards a low-carbon economy. Gas fired-power plants are favoured over other types of fossil-fuelled power plants due to their various advantages, including lower emissions, flexibility of technology, higher efficiency, short construction times and lower capital investment. The gas turbine is the main machine and the most technologically advanced part of a gas-fired power plant. There have been a limited number of companies in industrialised countries that have developed these sophisticated technologies over the last 50 years. The global market for land-based gas turbines has an oligopolistic structure. The evolution of these technologies has been greatly influenced by countries' government policies, and in particular energy policies. In this light, one question is: to what extent have industrialising countries built their technological capabilities in gas turbines? Consequently, one focus of interest here is the way in which, and the extent to which, industrialising countries have synthesised their indigenous technology development efforts with overseas technology inflows. Countries such as Iran, India and China, which have large and growing domestic electricity markets, are appropriate candidates for research in order to understand the possible technological gaps and associated dynamics between the industrialised and industrialising worlds.

To answer these questions, this thesis research deals with Iran's gas turbine industry and, for the first time, systematically examines this industry in the context of a developing country. The study delves deeply into the dynamics of interactions between indigenous technology development and overseas technology inflows. It casts light upon the influences, challenges, and difficulties associated with technological catching-up processes. The framework of the analysis is based on an extensive literature review on technological catch-up, the substitution/complementarity debate, and the gas turbine industry. The framework was operationalized through qualitative interviews as well as supplementary documents. The thesis uses a 'dynamic approach', and argues that understanding the interaction processes cannot be reduced to examining only the type of relationship between the two technology sources. Instead, far more attention needs to be devoted to analysing the complexity and associated influences on this relationship. The thesis also provides empirical insights into the development of gas turbine capabilities in India and China, the two largest emerging economies. It reveals that a high level of state involvement in developing countries is a prominent feature of the industry. It also demonstrates that the evolution of the industry also in both developed and developing countries is closely interrelated with each country's national energy policies.

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List of Abbreviations

ABB	ASEA Brown Boveri
ATS	Advanced Turbine System
BHEL	Bharat Heavy Electricals Limited
BOO	Build-Owned-Operate
BOT	Build-Operate-Transfer
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CBI	Central Bank of Iran
CCGT	Combined Cycle Gas Turbine
CFD	Computational Fluid Dynamics
CFG	Creep Feed Grinding
CNC	Computerized Numerical Control
CNG	Compressed Natural Gas
DEC	Dongfang Electric Corporation
DoE	Department of Energy
DS	Directional Solidification
EDM	Electro Discharge Machining
EIA	Energy Information Administration
EPC	Engineering Procurement and Construction
FDI	Foreign Direct Investment
FEM	Finite Element Analysis
GE	General Electric
HHV	Higher Heating Value
HTTT	High Temperature Turbine Technology
ICJ	International Court of Justice
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPO	Iranian Privatization Organization
IPP	Independent Power Producer

IPR	Intellectual Property Rights
LDC	Less Developed Countries
LHV	Lower Heating Value
LNG	Liquefied Natural Gas
MAPNA	Iran's Power Plant Projects Management
MECO	MAPNA Electric and Control Engineering and Manufacturing Co.
MHI	Mitsubishi Heavy Industry
MOE	Ministry of Energy
NACA	National Advisory Committee for Aeronautics
NIEs	Newly Industrializing Economies
NIS	National Innovation System
NLS	National Learning System
NTC	Nanjing Turbine and Electric Machinery Group
NVH	Noise, vibration and harshness
ODM	Own Design and Manufacture
OBM	Own Brand Manufacture
OECD	The Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturing
OPEC	Organization of the Petroleum Exporting Countries
PARTO	MAPNA Turbine Blades Engineering and Manufacturing Co.
PURPA	Public Utility Regulatory Policy Act
R&D	Research and Development
SECPG	Shanghai Electric Power Generation Group
SPRU	Science Policy Research Unit
STEM	Shaped Tube Electrolytic machining
SUNA	Iran Organization for new Energies
TUGA	MAPNA Turbine Engineering and Manufacturing Co.
TNC	Trans-National Co-operation
TBC	Thermal Barrier Coatings
XLG	Export-led Growth

Chapter 1: Introduction

1.1 Purpose of the Study

The gas turbine is the main machine and the most technologically advanced part of a gas-fired power plant. There have been a limited number of companies in industrialised countries that have developed these sophisticated technologies over the last 50 years. The evolution of these technologies has originated from multi-billion dollar military and civil programmes and other public R&D budgets (Mowery and Rosenberg 1982; Watson 1997; Winskel 2002; Watson 2004*a*). The development of land-based gas turbines has been influenced by the countries' governmental policies, including energy policies. Backup plants in the US and the UK in the 1960s, the PURPA Act plants in the US in the 1980s, and the 'dash for gas'[1] manifested in the UK in the 1990s are amongst the policy drivers for the development of land-based gas turbine technologies. Gas-fired power plants are favoured over other fossil-fuelled power plants due to their lower emissions, higher efficiency, flexibility of technology, short construction lead times, and reduced capital investment (Watson 1997; Islas 1997; Watson 2004*a*).

With respect to the global interest in gas-fired power plant, a question is: what is the status of developing countries in the land-based gas turbine industry? While the technological requirements for the gas turbine industry are extraordinarily complex and highly advanced, and there is still a limited number of gas turbine suppliers in the industrialised world, to what extent have industrialising countries built these technological capabilities?

Iran is one of the developing countries that have established a gas turbine industry. The state-owned company, MAPNA Group, was founded in 1992. In the early phases of establishment, MAPNA focused on power plant construction technologies, but the company gradually diversified its business into power plant equipment manufacturing. MAPNA is the parent enterprise for 29 subsidiaries. It is supervised by the state. However, the privatisation of the company is on the government's agenda. MAPNA is now the

[1] The 'dash-for-gas' was an unexpected market outcome of other policies, however, it affected the development of land-based gas turbine technologies.

biggest power plant equipment manufacturer in Iran and the biggest power plant constructor in Iran and the Middle East. The question is, what is the level of MAPNA's technological capability compared to the leading gas turbine suppliers? How has MAPNA acquired gas turbine technologies: to what extent has the company developed the technologies indigenously, and to what extent have they been imported? How has the company synthesised its indigenous technology development efforts with overseas technology sources?

Technological catch-up studies discuss the narrowing (or widening) of gaps between the technological capabilities of firms and economies (Bell and Figuieredo 2010). These studies argue that both indigenous efforts and overseas technology transfer are the key elements of the catch-up concept. On one hand, the literature underlines the accessibility of foreign technology and international technology flows from leaders to followers as a significant part of the process. On the other, it emphasises indigenous innovation and learning systems and highlights the important role of institutions, organisations and interactions in enhancing domestic technological capabilities. In this view, a number of studies have tried to understand the relationship between indigenous and overseas technology sources. Some of them have shown that these two main technology channels are alternatives or substitutes, while others have argued that the channels are complementary. Regardless of the small number of such studies, especially in a developing country context, the majority of the existing literature has placed too much emphasis on the 'correctness' of one of these ideas. They have often examined the type of relationship and paid inadequate attention to its dynamics, challenges, and difficulties. Although some of the studies (Pack and Saggi 1997; Radosevic 1999) have criticised the static viewpoint of the existing literature and have posed interesting questions about the dynamics of technological development of latecomer firms, the issue has barely been touched upon. These studies have left unanswered the nature and the details of dynamics.

This thesis delves deeply into the dynamics of interactions between indigenous technology development and overseas technology inflows. It aims to analyse the influences, challenges and difficulties of Iran's gas turbine industry through acquiring gas turbine technologies from both indigenous and overseas sources. This research introduces a new perspective, namely the 'dynamic approach', and argues that understanding interaction processes cannot be reduced to examining only the type of relationship. Instead, far more attention needs to be devoted to analysing its complexity and associated influences. It also provides empirical insights into the emergence of gas turbine capabilities in developing countries. For the first time, this thesis systematically examines the gas turbine industry in a developing country context and enables understanding of the industry similarities and differences between industrialised and industrialising countries. The thesis also aims to analyse the influencing factors in the Iranian context and compares the findings with the literature. It elucidates to what extent the explored influences fit with the literature.

1.2 Research Questions

The central question which this thesis examines is:

What have been the dynamics between indigenous technology development and overseas technology transfer in Iran's gas turbine industry?

The central research question will be approached by answering four specific supporting research questions:

1) *What types of gas turbines are manufactured in Iran by MAPNA, and how do they compare to the technological leaders?*
2) *How has the MAPNA Group acquired gas turbine technologies? To what extent has the MAPNA Group included imported and in-house technology?*
3) *Why has the MAPNA Group embodied this combination of indigenous and imported technologies, and what factors have influenced the interactions between the two knowledge sources?*
4) *How do MAPNA's capabilities compare to those in other developing countries?*

The above set of questions logically embeds an opportunity to more narrowly revisit, with the help of substantial empirical data, the critical relationship between indigenous and overseas technology sources. It sheds light on the dynamics of the combination of the two knowledge sources by the Iranian firms.[2] The research questions also provide insights into gas turbine industries in other developing countries, particularly China and India, both of which have also undertaken some licensed activities in relation to gas turbines.

1.3 Overview of the Thesis

Chapter 2: The Research Context and Background

Chapter 2 aims to clarify the extent to which the gas turbine industry is important in the Iranian context. This facilitates understanding the influence of government policies, including national energy policies, in the evolution of the gas turbine industry. In this light, as the country possesses a huge amount of oil and natural gas resources, as well as favourable potential to install renewable energies, it first reviews Iran's national energy statistics. Analysing these figures, it shows why fostering natural gas utilisation is a national policy in Iran. It then explains why gas-fired power plants and subsequently the gas turbine industry is recognised as a strategic choice in the electricity sector. Chapter 2, in its final sections, reviews Iran's power plant industry and power equipment manufacturing industry in terms of its actors and governance.

Chapter 3: The Theoretical Framework

Chapter 3 aims to establish a theoretical framework for the case study chapters. The thesis builds upon literature on technological catch-up and in particular on the studies of the substitutive/complementary relationship between indigenous technology development and

[2] MAPNA Group: the parent enterprise and its subsidiaries

overseas technology transfer. Chapter 3 first reviews different perspectives as well as different dimensions of the technological catch-up concept. It then critically reviews substitution/complementarity literature and contends that technological catch-up through indigenous R&D and/or technology import embeds various influences that are present simultaneously – beyond the will or power of managers and policy makers – and that have to be recognised, analysed and taken into account. It suggests the dynamic approach by which scholars are able to reach a deeper understanding of the dynamics, challenges and difficulties of these relationships. In the final section, Chapter 3 concludes with a matrix, which contains the important factors involved in the interaction processes between indigenous and overseas capabilities. These factors are implicitly or explicitly discussed in the literature in different studies in different contexts, and thus the matrix incorporates them to develop a structured framework for operationalizing the study.

Chapter 4: Research Methodology

Chapter 4 outlines the research methodology. It first illustrates how the research, including fieldwork and data gathering, was designed. It explains the methodological principles that can bridge the theoretical framework and the empirical research. It also provides a contextualised framework for operationalizing the study and exploring influences in the Iranian context. The research design section includes the rationale for choosing a case study approach as well as a justification for the choice of case. Chapter 4 then elaborates the research process and explains how data gathering processes were implemented during the fieldwork. The interviewed companies and organisations, as well as collected documents, are explained in detail. It finally sets out how the data for India and China were gathered.

Chapter 5: Gas Turbine Industry: Technological Requirements and Industry Characteristics

Chapter 5 aims to understand the gas turbine industry, both in terms of technologies and market dimensions. Before any attempt to analyse Iran's gas turbine industry, Chapter 5 brings to light the technological requirements of the gas turbine, the evolution of the technologies, and the structure of the market and suppliers. Such an illumination prepares the way to understand the global industry dynamics and subsequently to understand the similar and different challenges in developing countries. Thus, the first and the second sections elucidate different technological areas of gas turbines and explain their historical evolution. The final section of Chapter 5 then explains the market for gas turbines as well as the suppliers' characteristics. It explains why and how government policies have been playing an important role in this market.

Chapter 6: Iran's Gas Turbine Industry: The Evolution and Technology Acquisition Processes

Chapter 7: Influences on MAPNA's Technological Development Process

Chapters 6 and 7 present a detailed analysis of Iran's gas turbine industry. Chapter 6 investigates the industry development phases as well as the technological acquisition processes and their associated challenges. It brings to light various problematic situations and considerations that domestic companies faced throughout the technology development processes. Chapter 7 analyses the dynamics of the interactions between MAPNA's technology development efforts, such as in-house R&D and interactions with domestic universities, and foreign technology sources. It explains what factors have influenced these processes and how they have affected the technological catch-up of MAPNA Group. At the same time, Chapter 7 compares the findings with the existing literature on technological catch-up and shows which parts of these findings fit with the literature and which parts are dissimilar.

Chapter 8: India and China Insights

Chapter 8 aims to provide a comparative analysis between Iran's gas turbine industry and China and India. It helps to put the Iranian case into context by contrasting Iran's strategy and the development of MAPNA's capabilities with the national strategies and corporate capabilities within the two largest emerging economies. It illuminates the similarities and differences between the industries of these three countries as well as their evolutionary paths and policy drivers.

Chapter 9: Conclusions

Chapter 9 summarises the main findings of the thesis and answers the research questions. It also outlines the research contributions, limitations, and some questions for future research.

Chapter 2 : The Research Context and Background

2.1 Introduction

The purpose of this chapter is to illuminate the research context. The Iranian context is influenced by well-endowed natural reserves. This chapter explains that although Iran has huge amount of oil, natural gas reserves and favourable potential to install renewable energies equipment, gas-fired power plants and subsequently the gas turbine industry is recognised as a strategic choice in national energy policies. Such a background facilitates an understanding of the extent to which the gas turbine industry is influenced by government policies, including national energy policies.

This chapter follows a logical path to narrow the context of the thesis. It starts by analysing Iran's general energy statistics and examines electricity as well as the gas turbine industry. This chapter is composed of six sections and is based on valid and reliable data gathered during and after fieldwork. The majority of data are the latest published or issued; however, a few documents relate to the year 2006 which were the only published and valid data during writing of this thesis.

Section 2 explains how Iran's oil and natural gas reserves stand in the world. It will also explain the situation of Iran with regard to renewable energies. Section 3 elucidates why natural gas is favoured over other fossil fuels in Iran and how industrial and energy policy makers are determined to foster natural gas utilisation across the country as well as in all industrial sectors.

Section 4 discusses the national power plant industry in order to provide the background for the discussions of the gas turbine industry. It analyses national power plants in terms of capacity and combination and clarifies the extent to which gas-fired power plants are important in Iran's electricity sector. Finally, Section 4 reviews Iran's power plant industry and power equipment manufacturing industry in terms of its actors and governance. Section 5 draws the chapter's conclusions.

2.2 Iran: A Source of Energy

World energy outlooks underline the extent to which oil will remain the leading source of energy by 2030 (OPEC 2009; IEA 2009). Oil was the primary source of the world's energy in 2007 with the amount of 4045 million tons energy, about 36.4% of total fuel shares (OPEC 2009). The forecasts show that oil energy is set to rise by more than 40% from 2007 to 2030 (IEA 2009).[3] Although renewable and nuclear energies have both technology-push and demand-pull drivers, the share of such energies will only rise from 15% in 2007 to about 19% in 2030 and thus fossil fuels, with more than 80% of total fuel share, will remain the backbone of the world energy supply in 2030 (OPEC 2009; IEA 2009). The trend also shows that although overall oil share will fall, it will still satisfy 30% of total energy demand in 2030, making it the primary source (OPEC 2009; IEA 2009).

According to IEA (2009) and OPEC (2009), natural gas, after oil and coal, is the third main supply of energy in the world. Estimates show that the use of natural gas will increase annually by 1.5% between 2007 and 2030. Forecasts also demonstrate that the electricity generation industry will retain the largest portion of natural gas use in the future. This is particularly the case for those countries that have natural gas reserves or access to reliable sources of natural gas at a reasonable price.

Iran's oil reserves stand at 137.6 billion barrels, which is 10.9% of all the oil reserves in the world, and Iran ranks second amongst countries with oil reserves (BP Statistical Review 2009).[4] Iran produces 4325 thousand barrels of crude oil a day; this constitutes 5.3% of the world oil production, and consequently ranks the country fourth in the world and second among OPEC's members (BP Statistical Review 2009). Figure 2.1 compares oil reserves and production by country in 2008.

Over the last two decades, Asia and the Pacific and Western Europe have been the main markets for Iran's crude oil. For instance in 2008, the figures show that Japan, China and India in Asia as well as Italy, Spain, Greece and France in Western Europe were the main destinations for Iran's crude oil (EIA 2010). The direction of market for Iran's crude oil has been influenced by the US-led sanctions, as other Persian Gulf states are the

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[3] IEA has more than one scenario; however, in this thesis only the Reference Scenario is used.

[4] Canadian sands oil excluded; otherwise Iran stands third in the world.

significant oil suppliers for the United States. The sanctions have also influenced investments in the country's oil industry. Iran's aging oil industry is eager to attract foreign investment and is potentially an important market for American goods and technology (Wright and Bakhash 1997).

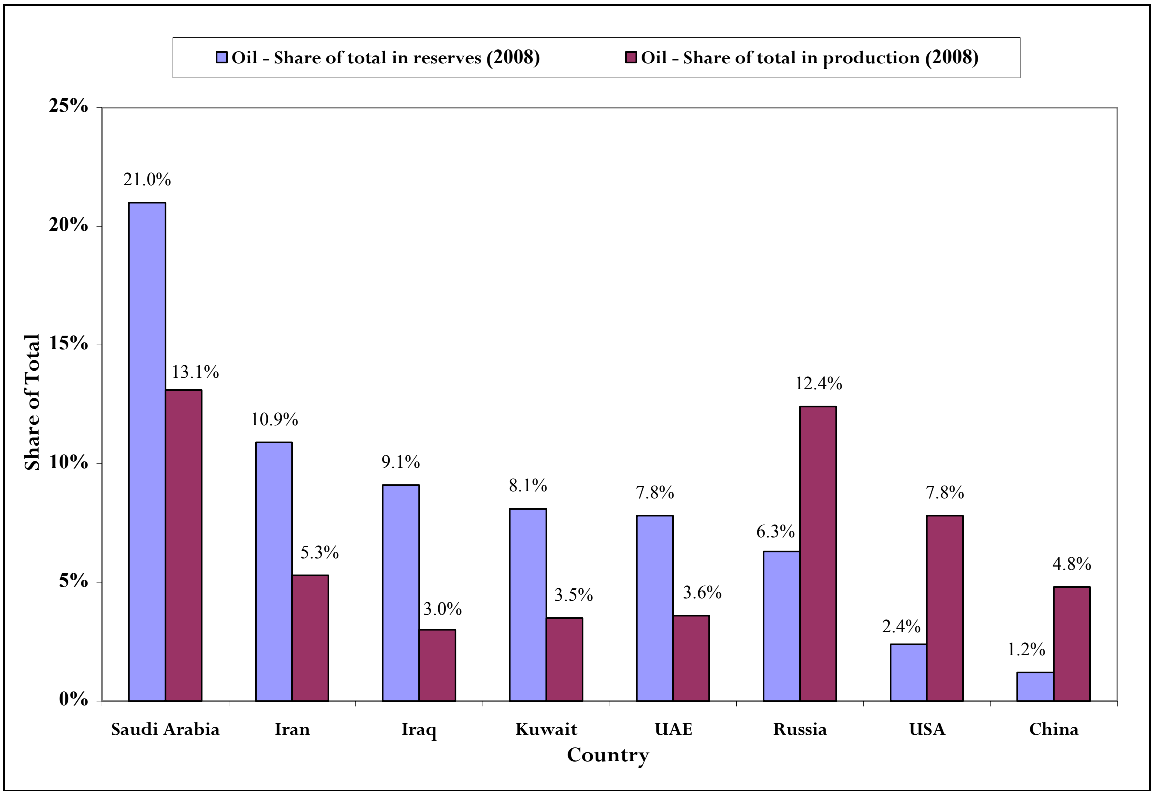

Figure 2.1: Distribution of Oil Reserves/Production in 2008 by Country - Percentage

Source: BP Statistical Review (2009)

According to the BP Statistical Review (2009), Iran possesses 16% of all the natural gas reserves in the world and ranks as the second biggest country (after Russia) amongst natural gas reserves countries. The figure for production is 3.8% of the natural gas market which ranks the country fourth in the world (BP Statistical Review 2009). Figure 2.2 compares natural gas reserves and production by country in 2008.

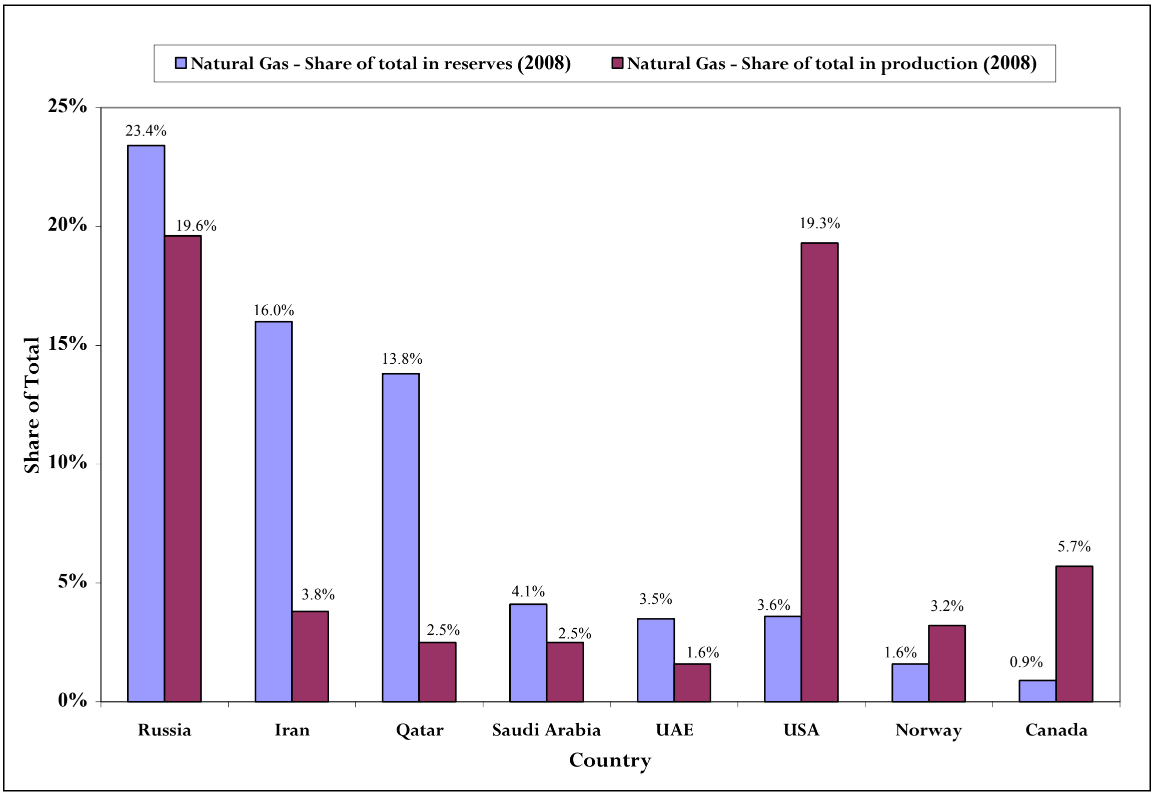

Figure 2.2: Distribution of Natural Gas Reserves/Production in 2008 by Country - Percentage

Source: BP Statistical Review (2009)

The above data represent Iran as one of the main sources of fossil fuel energy in the world, making the country a pivotal player in the global energy markets. In addition to fossil fuels, Iran is potentially rich in the sources of renewable energies. Iran has favourable natural conditions for making use of solar energy. According to MOE (2008), the average annual solar radiation in Iran is about 4 KWh per square meter and the average sunny hours reaches 2800 hours per year, which is about 7.7 hours per day. Furthermore, its vast land area makes Iran a suitable place to benefit from solar energy. Moreover, due to its geographical location, Iran has great potential to benefit from wind power. 26 regions (including 45 sites) in Iran have the potential to install wind turbine equipment that would enable the production of more than 6500 MW of power (SUNA 2007).

Despite the existence of potential in renewable energies, the share of these types of energies in satisfying national demands remains trivial, and Iran has not made a serious effort to build renewable energy infrastructure. This is because the country has plentiful oil and natural gas reserves and the net cost of produced energy is much lower than that from renewable energies. Although Iran is a leader amongst Persian Gulf countries in diversifying its energy mix by introducing renewable energies, according to Tavanir (2008), only 2.4% of total electricity in Iran in 2008 was generated from renewable energies, which number largely belongs to hydropower generation. However, in recent years, energy policy makers have emphasised the need to install renewable energy plants across the country to support the national distribution network and respond to growing domestic demands (MOE 2008).

In this light, over recent decades Iran has made serious efforts to install nuclear power plants. The national energy policy makers perceive the development of nuclear power plant technology as a strategic way of responding to the next decades' energy demands through low carbon energy technologies, particularly in the context of the depletion of oil and gas reserves. They argue that oil is a material that is too valuable to burn and should instead be employed to produce other valuable products. They believe that the money earned via oil exports should be invested in energy sectors to secure energy supply for future generations. In terms of renewable energies, they argue that these energy sources, such as wind and solar power, are able to satisfy only a very small share of the huge national demand (similar to the forecasts of OPEC's energy outlook 2009 and the IEA reference scenarios 2009). Thus, such energy sources are usually perceived as marginal in Iran's energy policy.

Along these line, the controversial nuclear power plant, Bushehr, was the first nuclear power plant in Iran, which was initiated as a contract between Iran and Germany in 1975. However, the construction process was withdrawn in 1979, at the time of the Islamic Revolution in Iran. The policy makers tried to resume construction, but when Iraq invaded Iran in 1981 the programme was stopped until the end of the war. In 1990, the energy policy makers begun to resume the construction of the nuclear power plant, but the tough political climate between Iran and the US overshadowed the programme and led Iran to look for other partners. In 1995, Iran and Russia signed a contract to complete the work.

However, the process was influenced by many international pressures, and this atmosphere incurred the extension of the process. The Bushehr nuclear power plant was finally inaugurated in August 2010.

Meanwhile, Iranian officials prioritised the indigenous supply of fuel for power plants, arguing that there was no trust in the United States and other Western countries to supply fuel to the national power plants. This argument was strengthened by the Eurodif[5] case.

This issue has been the subject of fierce debate within Iran's nuclear power plant programme, and has led to a controversial atmosphere with regard to Iran's diplomacy. In contrast, the Western countries and in particular the United States, which has taken the toughest stance against Iran, claim that Iran's nuclear programme is suspicious, due to Tehran's efforts to enrich uranium as the fuel for power plants. This conflict has resulted in a number of US-led sanctions against Iran, which have created negative consequences for Iranian companies in their collaboration with international actors. This issue will be discussed in Chapter 7.

The above background poses the following question: while Iran has plentiful natural reserves and envisions installing low carbon energies, what has been the trend of energy supply and energy mix in Iran over the last decades? Answering this question can offer different kinds of insights into this research. Figure 2.3 shows the total primary energy supply by fuel type in satisfying domestic energy demand between 1980 and 2007.

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[5] Eurodif (European Gaseous Diffusion Uranium Enrichment Consortium) is a subsidiary of the French company AREVA, which produces enriched uranium. It is a joint stock company and was formed by France, Belgium, Italy, Spain, and Iran in 1973. Iran owns a 10% stake, and is entitled to the plant's output. However, the political conflicts have caused enriched uranium not to be delivered to Iran by the French government. Iran points to this case as evidence of why the West cannot be trusted to provide credible fuel guarantees, and cites the Eurodif experience as the reason for wanting to achieve energy independence by developing all the elements of the nuclear fuel cycle itself (World Nuclear Association 2009).

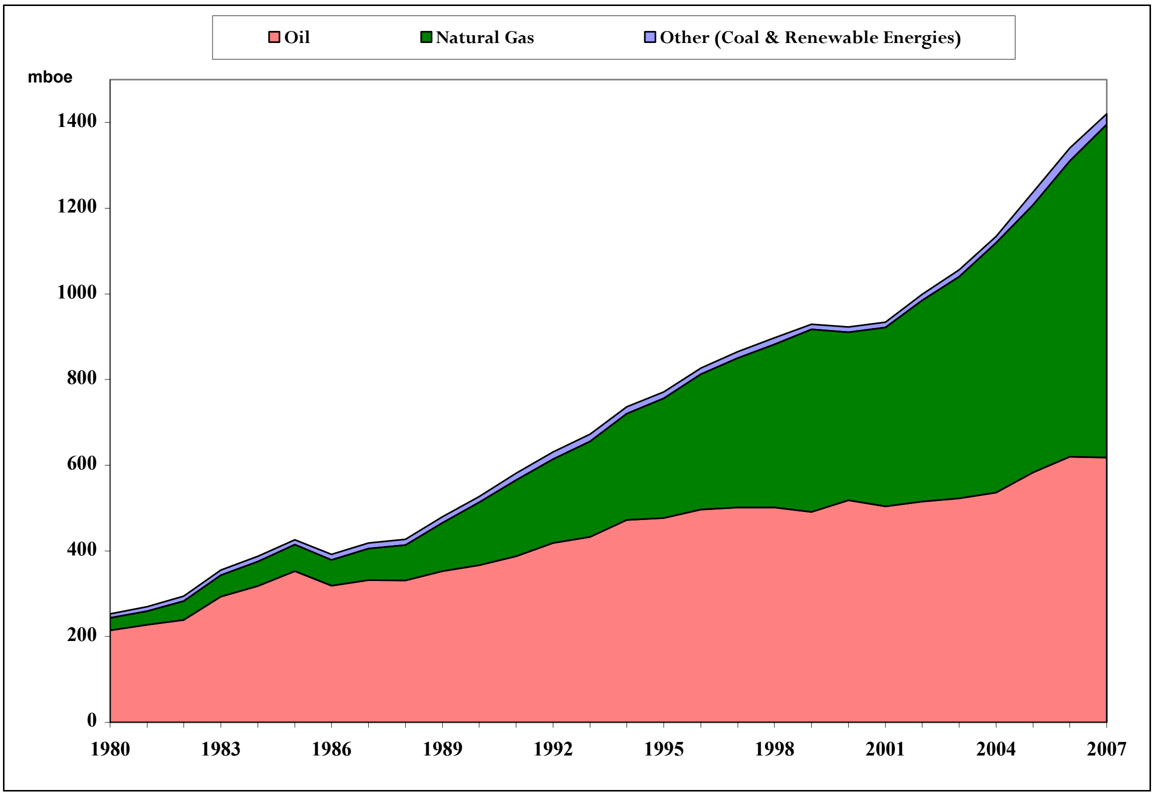

Figure 2.3: Total Primary Energy Supply (TEPS) in Iran

Source: Author's elaboration on Tavanir Data (2008)

This figure indicates a drastic increase in total energy premium supply over the last 30 years. This increase is particularly evident after the end of the Iran-Iraq war in 1988, when the country decided to renew and develop its energy infrastructure. There has been a huge gap between domestic energy supply and undeveloped infrastructure, and therefore Iran has made serious efforts to develop its infrastructure. Furthermore, the data show a steep increase in the share of natural gas in the total energy supply. The next section discusses why this is the case.

2.3 Fostering Natural Gas Utilisation: A National Policy

Iran's economy is highly dependent on oil production and export. According to the database of CBI[6] (2009), crude oil and its derivatives account for about 80% of Iran's total exports and about half of the government's revenues. However, Iran's economic outlook shows two emerging problem in the future. The first is the shortage of investment in the oil industry. This is obvious both in extraction and production of new oil fields and also in retrofitting the current production technologies in Iran's oil industry, which are slightly behind modern technologies. The second issue relates to growing domestic oil consumption. According to CBI (2009), vehicles consume more than a quarter of total domestic oil consumption in the form of petrol. The evidence suggests a further increase in the future. However, in spite of the existing oil refineries in Iran, there is still an under-capacity in domestic petrol refining, and a huge amount of petrol is therefore imported to fill domestic demands. Iran's petrol imports reached over 4 billion dollars in the fiscal year 21 March 2006 – 20 March 2007 (CBI 2009). After 2007, the parliament tried to mitigate petrol imports and thus the budget law, legislated by the Iranian parliament for the fiscal year 21 March 2007 – 20 March 2008 allowed the government to import only 2.5 billion dollars' worth of petrol. However, demand is still increasing, and the government is generally wrestling in vain with a rising rate of petrol imports each year. Today, Iran imports about 40% of its petrol to meet this growing demand.

The two issues outlined above threaten Iran's oil industry as well as its economy. In October 2009, Iran's Parliament Research Centre stated that Iran's oil industry needs investment of 4.5 billion dollars each year, otherwise based on the assumption of increasing internal consumption and lack of investment in the oil industry, it may need to start importing oil within a decade to fulfill all its domestic energy demands. These concerns have forced policy makers to find alternative solutions to respond to internal energy demands.

As discussed above, Iran also possesses plenty of natural gas reserves. This offers the possibility to develop natural gas as an alternative fuel for vehicles. This policy has

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[6] Central Bank of Iran

been followed as part of the national energy policy in Iran over the last decades for a number of reasons. Firstly, in comparison to petrol, Compressed Natural Gas (CNG) does not need the establishment of massive and capital-intensive refinery plants. The private sector is able to invest in the construction of CNG infrastructures and can supply the market. The government is also encouraging investors to build CNG stations across the country by granting long-term loans.

Secondly, CNG-based vehicles are an attractive economic consumer choice. According to Shamsavari and Majidpour (2008), for a typical vehicle in Iran, the cost of CNG is less than one-fifth of the cost of petrol. A typical vehicle in Iran, with its 90 km/h speed-limit on its highways, consumed 13.8 litres of petrol consumption over 200 km. Under the same conditions, only 12.3 kg of CNG would be consumed. The price of petrol in Iran in 2008 was $0.1 per litre, while the price of CNG was about $0.0215 per kg. Accordingly, the cost of fuel for over 20,000 km would be less than one-fifth the cost of petrol. This is one of the competitive advantages of the CNG-based engines in the domestic market. Table 2.1 compares the fuel costs for a typical vehicle in Iran. The prices are the subsidised prices ratified by the parliament and government. The importance of CNG-based engines in Iran is further clarified when we note the recent fuel rationing policy. The government began rationing fuel in July 2008, allowing each vehicle to consume only 100 litres of petrol per month using the subsidised prices. Further consumption requires petrol to be bought using unsubsidised prices, which are four to five time the subsidised ones. In Iran, the petrol price is a fixed price and does not vary with the fluctuation of global oil prices. Each fiscal year the government examines its budget and expenses and accordingly ratifies the price of petrol. However, the subsidised prices lead to some economic hardships for the government. In 2006, more than a quarter of the government subsidies in the energy sector went to petrol consumed by vehicles. Hence, the state strongly supports, both in moral and financial terms, any projects[7] in the automotive industry that will remove these high subsidies and corresponding budget deficiencies.

[7] Iranian National Engine Project was the main CNG-based engine development project in Iran. The case was published in Shamsavari and Majidpour (2008).

Table 2.1: Comparison of Petrol and CNG Costs in Iran as Alternative Fuels for Vehicles (2008)

Fuel Type	Price	Fuel consumption in 200 km	Cost of 200 km traversal	Cost of 20,000 km traversal
Petrol	0.1 $ per litre	13.8 litre	1.38 $	1380 $
CNG	0.0215 $ per Kg CNG	12.3 Kg	0.2625 $	262.5 $

Source: Shamsavari and Majidpour (2008)

This economic factor is not the only policy driver in the development of CNG-based vehicles in Iran. Vehicles are the main source of air pollution in Tehran and hence Iran's Department of Environment has been trying to regulate the rules to mitigate air pollution as much as possible. As one of the primary organisations in Iran, the Department oversees the domestic automotive industry and has set up many programmes to improve the quality of life, which is an urgent issue in Tehran. In these circumstances, the Department has been encouraging local automotive companies to develop vehicle engines that use alternative fuels which are cleaner than petrol. Since it is easy to reach these environmental standards through the use of CNG-based engines, the Department is encouraging those companies who plan the production of CNG-based engines.

Fostering the use of natural gas in the automotive industry has become an important policy in Iran. In 2010, the European Natural Gas Vehicle Association stated that as of late 2009, there were 1,734,400 gas-fuelled vehicles in Iran, accounting for about 15% of all gas-fuelled vehicles in the world, and ranking Iran third in the world for the use of such vehicles. As with the automotive industry, natural gas has become the focal point in the power generation industry. According to Tavanir (2008), natural gas accounted for more than 75% of the total fuel share for domestic power plants in 2008. The details of Iran's power plant sector will be discussed in the following sections. Figure 2.4 demonstrates the trend of natural gas consumption by sector in Iran over the last 30 years. It should be noted that Figure 2.4 does not show power as a use of natural gas. It only demonstrates the rapid growth of natural gas consumption (as a priority in Iran's energy mix) during the last three decades in non-power uses.

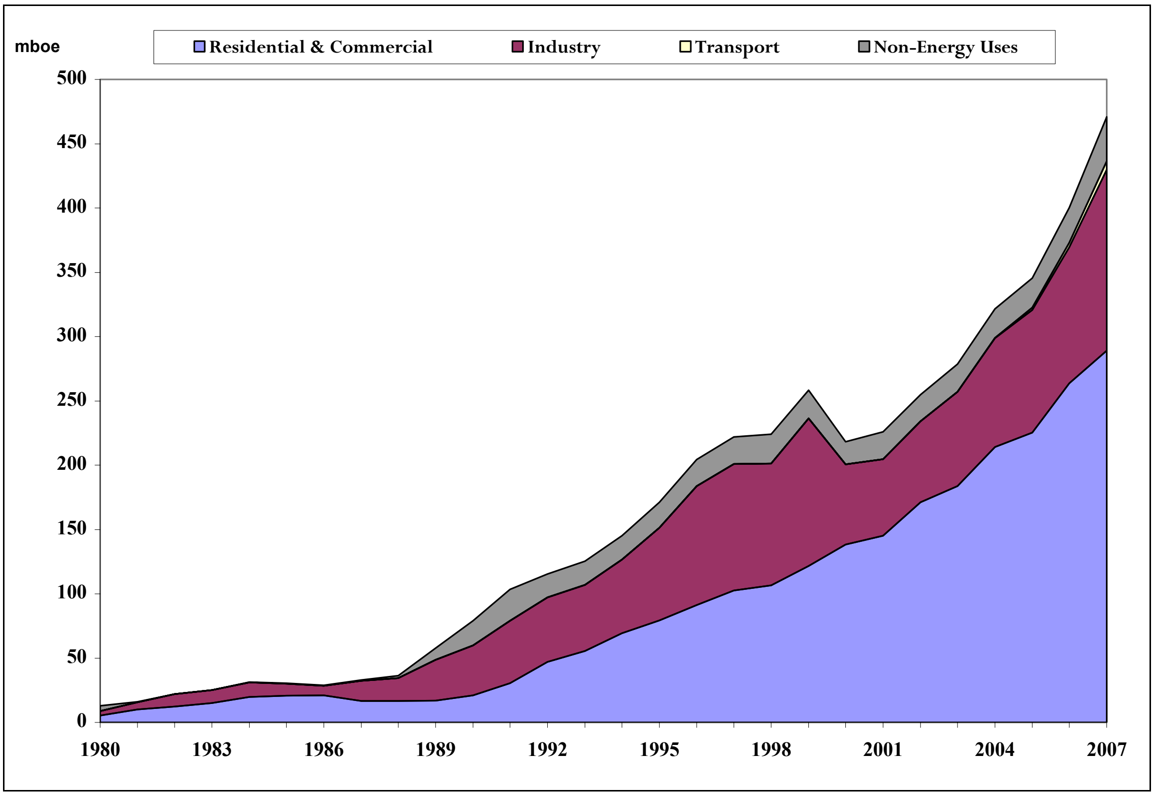

Figure 2.4: Natural Gas Consumption in Iran by Sector

Source: Author's elaboration on Tavanir data (2008)

Natural gas has recently become important in Iran's export industry. As a gas-surplus country, Iran seeks outward-oriented policies to consolidate its position in the international market. Iran has been a participant in the Nabucco[8] gas pipeline project with the aim of transporting natural gas to European countries, as well as the IPI[9] project to transport natural gas to the Indian subcontinent. In October 2008, Iran, Russia and Qatar,

[8] The Nabucco gas pipeline, which is still unresolved, calls for a 2050-mile pipeline connecting Iran and other Caspian states with Austria and the EU through Turkey. Construction is slated to start in 2010, and the entire project will cost an estimated $12.2 billion with the capacity to transport 3Bcf/d (EIA 2010).

[9] A controversial pipeline proposal is the $7.5-billion Iran-Pakistan-India (IPI) line which would transport Iranian natural gas south to the Indian subcontinent. With a proposed length of 1724 miles and a 5.4 Bcf/d capacity, the pipeline has been stalled in the past due in part to disputes over the cost of the shipments. Iran and Pakistan have finalised gas sale and purchase agreements, but without India's participation in the negotiations. (EIA 2010). On 16 March 2010, Iran and Pakistan signed the agreement in Turkey. The construction time has been estimated as five years and after completion Iran will export 21.5 million cubic meters of natural gas per day to Pakistan for a 25-year period. India has hesitated to sign an agreement in which India's energy supply depends on Pakistan, and hence has withdrawn from this agreement.

three of the world's major natural gas owners, agreed to form an OPEC-style organisation for gas-exporting countries (The Wall Street Journal 2008[10]) and consequently eleven countries[11] signed an agreement in Moscow creating the gas exporting countries forum (GECF) and confirming its statute (IEA Natural Gas Market Review 2009). Iran will also be able to "become Europe's most important source of energy as, in addition to its own oil and gas, it is the shortest and most economical transit link between the oil rich Caspian Sea region and Europe" (Tarock 1999, p. 42).

2.4 Iran's Power Generation Industry

According to historical documents, the first electricity generation unit was imported to Iran in 1885 to supply the light for the imperial palace. The first grant for power plant construction in Iran was issued in 1902 in Tabriz.[12] This is the first historical document in Iran in which the instructions for power plant construction as well as electricity price calculations were explained in detail. Subsequently another power plant with a capacity of 400 KW was established in 1906 in Tehran. However, the industry was not organised until 1963, when the Ministry of Water and Electricity, today named the Ministry of Energy, was established (Abbasi and Safavi 2006). Over the past decades, Iran has had a drastically increasing trend of power plant production, as in 2006 the real capacity of power plants was more than 48 times that of 1967. Figure 2.5 shows the trend of electricity generation in Iran between the years 1980 and 2008. It should be noted that the amount of electricity generation increased little during Iran-Iraq war (1980-1988), while the numbers increased considerably in the post-war era.

[10] Available at: http://online.wsj.com/article/SB122460817038154673.html

[11] Algeria, Bolivia, Egypt, Equatorial Guinea, Iran, Libya, Nigeria, Qatar, Russia, Trinidad & Tobago and Venezuela.

[12] One of the large industrial cities in the north-west of Iran.

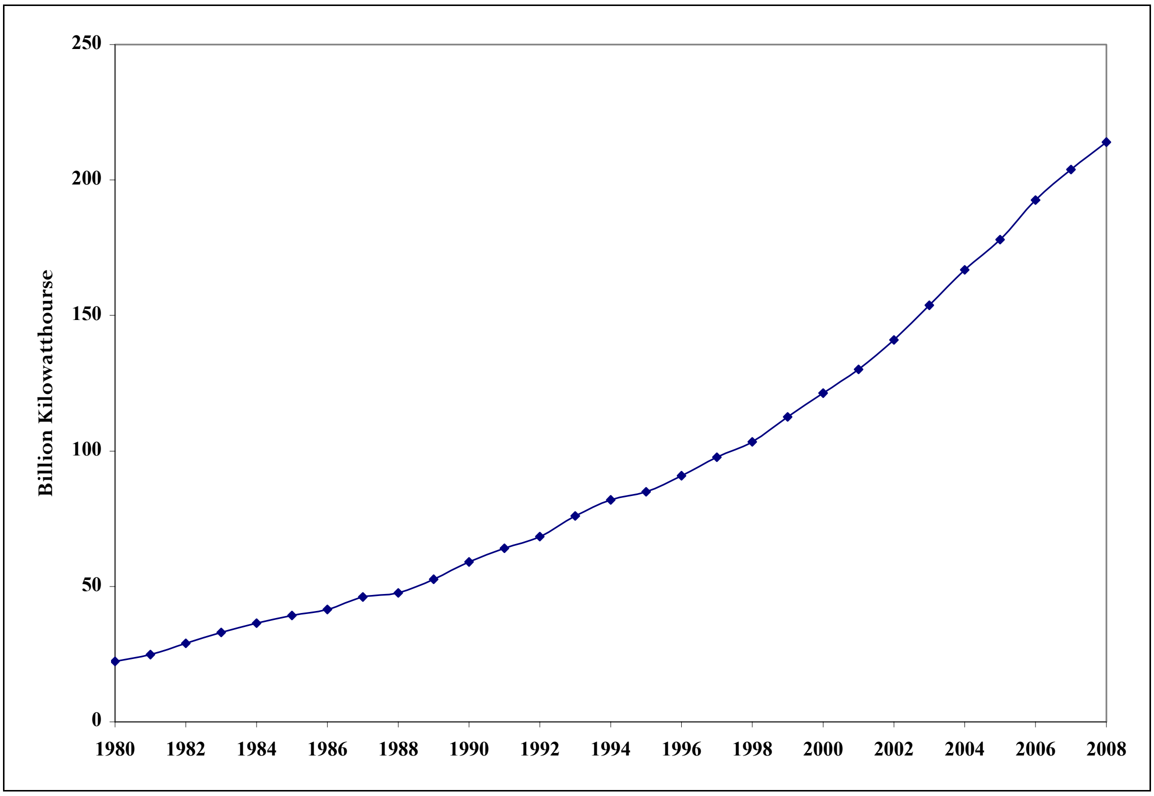

Figure 2.5: Electricity Net Generation in Iran between the years 1980 and 2008

Source: Author's elaboration on Tavanir data (2008)

The nominal installed capacity of electricity generation in Iran reached over 45138 MW in 2006, showing a growth of 10% compared to 2005 (MOE 2008). The figures were 49184 MW and 52944 MW in 2007 and 2008 respectively (Tavanir 2008). The statistics confirm the development of national power generation capacity in Iran's energy sector to meet increasing domestic demands. The residential, public and commercial, transport and agriculture sectors and also public illumination are the primary final consumers of electricity. Figure 2.6 demonstrates the share of different electricity consumers in total generated power in 2006, based on data from Iran's Ministry of Energy.

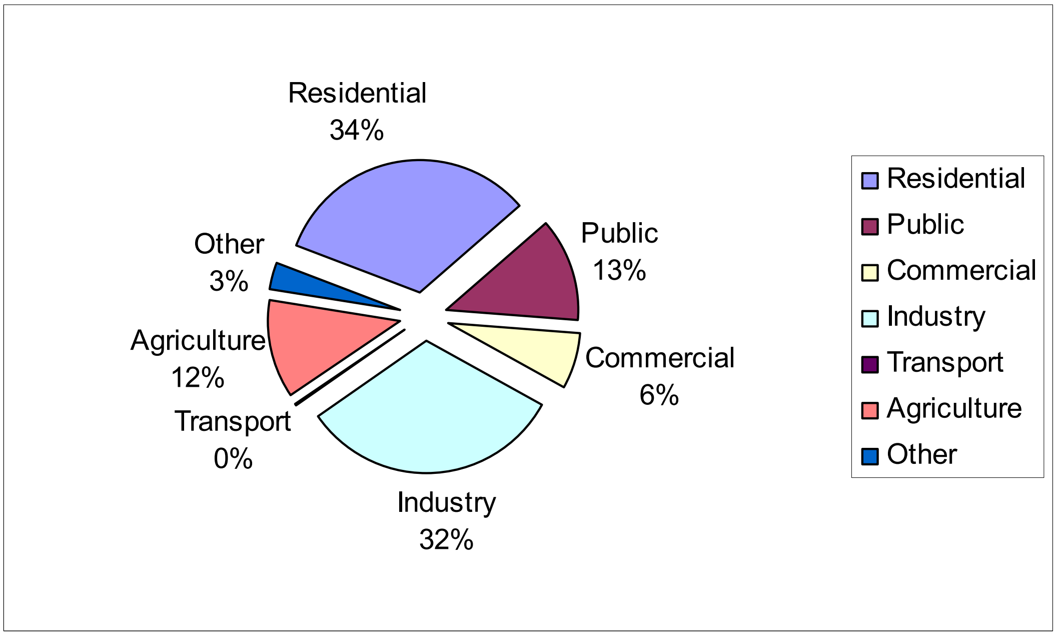

Figure 2.6: Share of Electricity Consumers in Iran (2006)

Source: Author's elaboration on the database of the MOE (2008)

Electricity exchange with neighbouring countries has also been undertaken to reduce peak hours during summer and balance electricity production during winter. Iran is now connected to all its neighbouring countries at the level of transmission voltage. Iran exchanges electricity with Turkey, Armenia, Turkmenistan, Pakistan, Iraq, Azerbaijan and Afghanistan (MOE 2008). In 2006, Iran exported 2775 GWh and imported 2540 GWh, and consequently the country's net export of electricity is about 235 GWh (MOE 2008). The data for 2008 were 3875 GWh for export and 1684 GWh for import (Tavanir 2008).

2.4.1 National Power Plants: Statistics and Combination

In 2008, the nominal capacity of Iran's power plants was 52944 MW, which shows an increase of 7.1% compared to the previous year (Tavanir 2008). The power plants comprised a range of gas, steam, combined cycle, hydropower, diesel and wind sites across the country. Gas-fired power plants with 34.1% of the total share of electricity production, steam power plants with 29.5%, and combined cycle power plants with 21% comprise the significant share of the national electricity supply network. Thus, thermal power plants comprise a high proportion, more than 84%, of national power plants. Figure 2.7 demonstrates the share of different types of power plants in the total nominal national power. Considering the energy policies in Iran, the share of gas and hydro power plants has been increasing over recent years (MOE 2008), and this policy will also continue in the future (Tavanir 2008). Furthermore, there have been a number of projects toward the installation of steam units next to gas-fired power plants, upgrading them into combined cycle power plants. This has been mainly to achieve higher efficiency and productivity as well as less consumption of fossil fuel type power plants.

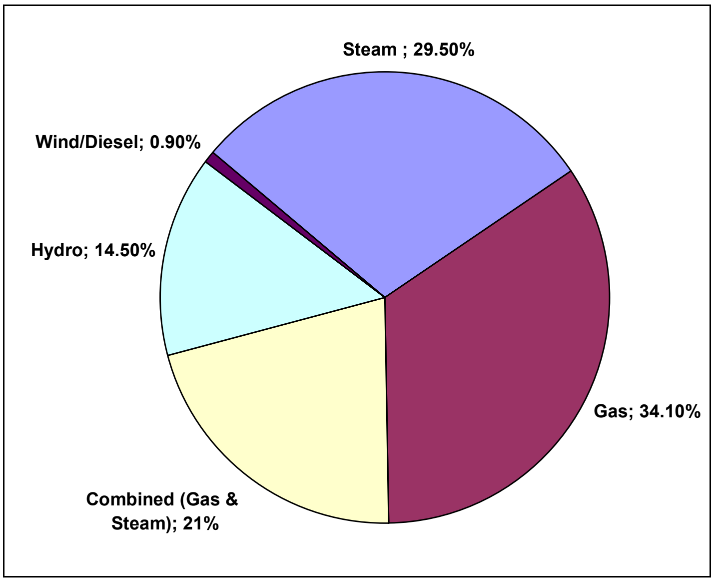

Figure 2.7: Iran Power Plant Combination in 2008

Source: Author's elaboration on Tavanir data (2008)

Accordingly, Figure 2.8 shows the combination of national power plants by fuel type.

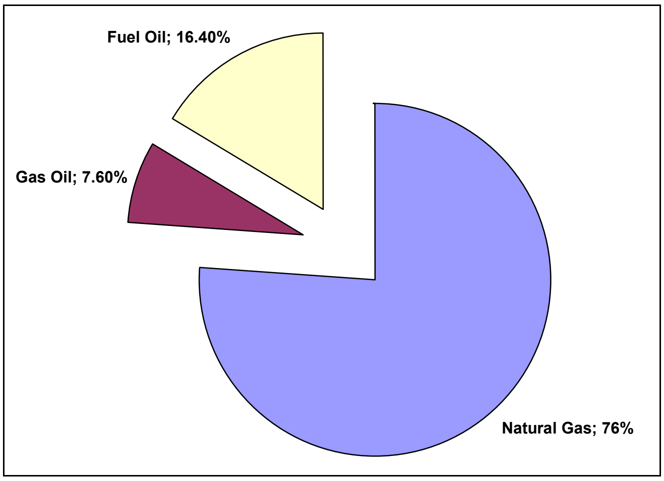

Figure 2.8: Share of Fuel in Iran's Power Plants (2008)

Source: Author's elaboration on Tavanir data (2008)

Figure 2.8 illustrates that fossil fuels, such as natural gas, heavy fuel oil and gas oil, are the major fuels used for electricity generation in Iran's thermal power plants. The type of fuel depends on many economic and technical factors. According to MOE 2008, power plants' fuels are selected based on the cost of fuels, the geographical location of the power plants, the availability of the fuels, environmental concerns and the medium- and long-term policies of the energy sector. Construction of new gas-fired and combined cycle power plants, and equipping existing fossil fuel power plants with dual fuel capabilities are part of the energy policies of the country.

2.4.2 Why Gas-fired Power Plants?

Iranian energy policy makers seek to increase national installed capacity by roughly 10% annually, in line with the projected 7% to 9% annual growth in domestic demand (EIA 2010). To meet future consumption needs, policy makers are seeking methods to respond at the earliest time and with a limited budget. The Combined Cycle Gas Turbine (CCGT) is a favoured choice. Each CCGT unit is typically comprised of two gas turbines and one steam turbine. The capital investment for CCGTs is very cheap to buy compared to most other electricity generating options (Watson 2004*a*; Islas 1997). This is a particularly important factor in Iran where the energy market is being privatised. Both state-owned companies and the private sector can invest in building and developing power plants. Low operating and maintenance costs contribute towards the advantages of CCGTs (Islas 1997). Furthermore, CCGT construction has a short manufacturing time (Islas 1997). "New plants can be completed in under 2 years rather than the 4-10 years that characterize other large scale technologies. For many private power companies, this further accelerates the repayment of bank loans since their only source of revenue is the sale of electricity" (Watson 2004*a*, p. 1068).

Gas-fired power plants also have environmental advantages. A typical CCGT emits around 65% less carbon dioxide than a traditional coal-fired power plant for each unit of electricity generated, almost no sulphur dioxide and relatively small quantities of oxides of nitrogen (PowerGen 2000).

Due to their small visual impact, gas-fired power plants can be sited nearer to population centres compared with large coal or nuclear plants (Watson 2004*a*). This is particularly the case in Iran where the majority of electricity consumption is in the metropolitan area of Tehran and a number of big cities in the central provinces.

High efficiency is another advantage of CCGTs in comparison with other fossil fuel power plants. The criterion for efficiency evaluation in CCGTs is defined by 'thermal efficiency'. Thermal efficiency is the amount of heat energy in fuel converted into electricity energy. According to Tavanir (2008), in 2008 in Iran, the average thermal efficiency for each of the steam power plants, gas turbines, diesel and combined cycle power plants was approximately 36.3%, 28.9%, 34.4% and 44.5% respectively. As these data show, the thermal efficiency of CCGTs is higher than that of other types of power plants. Meanwhile, the maximum thermal efficiency for CCGTs in Iran was 47.5% and the minimum was 42.1% (Tavanir 2008). The efficiency of CCGTs in Iran fits with the global average (45%), as it has become the standard option for new gas-fired power plants (Watson 2004*a*). For instance, the average thermal efficiency of the UK's CCGTs was around 46% between 2000 and 2004, though after 2004 year newer, more efficient and advanced CGGTs were installed. Figure 2.9 shows the thermal efficiency of the UK's CCGT power plants between 2001 and 2008.

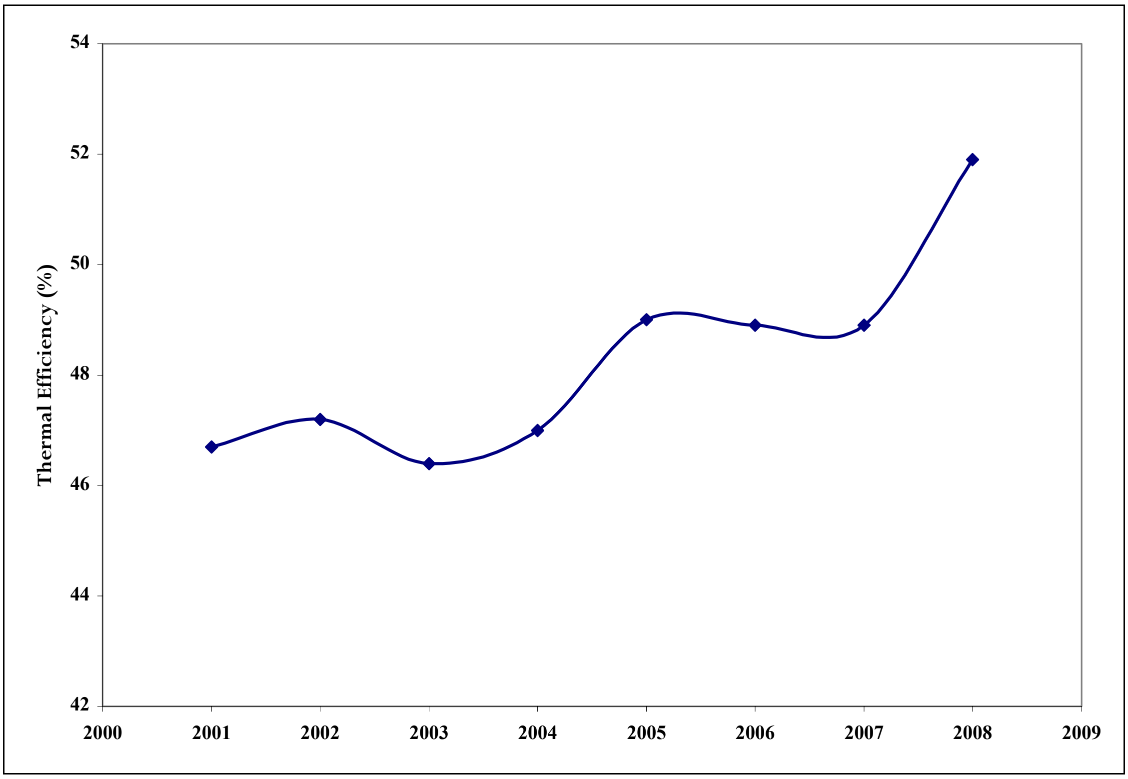

Figure 2.9: The Average Thermal Efficiency of CCGT Stations in the UK

Source: Author's elaboration on the Digest of UK Energy Statistics (DUKES), Department of Energy and Climate Change (2009)

Note: It should be noted that these numbers are based on lower heating values (LHV), not higher heating values (HHV). The difference between LHV and HHV is that the latter takes into account the latent heat of vaporisation of water and hence is slightly lower than LHV

Two points emerge from the above figure. Firstly, the average efficiency of Iran's CCGT power plants in 2008 was 44.5%, which is comparable with the UK's rate before 2004. Secondly, the figure demonstrates a considerable increase after 2004. This is mainly due to the installation of advanced and efficient CCGT power plants in the recent years in the UK. The new type of GE CCGT, namely the H System, in which a gas turbine works in conjunction with a heat recovery steam generator, installed at Baglan Bay on the south coast of Wales, has recently reached a record of just under 60% thermal efficiency (see Section 5.3.5). Similarly, Siemens is constructing a CCGT power plant in the Netherlands with a thermal efficiency rate of 59%.[13] These numbers demonstrate the technological gap between Iran's CCGT power pants and the global level in recent years.

The advantages discussed above make gas-fired power plants (particularly CCGTs) a favourable option and a priority in Iran's energy policy. The trend and its rationale have a good fit with the global CCGT boom (Watson 2004*a*; Islas 1997). Today, gas and electricity markets all over the world have become increasingly interconnected. The power sector has been the main driver for incremental gas demand in the OECD in recent years, and it is expected to remain so well into the coming decade (IEA Natural gas market review 2009). In the OECD countries, gas-fired power has grown rapidly as it has provided four-fifths of incremental power since 2000 and is now the second[14] most important source of power, accounting for more than three-quarters of new electricity demand (IEA Natural gas market review 2009).

The development of gas-fired power plants is now being seriously fostered in Iran. Figure 2.10 demonstrates the gross additions to capacity in Iran in 2008. The figure shows that, 75% of additions in 2008 were of simple cycle gas turbines and 18% of additions were of CCGTs. Thus, Figures 2.7, 2.8 and 2.10 clearly show the dominant position of gas-fired power plants in Iran. Similarly, according to Tavanir's 2013 outlook plan, gas-fired power plants form the dominant part of newly established thermal power plants in Iran.

[13] Siemens Press News, available at: http://www.energy.siemens.com/hq/pool/hq/energy-topics/living-energy/downloads/short_news.pdf

[14] Natural gas now accounts for 20% of global electricity production, second to coal at 41% (IEA Natural gas market review 2009, P. 109).

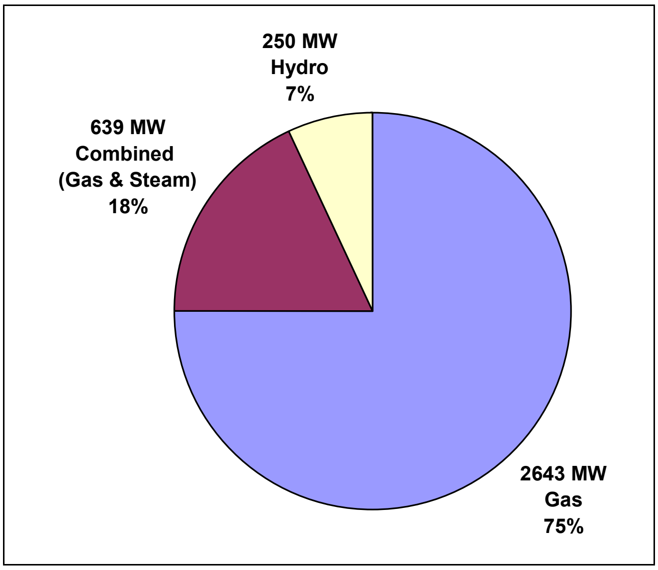

Figure 2.8: Value and Share of Operation of Newly Established Power Plants in Iran in 2008

Source: Author's elaboration on Tavanir data

2.4.3 Privatisation in the Power Generation Industry: An Ongoing Policy

Over the last three years, Iranian state officials decided to rescind Article 44 of the Constitution. According to this article "…The public sector includes all large-scale industries, mother industries, foreign trade, large mines, banking, insurance, power supply, dams and large irrigation channels, radio and television, post, telegraph and telephone, aviation, shipping, roads, rails and the like, which are public property and at the disposal of the Government …". In 2005, politicians started to change this Article and add or improve new laws facilitating privatization. The new legislation enables all major industrial, manufacturing and service sectors, except the National Iranian Oil Company and companies involved in the extraction and production of oil and gas, to be ceded to the private sector. According to IPO[15] (2010), the main objectives of privatisation are as follows:

- Accelerated growth of the national economy
- Promotion of broad-based public ownership to achieve greater social justice
- Enhancing the efficiency of economic enterprises and productivity of human and material resources and technology
- Enhancing the competitive capability of the national economy
- Reducing the financial and administrative burden on the government, which has been encumbered as a result of its controlling role in economic activities
- Increasing the general level of employment

Iran's Ministry of Energy has supervised numerous state-owned power plants and companies. Legislating Principle 44 paved the road to the privatisation of the industry. It also helps industry managers to overcome the financial challenges of the electricity industry by motivating private sector contribution and partnership. As the first measure, Zargan power plant, which has a capacity of 500 MW, as well as the construction of 20000 MW power plants, has been transferred to the private sector (MOE 2008). Along these lines, eight other thermal power plants and two wind power plants are engaged to be ceded to the private sector (MOE 2008). However, despite legal facilitation and national determination, the majority of power plants and equipment suppliers are still ruled and managed by the state. This thesis, however, is not about privatisation in Iran's power plant industry, which is an ongoing process.

[15] The Iranian Privatisation Organisation (IPO) is a governmental company affiliated to the Ministry of Economic Affairs and Finance, being a legal entity with financial independence. The director of its executive board and its managing director is the Deputy Minister of Economic Affairs and Finance.

2.4.4 Actors in Iran's Gas Turbine Industry

The Ministry of Energy in Iran is a multi-dimensional organisation, as it is responsible for administrating a number of large industries. The water industry, electricity industry, waste industry, and renewable energies industry are all supervised by the Ministry of Energy. This multi-dimensionality results in a particular complexity in the structure of administration and organisation. For instance, all subsidiaries that provide water, electricity and waste services are governed in a corporate form rather than by a bureau or organisation. Subsidiaries across provinces in the country have the authority to manage local issues. Consequently, decentralisation distinguishes the Ministry of Energy from other government ministries.

The aim of this section is to create a picture of how different organisations relate to one another in Iran's gas turbine industry. However, the aim is not to map all the actors involved in the industry, but to show the significant actors in the industry that are engaged in technology development processes in terms of institutions, procedures, and technologies. In the other words, the approach is to show the different actors focusing on technology and knowledge flows among them, which matches the scope and objective of this thesis. Below is an outline of the main actors in Iran's gas turbine industry, as discovered during the fieldwork of this thesis.

Tavanir

This organisation is responsible for management of generation, transmission and distribution of electricity in Iran. The main objective of Tavanir is to foster the supervisory activities of the government in the field of operation and development of the Electric Power Industry of the country, within the scope of policies issued by the Ministry of Energy. The specialised holding company of Tavanir is comprised of 16 regional electric companies, 42 distribution companies, 27 generation management companies and other subsidiaries, including the Organisation for Development of Electric Power, Iran's power plant project management company (MAPNA), the Iran Organisation for New Energies (SUNA), and the Iran Power Plant Repairs Company. Meanwhile, the development of thermal power plants in the national integrated network is the duty of MAPNA Company, and will be carried out through (local or foreign) contractors. The Tavanir database shows that in 2008, 90% of total electricity was generated by power plants belonging to the Ministry of Energy, 7.2% by private power plants, and 2.8% by main industries.

Niroo Research Institute

Established in 1997, as the major research organisation affiliated to the Ministry of Energy, the Niroo Research Institute has been playing a key role in developing new technologies for the electric power industry. On one hand, the organisation carries out research activities into specific fields of the power generation industry, which are specified and funded by the Ministry of Energy. On the other hand, the organisation collaborates with domestic universities and public research institutes to foster applied research in the required area of science and technology. Thus, the organisation has an intermediary role between universities and industry.

SABA Power and Water Industries Investment Company

This company was established in 1992 as private joint stock company, and was transformed into a public joint stock company in 2004. The core activity of this company is to provide financial resources, as direct or joint investments, in the field of the power and water industries. In compliance with the general policies of the Constitution’s principle No. 44, SABA is preparing to cede some of its subsidiaries to the private sector.

MAPNA Group (Iran Power Plant Project Management Company)

MAPNA Group, founded in 1992, is comprised of a parent enterprise and 29 subsidiaries. MAPNA is the main source of technology development in Iran's power generation equipment industry, and its subsidiaries manufacture gas and steam turbines and their ancillary equipment, turbo-compressors, turbine blades and vanes, power generators, heat recovery steam generators and conventional boilers, power plant electrical and control systems. Recently, the company diversified the business into the areas of oil and gas, the petrochemical industry, and manufacturing cargo and passenger locomotives and implementing railway transportation. To date, it has been supervised by the state. However, the privatisation of the company is on the industry agenda. At the first stage about 25% of the company's total assets were divested to the Stockbroker Company of Justice Shares.[16] Figure 2.11 demonstrates MAPNA's shareholders. It is evident from this that MAPNA Group, albeit indirectly, is still a state-owned company.[17]

[16] In 2006, the government decided to divest a partial share of state-owned companies to the public on the basis of the Justice Shares Distribution Scheme. Individuals included in the two lowest decimal groupings of income classification are the subjects of the scheme (IPO 2010).

[17] In spite of this, MAPNA is recognised as private company in Iran because it is managed as a business rather than as a state-owned bureau. MAPNA has its own internal institutions. The only direct influence of the Ministry of Energy on MAPNA is to change its board and managing director.

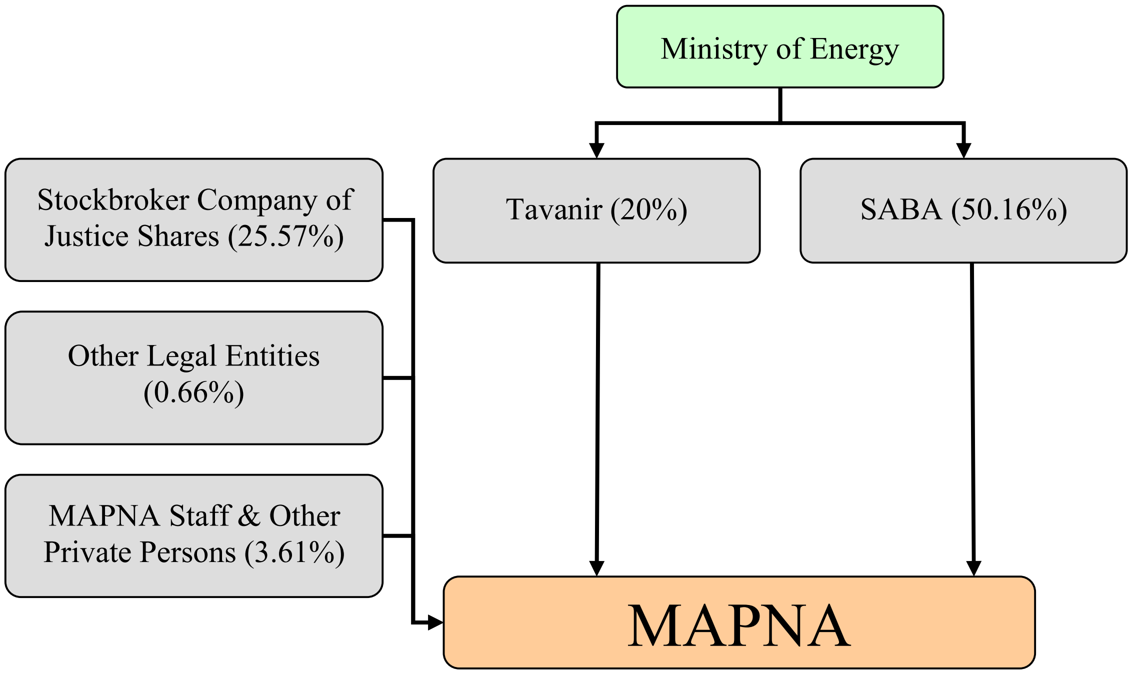

Figure 2.9: MAPNA Shareholders

Source: Author's Elaboration on MAPNA Database

As the core area of thesis, further data and analysis about MAPNA Group will be provided in subsequent chapters. MAPNA has three subsidiaries that are primarily involved in Iran's gas turbine industry, namely TUGA, PARTO and MECO.

TUGA (MAPNA Turbine Engineering and Manufacturing Co.)

This company was established in 1999 as a MAPNA subsidiary to focus on design and manufacturing of gas and steam turbines as well as other auxiliaries. Through technology transfer contracts, TUGA is now able to produce specific models of gas and steam turbines under the license of well-known global companies.

MECO (MAPNA Electric and Control Engineering and Manufacturing)

This company was founded in 2004 as a MAPNA subsidiary to focus on design and manufacturing of electric and control technologies of power plants. The company has tried to acquire technology through contracts from well-known foreign suppliers and is now manufacturing a number of types of equipment under license schemes.

PARTO (MAPNA Turbine Blade Engineering and Manufacturing Company)

This company was founded in 2004 as a MAPNA subsidiary with the aim of mass production of heavy duty industrial gas turbine blades and vanes for industrial and power generation applications. The main shareholders of PARTO are MAPNA and TUGA. PARTO has been able to produce the required blades and vanes through license agreements, reverse engineering and re-engineering.

MAPNA and the subsidiaries described above are the focal centre of Iran's gas turbine industry.[18] This thesis will analyse these companies in detail in the following chapters. This research will provide a deep understanding of technological acquisition processes as well as the evolution of the industry.

Figure 2.12 is a map of the main actors in Iran's gas turbine industry. It is worth noting that the figure includes any organisation which exists in the development of Iran's gas turbine industry, and the weakness or strength of the relationships cannot be elicited from the figure. However, the dashed arrows related to national universities which are outside the control and management of the Ministry of Energy, as will be explained in the case study chapters.

[18] Gas turbines are only applicable to the power plant industry, and neither MAPNA nor its subsidiaries are allowed to work on military-based technologies.

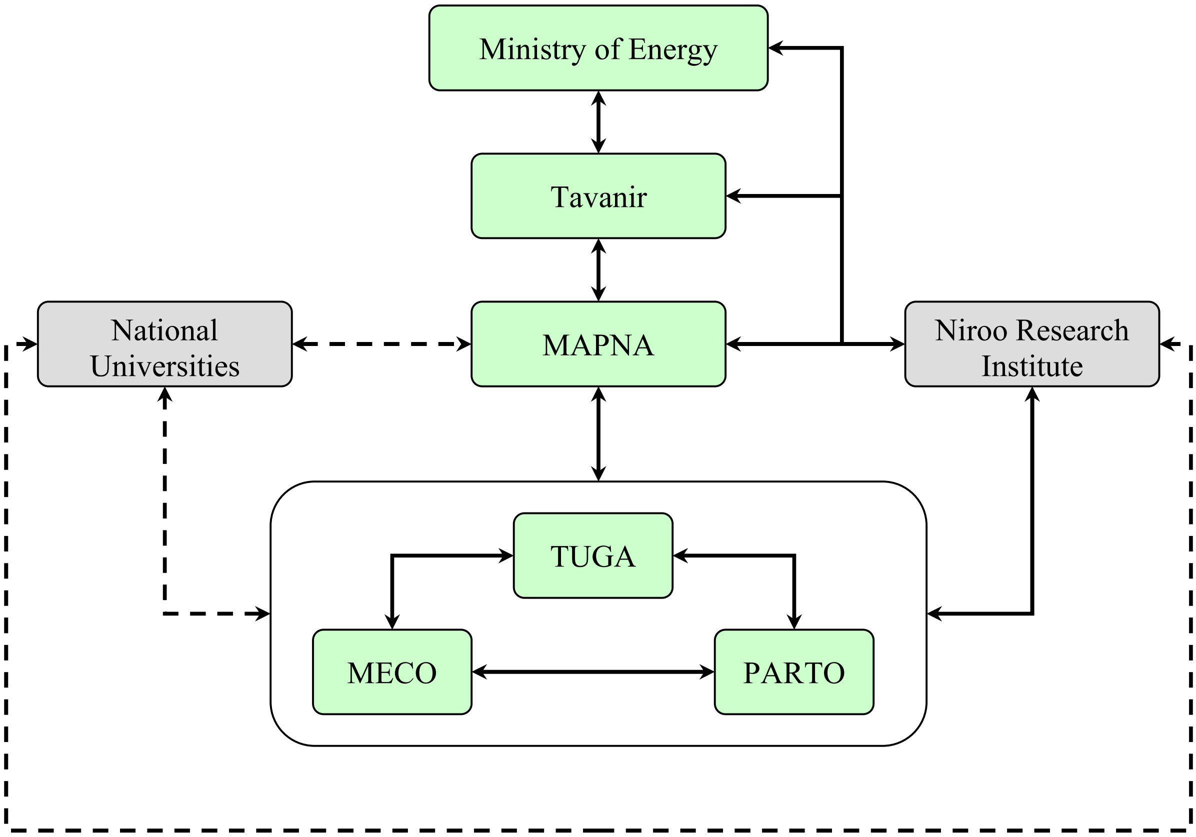

Figure 2.10: Actors in Iran's Gas Turbine Industry – Knowledge Flow Approach

Source: Author's elaboration

2.5 Conclusions

This chapter has clarified the research context. It has shown that Iran is a rich country in terms of oil and gas reserves. Likewise, it has great potential for the utilisation of wind and solar energies. However, national energy statistics in Iran show that natural gas is favoured over other fossil fuels, particularly in the electricity sector. This chapter has clarified why this is the case.

Iran's electricity demand is growing quickly and thus energy policy makers have tried to meet national demands by the development of gas-fired power plants and changing the traditional steam-based power plants into CCGTs. The rationale of this trend fits closely with the global paradigm shift in which CCGTs have become preferred due to their lower emissions than other fossil fuel technologies, the flexibility of their technology, their higher efficiency, the short duration of their construction, and their lower demands for capital investment. However, one of the influential factors in the Iranian context has been the existence of huge domestic natural gas reserves, which justify the trend in terms of accessibility as well as economics. The shortage of national oil refineries and the dependency of the national economy on oil exports add to those considerations. Due to these advantages, energy policy makers in Iran have tried to convert steam power plants into CCGTs in order to increase their capacity as well as their efficiency. Meanwhile, gas turbines, as the main component of CCGTs, play a crucial role in these developments. Thus, the development of gas-fired power plants in Iran has become increasingly interconnected with the gas turbine industry.

This chapter has also discussed the actors and governance of Iran's gas turbine industry. MAPNA and its subsidiaries are the main actors in Iran's gas turbine industry. MAPNA was established as a state-owned company and has had interesting challenges in acquiring technological knowledge. There have also been a number of internal and external factors influencing the company's efforts. This thesis mostly focuses on MAPNA and its subsidiaries, and their evolution. In the following chapters, the evolution of the industry and its technological acquisition processes will be analysed in detail.

Chapter 3 : The Theoretical Framework

3.1 Introduction

The purpose of this chapter is to establish a theoretical framework for the case study chapters. The thesis builds upon literature on technological catch-up and, in particular, on the studies of the substitutive/complementary relationship between indigenous technology development and overseas technology transfer. The chapter has two main objectives. Firstly, the chapter will review different perspectives as well as different dimensions of the technological catch-up. It will also review the overlapping concepts of the technological catch-up concept in order to provide a deep understanding about the substitution/complementarity discussions.

Secondly, the chapter will explain the framework through which this thesis intends to contribute to the literature. It includes a critical review of the existing studies, identifying the gaps, and introducing the new perspective.

This chapter is composed of four sections. Section 2 reviews the basic concepts of the framework within which substitution/complementarity literature has emerged. It explains that the technological catch-up literature on one hand emphasises the crucial role of indigenous technology development efforts. In this light, the literature on national and sectoral innovation systems has increasingly contributed to explain the indigenous aspects of successful technological catch-up cases. On the other hand, the chapter shows that in all successful catch-up cases, foreign knowledge flows have had a significant role. Along these lines, this chapter will explain how international technology transfer literature contributes to interpreting the issues of transferring technology from abroad.

Section 3 reviews the literature of substitution and complementarity, which focuses on the relationship as well as the interaction processes between the two main sources of knowledge, namely indigenous technology development and international technology transfer. It discusses how these two sources interact with each other, and also explains which factors influence their interaction processes. This section introduces the ‘dynamic approach’ as a new perspective to contribute to the existing literature.

Section 4 draws conclusions by investigating the shortcomings of the literature reviewed by this thesis.

3.2 The Basic Arising Concepts

This section reviews the three basic concepts of the basis of the framework within which the literature on substitution/complementarity has emerged. At the outset, it must be recognised that this approach does not reflect every conceivable way of approaching the literature. However, it allows an understanding of the different dimensions of the substitution/complementarity literature.

3.2.1 Technological Catch-up

"Catch-up relates to the ability of a single country to narrow the gap in productivity and income vis-à-vis a leader country" (Fagerberg and Godinho, 2005, p 514). Discussions of the means of technological catch-up typically focus on the role of technology and innovation. The idea of technological catch-up discusses the narrowing (or widening) of gaps between the technological capabilities of firms and economies (Bell and Figuieredo 2010). In this view, the flow of knowledge from leaders to followers is the very essence of the catch-up concept. There have been numerous studies in catch-up, and a number of these studies have focused on the processes involved in technological catch-up. Among these contributions, Abramovitz (1986) emphasises the vital role of social capabilities in catching-up, Gerschenkron (1962) highlights the importance of mobilisation of social intent to undertake rapid development, and Cohen and Levinthal (1989) emphasise issues of absorptive capacity.

Regarding the specific issues of knowledge and technology transfer, there are two distinct perspectives in the catch-up literature. The first perspective is that market forces, without large-scale involvement of firms and organisations, are able to coordinate catch-up developments (World Bank, 1993). This perspective, which originates from neo-classical economic theory, assumes that firms are aware of all the technological options available to them, rather than proceeding from the more intuitive starting point where firms possess little or no information and acquire information through experience and investment (Rosenberg 1994). This theory assumes knowledge is an exogenous factor in technical change and thus they underestimate and often neglect the fact that the innovators acquire knowledge through various types of learning, including learning-by-doing. Instead, this perspective assumes that "firms possess complete information concerning the economic value of the technologies "induced" by expenditures on R&D" (Rosenberg 1994, p 5). However, neo-classical economic theories of growth and information, in general, indicate that investment must be (and is) embodied in the theory, even experience is considered as in Arrow's 1962[19] paper.[20] As a result of pursuing such an approach, technology is assumed to be easily available, and to be a simply transferable good from one economic agent to another. In general, neo-classical economics, drawing on these assumptions and ignoring a number of real world complexities, has indicated that catch-up processes are rooted in market-based policies. Hence, one recurring theme in this perspective is the way in which, and the extent to which, the technological catch-up policies for different latecomer firms[21] in different countries are similar.

The Washington Consensus is one of the best-known economic policy prescriptions by neo-classical economists who study the catch-up concept. A set of ten market-oriented economic policy recommendations[22] made in 1990 aimed to reform developing countries'

[19] In this paper Arrow suggests an endogenous theory of the changes in knowledge and considers learning by doing in his study.
[20] I am grateful to Professor Steinmueller for this point.
[21] A latecomer firm is defined as a firm located in a developing country which operates in an environment with pervasive 'missing markets' and 'missing capabilities' (Radosevic 1999). The four main characteristics of a latecomer firm are: (i) disadvantages stemming from dislocation from technology sources and advanced markets; (ii) the existence of initial competitive advantages such as low costs, as well as (iii) the historically determined, rather than strategically chosen, position of the late entrant; and (iv) the strategic intent of catching up (Hobday 1995; Mathews and Cho1999; Mathews 2002; Bell & Figuieredo 2010).
[22] Fiscal deficits, public expenditure priorities, tax reform, interest rates, the exchange rate, trade policy, foreign direct investment, privatisation, deregulation, property rights (Williamson 1990).

economies. However, the application of the Washington Consensus package has led to the economic devastation of some Latin American countries. Furthermore, the experience of newly emerging economies such as China and India is in sharp contrast to the Washington Consensus. These countries have highly protected their markets, have had a lack of privatisation, and have developed extensive industrial policies throughout the 1990s (Rodrik 2006). Although their markets are far less protected now than they were in the past, their paths of development do not fit with the Washington Consensus package. In fact, the Washington Consensus policies are based on general assumptions and do not differentiate between these countries in terms of their size of economy, their stage of development, their indigenous capabilities and other contextual factors. Furthermore, the Washington Consensus policies, which focused exclusively on macro issues, ignore the coupling between foreign and domestic actors as a way for latecomer firms to create synergies and to leverage their capabilities (Radosevic 2009). Under these policies, openness, together with a favourable business environment, is seen as a sufficient and necessary precondition for technological catch-up (Radosevic 2009). Therefore, these policies assume that technology is an easily available and transferable good in the market and thus they underestimate the indigenous capability building efforts, the importance of tacit element in technology transfer process and engagement of both domestic and foreign knowledge sources in the catch-up.

In contrast, the second perspective, initially developed by Gerschenkron (1962), emphasises the variety of catching-up models and their roots, rather than presuming it to be a standardised process. Gerschenkron (1962) put emphasis on indigenously developed strategies for catching-up, and perceived the conditions of latecomer countries as different from one another. This could be because of different markets, technologies, and growth opportunities in the latecomer countries, and thus development is not an automatic stage. Hobday (2003) enriched Gerschenkron's (1962) concept of the "substitute of the missing prerequisites (or preconditions)", and argued that the Gerschenkronian approach believes in the variety of and differences between the development paths of nations.

Hobday argues that "imitation alone is likely to be insufficient to produce catch-up development…today's developing countries also need to find ways of substituting for the missing prerequisites of industrialization… based on its own distinctive resources." (2003, p 310). He explains and interprets the Gerschenkronian view in the context of newly industrialising economies (NIEs), in particular the Asian context, and comments that "the experience of the NIEs suggests that today's latecomers need to draw upon their own distinctive resources which will, in part at least, be shaped by their prevailing stage of backwardness" (2003, p 310). His analytical work on the Gerschenkronian approach provides insights into other countries. For instance, drawing on the substitution of missing prerequisites, he points out that in the development of electronics in South-East Asia, the expansion of TNC-led growth and technology transfer in support of exports was a significant institutional innovation. However, he argues that the technological development process for each of these countries was not a standard, automatic and painless process.

Such a line of reasoning suggests different policy implications for latecomer countries than those stemming from the neo-classical economic models. These conclusions emphasise indigenous capability building, the importance of national and sectoral innovation systems, and the essential role of tacit knowledge in international technology transfer. This approach has been supported by other researchers (Johnson 1982; Amsden 1989; Wade 1990; Shin 1996).

Catching-up, forging ahead and falling behind, published by Abramovitz in 1986, is widely recognised as the pioneering work on the catch-up concept. He put forward the vital role of social capability in the technological catch-up process, and the flow of knowledge from leaders to followers as the very essence of the catch-up concept. One of the particularly interesting aspects of his study is the attempt to introduce the role of both indigenous capabilities and international technology transfer in the catch-up process. However, the core part of his work is on social capability. He addressed social capability as a variety of efforts and capabilities – these may include improving education, building technological capabilities and investment – that latecomer countries should develop in order to catch up. Considering catch-up as a long-term process, he argues that:

> "Countries that are technologically backward have a potentiality for generating growth more rapid than that of more advanced countries, provided their social capabilities are sufficiently developed to permit successful exploitation of technologies already employed by the technological leaders."

He also argues that realisation of potential depends on some factors like “diffusion of knowledge, the rate of structural change, the accumulation of capital, and the expansion of demand” (1986, p 390). Furthermore, he considers an essential role for governments in terms of "support of education, research, and information, and its provision of physical overhead capital and of the host of local functions required for urban life" (1986, p 404).

Two points emerge from Abramovitz’s line of reasoning, as discussed above. Firstly, he puts emphasis on the indigenous capabilities of latecomer societies as the key element of the catch-up process. This view has been supported by subsequent studies (Hobday 2003; Fagerberg and Godinho 2005; Mazzoleni and Nelson 2007), as touched on above. Secondly, his view adds up to a Gerschenkronian approach, not only in terms of highlighting indigenous capabilities, but also in terms of emphasis on the active role of governments in the process.

Shin (1996) tries to critically analyse the catch-up literature. Drawing on Gerschenkron (1962), he focuses on highlighting the institutional dimensions of catching-up, and attempts to link institutions and technology. He argues that such a relationship is critical in catch-up literature because institutions are widely diverse across countries, and all function within their own context. Shin criticises the work of Abramovitz (1986) in some respects. He holds that Abramovitz’s distinction between ‘realisation’ and ‘potential factors’ remains unclear because “Abramovitz's realisation factors, which have mainly to do with international conditions, are in fact the external environment for individual latecomers. They (latecomers) look more like factors governing the potential of a latecomer at a point in time” (1996, p 25). He then attempted to modify Abramovitz’s notions of potential and realisation in the following way:

“The potential factors include all the initial conditions of a latecomer, such as technology gap, initial level of social capability, resource endowments, international conditions and so on. On the other hand, the realisation factors refer to particular ways of organising the catching-up effort, which are related to the change in social capability” (1996, p 25).

Despite the importance of Abramovitz’s concept of social capability in the catch-up process, it remains a very wide term that encompasses scattered and diverse aspects and is hard to materialise, an issue mentioned by Shin (1996).

Lee and Lim (2001) examine the experiences of selected industries[23] in Korea and try to distinguish between different catching-up cases. They identify three different patterns for catching-up in the Korean context: path-following, stage-skipping, and path-creating. Path-following catch-up means that the latecomer firm follows the same path taken by lead companies in advanced countries; stage-skipping means that the latecomer firm follows the path but skips some stages and thereby saves time; and path-creating means that the latecomer firm explores its own path of technological development. Although such a distinction is illuminating in terms of different catch-up stages, it is, however, in contrast with the Gerschenkronian approach which believes each country or industry should follow its own contextual path of technological development. Successful catch-up cases have benefited from following advanced countries' firms' knowledge, but the whole process of technological catch-up has been associated with numerous contextual factors. In fact, the literature of catch-up rejects the ideas of mere imitation and following of advanced countries' paths. It argues that strategies and methods of development should be developed based on each country's context. Thus, the path-following distinction may result in confusion in understanding the catch-up dynamics in different contexts. However, Lee and Lim (2001) mention an interesting point in their study. They argue that technological catch-up "conditions differ between different industries facing different technological and market conditions. The process is an outcome of a complex interplay of in-house R&D, the government, the modes of technology transfer, market conditions, absorption capacity, and the nature of the technology or knowledge itself" (p 482).

The large and eclectic collection of contributions edited by Fagerberg et al (2005) is an interesting effort at understanding innovation, in which Fagerberg and Godinho (2005) published a chapter on catching-up. They initially criticise the first perspective of catch-up – primarily the World Bank (1993) approach – perceiving it as a Veblen-type approach (Veblen 1915). They argue that although Veblen (1915) initiated discussions on catch-up, he believed that knowledge could be held and transmitted in a certain shape, and that it is not an uncertain matter. Fagerberg and Godinho (2005) believe that this approach has never been valid, particularly with regard to the emergence of the new Asian industrialising

[23] The D-RAM, automobile, mobile phone, consumer electronics, personal computer and machine tool industries.

economies. They also analyse and confirm the Gerschenkronian approach and interpret the successfully caught-up countries as solid evidence for this approach. Drawing on Gerschenkron (1962), they attempt to understand the relevant dimensions of catching-up. The common theme of their study is to emphasise the important role of government policies in catching-up processes. They put in this way: “Suffice it to say that government/bureaucracy intervention, through activist economic, industrial, and trade policy (protectionism), was very important, especially in the early phases” (Fagerberg and Godinho, 2005, p 519).

However, the differentiating element of their study is to distinguish such policies from one country to another in terms of industrial structure, government bureaucracy and the market. In term of industrial structure they comment that South Korea – as with Japan – is characterised by large and diversified business groups (in Japan these were family-owned groups in the pre-war period), while in Singapore foreign multinationals, and in Taiwan small and medium-sized private firms dominate.

In terms of government bureaucracies they also argue that “in both Japan and South Korea, credit rationing by the state (so-called “directed credit”) was extensively used to persuade private business to go along with the government’s objectives, while this mechanism played virtually no role in Taiwan (which underwent a financial liberalization early on). In the Taiwanese case, the government had to rely on other instruments such as state-owned firms (which came to play an important role) and, in particular, heavily supported “intermediate institutions” (R&D infrastructure etc.) with mixed public/private sector participation” (Fagerberg and Godinho, 2005, p 521).

Finally, in terms of market orientation, they believe that in the USA, Germany and Japan industrialisation was firstly geared towards the home market, while for the new Asian caught-up countries exports played a similar role. Moreover, despite the similarity between Japan’s and South Korea’s catch-up experience, there is a significant difference in terms of financing, as “Japanese catch-up was largely self-financed, the South Korean catch-up came to depend heavily on foreign lending” (Fagerberg and Godinho, 2005, p 522).

Agreeing with what Abramovitz (1986) argued regarding educational improvement as an important effort to build social capability, Fagerberg and Godinho (2005) address this as a necessary but not sufficient factor. They argue that although some countries (like

Argentina and the Philippines) have substantially invested in higher education, they are less successful compared to the new Asian economies as they were not able to put this educational expansion into use and expand employment opportunities. In fact, unlike these less successful countries, for the new Asian caught-up countries, "industrial, technology, and education policies were complements, not substitutes" (Fagerberg and Godinho, 2005, p 530).

Lee (2005) studies the catch-up process from a detailed perspective. In an interesting attempt, he analyses the barriers and opportunities for technological catch-up in the Korean and the Taiwanese contexts. As one of the barriers, he emphasises the uncertainty involved in this stage of development, in which the latecomer firm is keen to acquire design capabilities while the forerunner firms refuse to transfer these capabilities. He observes such a deny of collaboration by forerunner firm as a crisis as well as a window of opportunity for latecomer firm to catch up, because the arrival of a new techno-economic paradigm can serve as a pull factor for catching-up. This is based on the argument by Freeman and Soete (1997) and Perez and Soete (1988), in which they put forward that emerging technological paradigms serve as a window of opportunity for latecomer countries, because these countries have not been locked into the old technological system and, thus, are able to grab new opportunities in emerging industries. However, Lee (2005) emphasises that this opportunity involves two types of risks, namely the risk of choosing the right technology or standards, and the risk of creating initial markets. He goes on to explain how the Korean and Taiwanese firms overcame these risks by diversifying overseas knowledge sources as well as establishing indigenous R&D consortiums.

As with Fagerberg and Godinho (2005), Lee differentiates the Korean and Taiwanese governmental policies in the technological catch-up processes. He argues that the Korean catch-up model includes a few large firms (*chaebols*) which are nationally owned, and which the government helps in the form of R&D consortiums in large and high risk projects, diversification of overseas knowledge sources and subcontracting with MNCs at the early stages of development, without much collaboration or exchange of knowledge among *chaebols*. In contrast, the Taiwanese model is based on a large number of SMEs which are more or less integrated with the MNCs, subcontracting with MNCs at all stages of development, as well as new spin-off firms from the government sector, while there is intense collaboration and knowledge exchange among the Taiwanese firms.

The outcomes of the discussions above have encouraged researchers to focus on the process and to identify the factors of catching-up in different contexts. Mazzoleni and Nelson (2007) attempt to address the common features associated with past successful catch-up experiences. Summarising and articulating earlier studies, they maintain that all successful catch-up cases are defined by the interplay of three sets of factors, namely cross-border flows of people, active government support of industrial development, and loose intellectual property rights. Their study is a valid contribution because it represents some general aspects of the catch-up process for latecomer countries. This approach was then continued by Malerba and Nelson (2007) as they contextualise the discussions across six different sectors in different countries. These discussions will be explored in Section 3.3.3 of this chapter.

This section has reviewed the technological catch-up concept and elaborated the different perspectives on it. It should be noted that in this thesis, the term 'catch-up' reflects the second view, which is based on a Gerschenkronian approach. Furthermore, two key points emerge from the above discussions. Firstly, all the studies following the Gerschenkronian approach emphasise indigenous efforts – including technology development, institutions and policies – in the process. Secondly, the studies tend to emphasise the role of foreign technology sources in the development of national skills. Therefore, the two most important aspects of the catch-up process have been accentuated in the literature, which will be further explained in the next two sections.

3.2.2 Technological Catch-up and International Technology Transfer

The first aspect of the technological catch-up concept is the important role of foreign technologies in enhancing domestic firms' technological capabilities. The experience of successful catch-up by some countries[24] consolidates the vital role of foreign knowledge flows in the process. In fact, historical evidence suggests that latecomer countries have grown by effectively exploiting an international pool of existing technologies available from industrial leaders (Gerschenkron 1962; Abramovitz 1986; Hobday 1994; Radosevic 1999; Mazzoleni and Nelson 2007).

Radosevic (1999) published a very relevant book on this issue and attempted to reach a deeper understanding of the relationship between international technology transfer and catch-up. Summarising earlier authors, Radosevic (1999) argues that "the catching-up literature is based on the proposition that technology followers will benefit from the technology created by technology leaders" (1999, p98). Two distinguishing elements emerge from his study. Firstly, he also perceives international technology transfer as the crucial part of the catch-up process. He comments that "the catching-up of Japan in the 1960s and 1970s and South Korea in the 1980s also relied initially on imported technology from the West. The reason for this is that the cost of imitation and technology import are lower for followers than the cost of innovation for the leaders" (1999, p97). Secondly, he has laid the basis for a Gerschenkronian approach and argues that "at least under certain conditions, backward countries would tend to grow faster than rich countries. The greater the gap, the greater the possibilities for followers to imitate and catch-up, leading to convergence in development levels" (1999, p 98).

The recent experience of successful Asian countries has also been emphasised by other researchers. Agreeing that Asian catch-up has greatly benefited from technology developed elsewhere, Fagerberg, and Godinho (2005) argue the need to distinguish between the mechanisms used to transfer foreign technology sources. In the context of the Asian newly industrialised countries, Fagerberg, and Godinho (2005) argue that "one central mechanism, used extensively by Singapore, is inward Foreign Direct Investment (FDI). By contrast, Taiwan and especially South Korea relied mostly on a form of subcontracting, Original Equipment Manufacturing (OEM)"[25] (2005, p 533). The corollary

[24] For example South Korea, Singapore and Taiwan (Hobday, 2003; Fagerberg and Godinho, 2005).

[25] "Original equipment manufacturer is a specific form of sub-contracting. Like a joint venture, it requires a close connection with the foreign partner. Under OEM deals, the local firm produces a good to the exact specification of the foreign company. The foreign firm then markets the product through its own distribution channels, under its own brand name. OEM often involves the foreign partner in the selection of equipment, training of managers, engineers and workers." (Hobday, 1994; p.337).

of this is that although all successful catch-up cases have been associated with overseas technology transfer, the method of transferral may significantly differ from one country to another. This is a Gerschenkronian approach, which differentiates between technology transfer mechanisms that should be developed based on indigenous circumstances. This argument has been reinforced by subsequent studies (Malerba and Nelson 2007).

Lee (2005) also argues that "among the diverse resources constituting a firm, knowledge is critical in the context of technological catch-up which is basically an act of reducing the knowledge gap with the advanced countries. Then, the possibility of access to existing knowledge base determines largely the possibility of catch-up because the late-comer firms do not command sufficient capability to generate knowledge by themselves" (p 116). Nevertheless, one of the salient features of Lee's study is that not only does he differentiate among overseas technology transfer channels but he also believes that these channels evolve throughout technological catch-up process. In the Korean context, he demonstrates that local companies started with FDI and subcontracting with foreign companies, then switched to licensing and other active learning mechanisms. In the third stage, Korean firms employed in-house R&D and made co-development contracts with foreign firms, and finally they were able to make horizontal collaborations such as alliances.

Some researchers believe that interactions with overseas sources can have other positive effects. They have explicitly argued that latecomer firms can expand their relations with foreign sources to the extent to which they penetrate into their markets as in tandem they will benefit from the foreign firms' technologies. This group of researchers believes that participating in foreign markets opens a substantial channel of technological knowledge flow to domestic players which can serve as a catalyst for the catch-up process. Hobday (1994) studied the electronics industry in the four 'Dragons' of East Asia (South Korea, Taiwan, Hong Kong and Singapore) and shows how export demand shaped the pace and pattern of technological progress in these countries (Export-led Technology Development). He suggests that OEM might be seen as an organisational innovation, facilitating learning and technological upgrading in latecomer firms. He then explains how the newly industrialised Asian countries have incrementally progressed from OEM to

ODM[26] and then to OBM[27]. Hobday (2003) further analysed this incremental progress in his next study in which he interprets the Gerschenkronian perspective in the context of the new industrialised Asian context. In this paper, he characterises the stage of development of these countries based on historical evolution and distinguishes that OEM took place mostly in the 1960s and 1970s, ODM in the 1980s, and OBM in the 1990s.

Agreeing with Hobday's (1994) perspective on export markets, Radosevic (1999) comments that "…export and domestic growth interact in a dynamic way. Foreign markets are not only a source of demand but also sources of knowledge, competitive pressure, and close interaction with foreign suppliers and buyers. Buyers are very often a valuable source of knowledge on technical and marketing aspects of products (1999, p3)".

However, Lee (2005) challenges Hobday's argument regarding the historical evolution of firms in East Asian countries. He shows that Taiwanese firms followed the sequential steps of OEM, ODM and OBM in collaboration or integration with MNCs, whereas Korean *chaebols* jumped from OEM directly to OBM, even without consolidating their design capabilities. In fact, Korean firms have long had their own brands and have been independent from MNCs in terms of financing, production and marketing. They have followed the stages of OEM, OBM and then ODM.

The common theme that runs through the above discussions is that in the catch-up literature, international technology transfer is deemed a key process through which domestic firms are able to enhance their technological capabilities. Although the channels of technology transfer depend upon each country's context and therefore differ from one country to another, accessing foreign knowledge is the common and vital element in the technological catch-up process.

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[26]" Today, with the improvement in local firms' design capabilities, overseas manufacturers often purchase under so-called ODM (own design and manufacture) arrangements. Under ODM the latecomer firm designs and manufactures a range of products with little or no assistance from the overseas purchaser" (Hobday, 1994, p 351).

[27] "Under OBM (own brand manufacture), the latecomer firm carries out all of the stages of production and innovation, including manufacturing, new product designs and R&D for materials, processes and products. At this advanced stage there is little difference between a latecomer and a leader (or a follower). The latecomer firm has typically developed its own brand, organizes its own distribution abroad, carries out R&D and is able to capture all of the value added associated with production, branding and distribution" (Hobday, 2003, p 298).

3.2.3 Technological Catch-up and Innovation Systems

Other important aspects which are highlighted in the literature on catch-up are the active role of domestic firms, the typology of their interactions, and the contributions of institutions, financial systems and infrastructure. The national/sectoral innovation system literature has contributed to catch-up studies on both national and sectoral levels. This section aims to elucidate the aspects of technological catch-up which are addressed by the national/sectoral innovation system literature.

3.2.3.1 Technological Catch-up and National Innovation System

Gerschenkronian scholars over the last two decades have increasingly underlined the importance of indigenously developed strategies and in-house technology development efforts in the catch-up literature. A closer look at the main argument of the Gerschenkronian approach to technological catch-up reveals that these scholars have understood how the national innovation system literature is able to foster indigenous-oriented issues in the catch-up concept. Today, the national innovation system, as an overarching concept capable of integrating many different elements, is a substantial part of the catch-up concept. Malerba and Nelson are working on a large project on catch-up in which a significant part of the project addresses national and sectoral innovation system issues. The first and the only paper of this project published to date was in the 5th Globelics International Conference in Russia in 2007. The project outcomes are an insightful contribution to the catch-up literature. Malerba and Nelson investigate various aspects of the catch-up concept in economic development, such as the role of domestic capabilities of firms, the differences existing across sectors, the measurement of catch-up, and the effects of IPR. They examine catch-up processes in six different sectors – automobiles, telecommunications, pharmaceuticals, software, semiconductors, and agro-food – in several different countries – China, India, Brazil, Korea, Taiwan and others.

Malerba and Nelson emphasise the importance of the national innovation system in the catch-up process in this way:

> "But firms do not act alone. They must be understood as operating in the context of innovation systems that includes other kinds of economic actors that are involved in supporting and orienting the dynamics of economic activity and innovation: financial systems, primary and secondary education, universities, the public research system and government programs" (2007, p 4).

Framed in this way, the technological catch-up process cannot be reduced to merely transferring technology from developed countries and imitating their routines among latecomers. Malerba and Nelson (2007) contend that "the organizational, managerial, and institutional aspects of productive practices often are the most difficult to replicate, and the most in need of adaptation to indigenous conditions, norms, and values" (2007, p 4).

The common theme that runs through Malerba and Nelson's argument is that a deeper understanding of the catch-up process is realised by overlapping the national/sectoral innovation system with technological catch-up concepts. This is particularly the case when studies aim to understand the indigenous elements of the technological catch-up concept. Along these lines, Malerba and Nelson (2007) maintain that a system innovation approach, both on national and sectoral levels, is able to explain the context-specific factors to understand the dynamics of technological catch-up. They mention three different aspects of the innovation system which are important in the catch-up process. The first aspect is the fact that the improvement of the education system has been a common thread in successful countries. In this light, they argue that similar to the education system, research at universities and in public laboratories is also important because "today so much of technology is science based means that a country's system of advanced training in science, technology, and the other bodies of knowledge needed to master modern ways of doing things, is quite important" (2007, p 4). Similarly, Lee (2005) argues that in the catch-up process, university-industry collaboration plays an important role "not only in the traditional forms of supplying human resources but also conducting contract R&D for industry and even establishing companies directly using the resources of universities" (p 125).

The second aspect is the important role of government policies. “Active government policies have supported the catch-up process, involving various forms of protection and direct and indirect subsidy” (Malerba and Nelson 2007, p 4). This has also been argued by past studies (Hobday 1995; Kim 1998; Radosevic 1999; Viotti 2002; Fagerberg and Godinho 2005; Lee 2005; Lee and Tunzelmann 2005). These studies explain how efficient and supportive government policies facilitate the catch-up of latecomer firms in different contexts. However, Malerba and Nelson (2007) argue that government protection sometimes results in a protected inefficient home industry instead of successful catch-up. This has raised a hotly debated topic in the literature that will be explained in the section on substitution versus complementarity.

The third aspect mentioned by Malerba and Nelson (2007) refers to the institutions that shape the actions of domestic firms, namely “the labor market, the education system, financial institutions, regulatory structures, and other institutions that shape economic dynamics more broadly” (2007, p 5). Institutions are a crucial part of the national innovation system literature (Freeman 1987; Lundvall 1992; Nelson and Rosenberg 1993; Edquist 1997). This issue was also analysed by Lee and Tunzelmann (2005) with regard to Taiwan's IC industry, where they developed an activity-based model of the innovation system.

The indispensable interrelationship between catch-up and the innovation systems is widely accepted by other scholars in the literature. Fagerberg and Godinho (2005), by stressing the significant role of governments, educational and financial systems, suggest that developing countries may need to improve their local innovation systems and networks in order to catch up. Their work explicitly shows the importance of the national innovation system literature in the catch-up process.

In this light, Mazzoleni and Nelson (2007) argue that “the acquisition of indigenous technological and scientific capabilities have become, and will continue to become, of ever greater importance for countries attempting to successfully catch-up with respect to key technologies” (Mazzoleni and Nelson 2007, pp 1515). They ground their argument on two global trends that characterise the contemporary catch-up context. Firstly, due to changes in international economic relations – such as the creation of the WTO and the TRIPS agreement – developing countries face considerable limits on their ability to protect or subsidise domestic firms and to restrict foreign firms' access to domestic markets. Moreover, "in the new regime of stronger global protection of intellectual property, countries trying to catch-up will find it increasingly important to develop their capabilities to revise and tailor manufacturing technologies relatively early in the game" (2007, p 1516).

Secondly, Mazzoleni and Nelson believe that the changing trend is due to the close interrelationships among scientific and technological disciplines in modern fields[28] compared to the older fields[29] and their openness to those who have the training and connections to access the relevant networks. The corollary of this is that the national innovation system literature can contribute to the development of the fields of modern science and technology.

Building on the notion of the national innovation system and with the approach of catching-up, Viotti (2002) introduces a new perspective. He casts doubt on the strength of the existing national innovation system literature to interpret the technological catch-up of industrialising countries. Viotti suggests instead that the 'national system of learning (NLS)' is more relevant in a developing country context, as he believes that innovation has a secondary role in these countries, but learning is the very essence of catch-up process. In this framework, activities, institutions and relationships are associated with learning rather than with innovation.

Based on empirical data analysis, Viotti distinguishes between passive and active learning. The differentiating element lies in the fact that simple assimilation of production capability and substitution of local efforts with importing foreign technologies mostly fail to indigenously develop a complex set of institutions, relationships and incentives for technological catch-up. His approach leads to a precise and neat conclusion that developing countries – if they are determined to catch up – should build adequate institutions and create the type of environment that induces active learning, what Viotti refers to as Active NLS.

The above discussions shed light on the close relationship between the national innovation system and catch-up literature, which is a broadening trend. The discussions

[28] Modern fields such as computer science, biotechnology and immunology
[29] Older fields such as chemical and electrical engineering

also demonstrate the overlapping parts of both concepts. However, the new discussions in the literature move to distinguish among several sectors and to address the specific characteristics of sectors in the innovation system, which raises the sectoral innovation system literature accordingly. This will be explored in the next section.

3.2.3.2 Technological Catch-up and Sectoral Innovation System

The crucial function of the national innovation system in technological catch-up process has encouraged researchers to study the issue across dissimilar sectors. There are often notable differences across sectors in terms of knowledge base, players and the interactions among them, rules and other aspects. The heterogeneity of industrial sectors influences catch-up policies and thus should be taken into account in the studies. Therefore, as some studies have focused on illustrating the national innovation system in technological catch-up process, some researchers have meanwhile become keen to contextualise the catch-up studies across different industrial sectors.

Kim (1998) studied the technological catch-up of Hyundai, one of Korea's large automotive companies, to understand the detail of the processes. Kim maps the organisational learning of the Hyundai Company. He elucidates the incremental growth of learning of the Hyundai Company and explains how the company enhanced its technological capabilities by implementing learning-oriented policies. In fact, Viotti (2002) benefited from Kim's empirical findings in his differentiation between the national innovation system and the national learning system.

Kim's research is a well-focused study on firm level issues. At the same time he addresses how governmental industrial policies, as an external factor, helped the Korean automotive company to catch up. This will be explained in Section 3.3.3 of this chapter, where the influencing factors are examined. However, Kim's study contains some seeds for subsequent researchers to investigate sectoral innovation system issues in the catch-up literature.

Lee and Tunzelmann (2005) mapped the innovation system of Taiwan's integrated circuits (IC) industry and discuss the associated dynamics. They break down the sector into five major interrelated elements: human resources, the market, finance, science and technology, and innovation commercialisation. They elucidate how this Taiwanese sector has caught up within the sectoral innovation system framework. This study also provides some useful insights for understanding the relationship between the sectoral innovation system and government macroeconomic policy, as well as government legal and financial systems. Based on Lee and Tunzelmann's arguments, technological catch-up cannot be reduced to national level elements, and the process is very much dependent on sector-specific characteristics.

Consequently, the sectoral innovation system approach has recently contributed to the catch-up literature to illuminate industry-specific factors. It is worth mentioning that along these lines,[30] scholars have largely benefited from Pavitt's taxonomy (Pavitt, 1984) in which the sectors are classified and interpreted based on their own specific characteristics through sectoral patterns of technical change. This perspective is illuminating because there are considerable differences across economic sectors in terms of key variables and mechanisms involved in catching-up.

Malerba and Nelson (2007) argue that "while national innovation systems take innovation systems as delimited more or less clearly by national boundaries, a sectoral system approach would claim the boundaries of the innovations process in sectors may have local, national, and/or global dimensions" (2007, p 9). In fact, one of their rationales of working on sectoral catch-up projects is to identify and to distinguish between different variables and mechanisms across economic sectors. They believe that the sectoral innovation system literature can illuminate the dynamics of catch-up processes. While they concentrate on the essential role of firms in technological catch-up processes, drawing on the sectoral innovation system literature,[31] they argue that "firms' specific learning processes, competences and organizations, as well as beliefs, expectations, and goals, are

[30] For example Breschi and Malerba (1997) and Malerba (2004) when they developed the sectoral innovation system approach.
[31] They referenced the works of Kim (1997), Lee and Lim (2001), Mathews (2002), Amsden and Chu (2003), and Lee (2005) as examples of catch-up literature in which the firms played a central role in the process.

highly affected by the specific sectoral system they are in" (2007, p 6). They ascribe five main characteristics for a sectoral system relevant to catch-up studies, as follows:

- *Key actors*: the key actors are firms, but other relevant actors exist which could be summarised as
    - "Users, customers, the sources of demands
    - Upstream suppliers
    - Universities and public laboratories
    - Financial organizations
    - The public sector." (2007, p6)
- *The knowledge base*: the scientific and technological activities within each sector
- *Institutions*[32]: institutions may differ widely across sectors. This is particularly the case when a sector is influenced by environmental discussions.
- *Government programmes and policies*: this could be very important, especially when the governments aim to catch up in specific sectors.
- *The particular dynamic process involved in catch-up*: Malerba and Nelson argue that "catch-up is inherently a dynamic process" (2007, p 9) and the dynamics result in "sector specific co-evolutionary processes" (2007, p 9).

One of the illuminating points in Malerba and Nelson's (2007) work is their attempt to identify and explain the influencing factors across different sectors in the above mentioned countries. This will be elaborated in Section 3.3.3.

[32] These include "laws, rules, standards, norms, routines, common habits, established practices and so on" (2007, p 8).

3.3 Interactions between Indigenous Technology Development and Overseas Technology Transfer

The discussions above highlight an important theme in the literature. On one hand, the catch-up literature underlines the accessibility of foreign technology and international technology flows from leaders to followers. On the other hand, the literature emphasises indigenous innovation and learning systems and highlights the important role of institutions, organisations and interactions in enhancing domestic technological capabilities. In this respect, the literature puts indigenous capability building at the heart of the process. Here, the question is how indigenous capabilities and foreign knowledge – as the two main sources of knowledge – interact with each other. Is there any contradiction between these two main sources? How does a developing country firm deal with the challenges and difficulties of combining these two sources of knowledge? What factors influence the dynamics of this process? And finally, the crucial question is whether these components are complementary or substitutes for one another. The extent of complementarity and substitution has become a focus for debate in the literature. Some researchers have argued that the two important technology sources work together in a substitutive way. In contrast, other researchers, using different case studies, have argued that both means interact in a complementary way. The literature on substitution/complementarity specifically focuses on understanding of the interaction processes between indigenous and overseas capabilities. This part of the literature will be scrutinised in the next section. However, it is worth mentioning that beyond the literature on substitution/complementarity, the literature on FDI spillovers is also interesting to understand the relationship between FDI and knowledge spillovers to the host country. These studies have investigated the outcome of FDI on the generation of spillovers in host country's firms. Meyer and Sinani (2008), Liu (2008), Marin and Sasidharan (2010), and Hallin and Lind (2011) are the most recent studies on this specific issue.

Meyer and Sinani (2008) studied the relationship between spillovers and the host country's level of development in terms of income, institutional framework and human capital. They concluded that FDI spillovers are influenced by the specific context of the study in a way in which very poor and very rich countries appear to benefit most from inward FDI. Likewise, the study of Marin and Sasidharan (2010) in the Indian context revealed that subsidiaries should be at the centre of the spillover process, and the study of Hallin and Lind (2011) examined the impact of MNCs on the occurrence of knowledge spillovers in local host country firm. Hallin and Lind (2011) used econometric method and showed that competitive pressure activates local competitors to react to new innovations introduced by MNC subsidiaries.

Despite these studies, this thesis does not include this literature because of three main reasons. Firstly, in this thesis, as explained in Section 3.2.1, the term 'catch-up' reflects the Gerschenkronian approach rather than the neoclassical economic perspective. Most of the studies in the literature on FDI spillovers have used neoclassical economic theory in their analysis. Secondly, MAPNA was not established either in the form of FDI or as a MNC. Thus, the discussions of FDI spillovers are not relevant for the scope of this thesis. Thirdly, and the most importantly, all these studies, with their econometric focus, explain a story only about results, not processes. Rather, this thesis aims to delve deeply into the interaction processes between indigenous and overseas technology sources and thus the relevant literature should be investigated. Further justification will be explained in the methodology chapter (Section 4.2.1). The next section reviews the origin and the trend of the substitution/complementarity discussions, and explains how these discussions can be enlightened by the new perspective that this thesis intends to introduce.

3.3.1 Emerging Literature: Substitution and Complementarity

This section approaches the above idea by identifying relevant concepts which are contextualised in different countries as well as in different sectors. Such an assessment requires a broad literature review, identifying the origins of each concept, finding the possible gaps in the literature, locating my research and capturing insights from multiple disciplines. Accordingly, the following section describes the concepts of complementarity and substitution and reviews how the literature, explicitly or implicitly, has discussed these issues.

It might be better to start with the definitions. Within the literature, complementarity is mostly used as an economic term. Milgrom and Roberts (1992) state that "several activities are mutually complementary if doing more of any one activity increases (or at least does not decrease) the marginal profitability of each other activity in the group" (p 108). In the literature on technology transfer Radosevic (1999) states the econometric definition of "mutual complementarity as the process where the rise in one variable raises the payoff of increasing the other" (p 115). In contrast, a substitutive relationship between two variables reflects the decrease of one if the other increases. For example Braga and Willmore (1991, p 421) argue that "increased imports of technology imply a decrease in local R&D". Similarly, Radosevic (1999) defines substitution as "the more foreign technology was imported the less likely it was that domestic R&D would develop" (p 115). Complementary and substitutive relationships between indigenous technology development efforts and overseas technology transfers result in different policy implications, which have been highly controversial in the literature.

The substitutive view originates from import substitution policies, which were part of the mainstream development position of the 1960s and 1970s and were practised by the majority of developing countries such as India and Latin America (Radosevic 1999; 2009). This view has been mainly articulated by Mytelka (1978) in the literature. She studied two industries – metalworking and chemical firms – in the Andean Group of Latin American countries, and contends that by reducing the need to create indigenous technology, technology imports curtail domestic technological development and create a reliance on foreign technology. Both Mytelka (1978) and Pillai (1979) believe that imports reduce developing countries' need (or incentive) to undertake their own technological efforts: the developing country enterprises become 'dependent' on the imports.

The dependency idea has been criticised by Pack and Saggi (1997). They put it in this way: "a central tenet of dependency theory which long dominated policy thinking in Latin America and other regions was the harmful long-term impact of trade in technology as well as that in goods and services" (p 86). Despite these critiques, at that time Mytelka argued based on the circumstances of the 1960s and 1970s. She had observed unsuccessful technology transfer projects in Latin America and she was concerned with the traditional approach of technology flows from North to South, in which technology transfer regimes sufficed to import machines and equipment. These regimes often neglected the transfer of tacit elements of knowledge and did not include the engagement of indigenous people in learning-by-doing processes. Mytelka believed that technology imports from the North in the form of licensing agreements to produce goods without indigenous efforts will not lead to technology development and will even reduce domestic technology development efforts, because these countries typically suffer from a lack of a technological base as well as a structure of demand for technology, and thus they are not able to assimilate imported technologies. This is why Mytelka interpreted dependency as a negative consequence of technology import to Andean Group countries. Perez (2001) also interprets Latin American cases in a similar way. She argues that these countries, in contrast to the newly industrialised Asian countries, have passively engaged in technology transfer processes. Furthermore, Perez (2001) argues that these Latin American countries did not adapt themselves to the technology life cycle, and they have therefore stultified over a long period in the mature stage of technologies. The reason for this is that “development opportunities are a moving target and … development strategies are temporary and must be updated and reshaped accordingly” (Perez 2008, p 5). Nevertheless, the substitutive idea, or the idea of import substitution, is no longer valid in the literature and the trade circumstances have been largely altered over the last three decades: this matter has also been argued by Perez (2008) in terms of changing conditions, changing strategies.

After Mytelka (1978) and Pillai (1979), Lall (1985) studied the interaction of both domestic and foreign technology sources. He argues that the relationship between technology transfer and domestic technological efforts is changeable, and at certain stages the two are substitutes while at others they are complementary. However, he believes that “a strategy of low technology import may lead to a certain build-up of capabilities (which spillover into technology export). When carried too far it may lead to technological stultification because of inherent limits of what developing country enterprises can do on their own. Their capabilities can grow but so slowly (and at so great costs) that society loses in relation to its more liberal competitors” (Lall 1985, p.68). This study challenged the substitutive relationship that conceives foreign technology transfer as curtailing domestic technological efforts, because it does not take into account the role of foreign knowledge in enhancing domestic capabilities. The concept of the complementary relationship has been somewhat raised accordingly. Lall (1989), in his next piece of research, interpreted importing technology as a "building block" for domestic capabilities. His studies cast light upon the crucial role of foreign knowledge and interaction with domestic technology sources in building domestic capabilities. However, in Lall's studies this question remains unanswered: why does the relationship between technology transfer and domestic technological efforts change, and what factors influence this?

In fact, the complementary relationship between indigenous technology development and overseas technology transfer originates from the accepted concept of 'absorptive capacity' in cross-border technology transfer. Cohen and Levinthal (1989) coined the term 'absorptive capacity' and argue that "while R&D obviously generates innovations, it also develops the firm's ability to identify, assimilate, and exploit knowledge from the environment" (p 569). Subsequently, Cohen and Levinthal (1990) developed the concept of absorptive capacity, arguing that "the ease of learning, and thus technology adoption, is affected by the degree to which an innovation is related to the pre-existing knowledge base of prospective users" (pp 148-149). They divide the concept into two important elements, namely the "prior knowledge base" and "intensity of effort". The corollary of this argument is that foreign knowledge absorption needs prior indigenous capability building efforts as well as the extent to which latecomer firms makes the effort to acquire knowledge from leader companies. This concept has subsequently become central in the substitution/complementarity literature. Drawing on the notion of absorptive capacity, Mowery (1993) argues that absorptive capabilities are needed to deal with the tacit components of the transferred technology (which are difficult to transfer), as well as the modifications that will be necessary to configure a foreign sourced technology for domestic application. This line of reasoning indicates, based on the complementary definition of Milgrom and Roberts (1992), explained above, the complementary relationship between a firm's technology development efforts and external knowledge sources.

Along these lines, a significant number of studies have tried to investigate the role of absorptive capacity in the substitution/complementarity literature. Although it has been widely acknowledged in the catch-up literature, there remain multiple questions and sceptical views about the complementarity between in-house technology development and overseas technology transfer. Accordingly, scholars have begun to examine whether those two main sources are interrelated as substitutes, or are complementary.

Braga and Willmore (1991) investigated affecting variables (mostly at the firm level) to analyse the relationship between technological imports and technological efforts in Brazilian firms. They commented that "[s]ince firms can choose between purchasing technology and developing it themselves, it is logical to expect some substitution: the greater the dependence of a firm on imports of technology, the lower its technological effort. On the other hand, a complementary relationship is also likely, both because foreign technology can be a 'catalyst' for domestic effort and because imported technology must often be adapted to local conditions" (1991, p 424- 425). Two points emerge from their argument. Firstly, Braga and Willmore believe that both substitution and complementarity are possible depending on the circumstances. Greater dependence leads to technological stultification (Lall 1985), while if technology imports are well-managed, they could be a catalyst or building block (Lall 1989) for indigenous technological efforts. Secondly, the decision making of firms' managers, in some circumstances, reflects, to some extent, a substitutive relationship. In order to identify the type of relationship between in-house technological efforts and importing technology in Brazilian firms, Braga and Willmore covered a broad range of firms in various sectors. Using purely quantitative analysis,[33] they concluded that complementarity dominates any effects of substitution between technological imports and technological efforts. Thus, the policy implication for Brazilian firms is that accessing foreign knowledge will increase Brazilian technological efforts. Critically, this study did not identify the essential factors (particularly at the meso and macro levels) in the dynamic context in which firms interact with foreign companies. Furthermore, because of the methodology used in the study, it is not possible to distinguish cross-sectoral differences among the firms.

Bell and Pavitt (1993) tried to understand the dynamics of industrialisation in developing countries before examining the substitution/complementary ideas. They argue that "the process of technical change in dynamic industries in developing countries bears

[33] They used survey analysis and employed logarithmic models to measure the explanatory variables.

little resemblance to the technology adoption process represented in conventional innovation-diffusion models" (p 158). Thus, "policies which continue to rest on these perceptions of the processes of technological accumulation and technical change are likely to hinder rather than hasten industrial catching-up" (p 158). Therefore, they suggest distinguishing between production capacity and technological capabilities in order to understand the dynamics of industrialisation. They believe that such a distinction is necessary to generate and manage that dynamism, and suggest 'active involvement' in technical change by firms, industries, and economies that acquire technology developed elsewhere. This study raises the issue of dynamics in complementary/substitutive studies which could open up a new approach for further studies. Furthermore, their attention to the complementary/substitutive debate in the context of developing countries contains some seeds for further studies. They cast light upon the complementary/substitutive debate in the context of developing countries by examining the case of Japan's shipbuilding industry in which the licensing of designs and the acquisition of foreign technological knowledge was complemented by large in-house investments in capability building. This issue was initially raised by Nakaoka (1987), who explores the combination of local efforts – mostly through reverse engineering – and international technology transfer – via licensing and FDI – in Japan's shipbuilding catch-up process.

One of the salient features in the work of Bell and Pavitt (1993) is to highlight the important role of preliminary capability building (or prior knowledge base) before attempting technology import. Given the evidence of the Asian newly industrialised countries, they argue that "the process of importing technology may also be preceded, not just followed, by local investment in related technological capabilities" (1993, p 172). "Firms did not choose between imported and local technology as sources of technical change. They chose both!" (1993, p 193). The common theme that runs through this line of reasoning is the existence of both imported and domestic channels in a successful catch-up, and the process in which the prior knowledge base plays a significant role and facilitates active involvement in the technology transfer process. However, Bell and Pavitt do not discuss active involvement in detail as well as contextually, and thus technology-specific discussions are missing from their study. They also do not address the associated factors that influence the interaction between indigenous capabilities and overseas technology transfer. These factors are important in understanding why firms in some circumstances rely on their own capabilities, while in other circumstances some firms attempt to transfer abroad.

Freeman and Hagedoorn (1994) attempt to explain that international technology transfer *per se* does not lead to technological catch-up. They show that strategic technology partnerships or any other forms of technology transfer agreements do not necessarily entail catch-up by developing countries and may even lead to falling behind. The reason for this is that "it would not be reasonable to expect that the least developed economies with very little manufacturing industry, very low levels of per capita income, and very limited resources in terms of skilled engineers and scientists, would have a similar pattern of technology transfer activities as the most developed economies" (1994, p 778). Freeman and Hagedoorn also differentiate between developing countries based on their stage of development, size of economy, resource endowment and so forth. They exemplify the East Asian 'dragons' as successful countries in terms of the catch-up process, and argue that "autonomous domestic technological activities and the import of technology are not alternative but complementary activities in technology: to him that hath shall be given" (1994, p 779). They conclude that "apparently the construction of a level of indigenous technological capabilities, that comes close to the worldwide technological frontier, appears compulsory for those that intend to enter the game of international technology collaboration" (1994, p 779).

Freeman and Hagedoorn's study provides guidelines on how to differentiate between successful and unsuccessful technology transfers: the first may result in catch-up, while the second may result in falling behind. This leads to the precise and neat conclusion that technological catch-up requires the combination of both indigenous technological efforts and overseas technology transfer. Although this study confirms the complementary relationship, the details of this complementarity, its dynamics and influencing factors are still shrouded in mystery. Furthermore, the study does not focus on the role of business firms, unlike the work of Bell and Pavitt.

The studies discussed above are based in the general context of developing countries. Within the literature, scholars have identified the need to be more specific, and hence studies have begun to examine complementarity/substitutive ideas in specific contexts.

Lee (1996) studied the relationship between technology imports and R&D efforts in the context of Korean manufacturing firms. He argues that substitutive or complementary relationships can only be meaningfully discussed for the small proportion of less developed countries' firms that are committed to R&D efforts. He shows that within Korean manufacturing firms, those importing technology tend to commit themselves to R&D efforts through having formal R&D institutes. Using an econometric technique, Lee demonstrates that for this group of firms, technology imports have no complementary relationship with R&D efforts – in contrast to the results of previous studies. He concludes that "among the whole population of firms, technology importers are more likely to commit themselves to R&D efforts than non-importers; but among the firms committed to R&D efforts, technology imports have no complementary relationship with R&D efforts" (p 206). The problematic aspect of Lee's argument is that if a latecomer firm imports technology, it may establish an R&D institute because it is more likely to commit itself to R&D. However, if this firm imports any other technology following the previous technology transfer, this transfer will then become a substitute for its indigenous efforts. This paradoxical argument, however, is in contrast with the engagement of both domestic and foreign technology sources in technological catch-up. The corollary point of this is the one-off technology transfer for a latecomer firm. Similarly, Lee's argument does not answer the question for the firms that do not have R&D departments. How should these firms deal with foreign sources of technology? Furthermore, Lee's study was unspecific regarding technology import, which covers a very broad range of foreign technology flows. Do technology imports relate to machinery imports, informal relationships (like training), or mutual R&D contracts? How can the findings be interpreted in the context of today's R&D contracts? Moreover, Lee's research did not take a dynamic approach to analyse these relationships. Does the type of relationship vary over time, and what factors influence the shaping of such relationships? However, one of the positive steps of Lee's analysis was to distinguish between firms in terms of having or not having R&D institutes, and the suggestion to discuss complementarity and substitution in specific firms rather than in the general context of developing countries.

Katrak (1997) implemented a similar study in the Indian context. He tried to test the ideas of substitution and complementarity in the electrical and electronic industry in India. Using quantitative methods and implementing logarithmic regression, Katrak concludes that the "probability of importing technology was only weakly affected by the initial in-house capabilities, though the probability was greater amongst larger and older enterprises" (1997, p 81). Katrak also attempts to identify some influencing factors on the decisions of firms, and emphasises that the technological decisions of Indian enterprises may well have been influenced by the government's protectionist and industrial licensing policies. The distinguishing feature of Katrak's study is in his attempt to highlight this point that the relationship between domestic efforts and foreign technology imports is influenced by Indian governmental policies. He argues that the government restrictions have resulted in a number of barriers that have reduced the incentives (and pressures) to undertake technological efforts. However, due to the static approach and the methodology used in this study, it has left unanswered a number of issues, which are mentioned in the study review of Lee (1996).

Pack and Saggi (1997) critically observe that the previous literature had mostly utilised static viewpoints on complementary and substitutive discussions. They comment that "even though the empirical work has provided evidence largely supporting complementarity between technology imports and indigenous R&D, it leaves many complex issues untreated and there is little guidance from the theoretical literature that might suggest more subtle testable hypotheses" (p 86). They thereby emphasise the complexity of the issue and assess a number of major influencing factors, including government policies (through a comparison of Japan and Korea with China) and intellectual property rights, to explain the dynamism. This is a step forward in understanding the dynamics of interactions between indigenous efforts and overseas technology transfer. This issue will be analysed in the following section, when influencing factors are explained.

In terms of complementarity/substitution ideas, Pack and Saggi mention 'threshold effects' and argue that "below a certain level of technological capability, technology transfer may not even be feasible. Therefore, countries may earn significant dividends from setting the process of technology absorption in motion" (1997, p 83). This is a common thread with regard to the results of Freeman and Hagedoorn (1994), as they also perceive the construction of a level of indigenous capability compulsory before entering the game of international technology transfer. Drawing on this argument, Pack and Saggi (1997) finally conclude that “international technology transfer and domestic education–technological effort are two blades of a scissors whose joint effect will be considerably greater than the impact of either one alone” (p 95). While they perceive reverse engineering as a passive mode of technology transfer, they suggest developing countries’ firms interact with innovating firms to obtain the tacit component of foreign knowledge. Such a perspective, however, contrasts with the argument of Bell and Pavitt (1993), who underline the role of reverse engineering in the technological catch-up of newly industrialised Asian countries. In fact, Bell and Pavitt (1993) suggest reverse engineering as one of the indigenous efforts which can be well coupled with foreign technologies when transferred.

Although Pack and Saggi (1997) attempt to understand the dynamics of interaction processes between indigenous technological capabilities and foreign technology transfers, the majority of such influences have remained unclear. Furthermore, due to their methodology, which was based on literature review and document analysis rather than in-depth cross-sectoral or case study analysis, specific features of sector-specific or context-specific factors cannot be elucidated. Moreover, the question remains unanswered that although complementarity does exist, why do firms intend to rely on their own technological efforts in some circumstances, while intending to transfer technology from abroad in others?

Kim (1998) studied Hyundai, the Korean automotive company, to understand how organisational learning is progressed during the technological catch-up process. He exercises the substitution/complementarity concept in his study and explained how both indigenous and foreign technology sources are coupled to upgrade the level of organisational knowledge. He develops a model in which absorptive capacity plays a significant role in migratory knowledge acquisition. He also explains how Korean governmental policies have played an important role in the success of Hyundai.

In 1999, Radosevic published a book entitled *International Technology Transfer and Catch-up in Economic Development* in which he collected a large number of studies about the role of indigenous versus foreign knowledge in the technological catch-up process. The basic assumption of Radosevic’s book is that technological catch-up requirements for developing countries have changed since the 1960s and 1970s, in that developing countries today use technology transfer as a mechanism for fostering growth rather than import substitution. Radosevic differentiates technology transfer policies before and after the 1980s, and argues that after the 1980s developing countries have used technology transfer as a learning device in order to catch up, and hence both indigenous technological efforts and foreign technology transfers complement each other. Meanwhile, government policies are important but governments are no longer the key players in technology transfer contracts; instead, firms are at the heart of technology transfer processes. Based on Radosevic (1999), Table 3.1 summarises technology transfer policies and issues before and after the 1980s.

Table 3.1: Historical Comparison of Technology Transfer (TT) Policies

	The 1960s and the 1970s	**After the 1980s**
Key TT issues	▪ Contractual terms and conditions ▪ TT channels did matter (neglecting the role of firms)	▪ Indigenous firms' capabilities use technology imports as a learning device and as a form of leverage for further innovation ▪ Appreciation of the role of firms as a key agent of TT
Firms and governments	Firms' technological behaviour was to a great extent determined by government policy (firms were passive)	▪ Active involvement of domestic firms ▪ Macro-organisational strategy ○ TT as a domestic policy ○ Networking capability
Indigenous R&D and foreign technology	As a substitute	As complementary
TT channels	▪ Hierarchy of TT channels ▪ Formal channels were important	▪ Multiplicity of channels ▪ Informal channels are more important (alliance, subcontracting)
TT policy approach	Import substitution	Market access as learning inducement (export-led growth)

Source: Adapted from Radosevic (1999)

Radosevic (1999) believes that despite the general acceptance of a complementary relationship between indigenous technological efforts and international technology transfer, there is not enough empirical data to support this view and the substitution idea remains because "it is primarily a policy induced idea" (1999, p 119). He emphasises the role of the technology life cycle, and comments that in-house technology efforts have been more often a substitute for foreign technology in the case of 'mature' technologies in developing countries. However, he criticises the substitution idea, and argues that "the main problem in the substitution idea is not its feasibility but its cost and the dynamic potential of technological development behind the protective barriers. If a policy of forced substitution goes too far, as happened in India, much of the technology effort can be socially wasteful and redirect technology effort in directions which are not dynamic in the long term" (1999, p 119).

Radosevic is more inclined towards the complementary idea however, he challenges the simple acceptance of complementarity and notes that "generalizations are difficult as there are many factors in the market structure and the economic behaviour of the firms that interfere with this relationship" (1999, p 116). The discussions of Radosevic (1999) show that although the majority of studies have been inclined towards the complementarity idea, the dynamics of complementarity still remain unclear and the policy conclusion is not a simple generalised statement.

The outcomes of these discussions have encouraged researchers to focus on the processes of interaction between the two main knowledge sources, and to approach the dilemma with a dynamic perspective in their analysis. The studies have also tried to differentiate between developed and developing country contexts, as Bell and Pavitt (1993) distinguished between the processes of technical change.[34] In addition, as each sector has its own players, technologies and institutions that require different policies, the studies have attempted to examine substitution/complementarity in specific industries instead of in non-focused discussions.

Caloghirou et al (2004) examined five sectors[35] from seven European countries[36] to analyse the complementary and substitutive relationships between the internal capabilities

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[34] Bell and Pavitt (1993) show that the process of technical change in developed countries is based on innovation-diffusion models, while in developing countries these perceptions lead just to the accumulation of physical equipment and consequently the catch-up is hindered rather than hastened. This is why they distinguish between production capacity and technological capability.

[35] Food and beverages, chemicals (pharmaceuticals excluded), radio/television and communication equipment and apparatus, telecommunication services, computers and related activities.

of the firms and the external sources of knowledge for innovative performance. In their study, the separating element between internal and external capabilities was firm boundaries, not domestic/foreign capabilities. However, the study offers some insights regarding the notion of substitution/complementarity. Caloghirou et al. examine the research through survey analysis methods, and build the study on two basic concepts. The first concept is that of knowledge creation using a shared space of emerging relationships, which was originally developed by Nonaka (1994) and Nonaka and Takeushi (1995). Caloghirou et al (2004) argue that such an interactive context directly relates to the generation, utilisation and distribution of knowledge. The second concept is the openness of the firm to external sources.[37] The openness helps the firm to develop information and knowledge. Caloghirou et al (2004) conclude that both internal capabilities and openness toward knowledge sharing are important for upgrading innovative performance.

The application of the knowledge management concept by Caloghirou et al (2004) in substitution/complementarity literature provides a useful insight. It highlights the methods that facilitate the creation and transfer of knowledge in intra-firm and inter-firm contexts, which have been discussed by Von Korgh et al (2000) and Nonaka and Toyoma (2003). A closer look at these studies revels that the transfer of physical aspects of technology from the North to the South does not necessarily entail catch-up, and perhaps leads to falling behind, an issue that has been mentioned by Bell and Pavitt (1993) and Freeman and Hagedoorn (1994). In addition, it reveals that knowledge is transferred and created through a dialectical process (Nonaka and Toyoma 2002) and in a context in which many contradictions or considerations are synthesised through dynamic interactions between individuals, organisations and the environment (Nonaka and Toyoma 2003).

In fact, the main stream of neo-classical economics treats the process of technical change as an exogenous variable (Rosenberg 1976). Furthermore, the neo-classical theory of the firm assumes the firm as a passive entity, which merely adapts to the environment and never tries to shape it (Teece 2003). Von Korgh et al (2000) and Nonaka and Toyoma (2003) criticise these assumptions and show that they lead to an underestimation of the important role of tacit knowledge and interactive environments in which tacit knowledge

[36] Greece, Italy, Denmark, the UK, France, Germany and the Netherlands
[37] Patents, journals, reverse engineering and the internet

can flow and circulate within firms. Their new perspective results in adequate attention being paid to the absorption of tacit knowledge in interactions with foreign firms in the context of catching-up. This is why the new perspectives of Nonaka (1994), Nonaka and Takeushi (1995), Von Korgh et al (2000) and Nonaka and Toyoma (2003) have illuminated technology transfer issues and the technological catch-up concept.

However, the research of Caloghirou et al (2004) was carried out neither in the context of catching-up nor of developing countries. Catch-up discussions, particularly those related to developing countries, need to consider contextual factors, the role of foreign knowledge and the building of indigenous capability. Furthermore, although Caloghirou et al's research methodology reflects a diversity of sectors,[38] the study does not shed light on sector-specific factors and thus, in-depth analysis of dynamics and influencing factors and the process of their influence remains unclear.

Belderbos et al (2008) examine similar issues but in the Japanese context. Using econometric methods, they explore the simultaneous impact of local R&D and intra-firm international technology transfer on productivity growth in foreign affiliates in a large sample of Japanese manufacturing affiliates. The study suggests that "international technology transfer and local R&D are complements: the marginal impact of technology transfer is greater if the affiliate also engages in local R&D and vice versa" (2008, p 317). However, their study focuses only on multinational firms' activities in the Japanese context, which are not concerned with catch-up, nor are they in the context of a developing country. Besides this, Belderbos et al generalize that host countries' trade policies and tax or tariff subsidies are not effective tools to stimulate domestic R&D efforts, and perhaps such policies reduce productivity growth. This statement contrasts with a number of cases discussed above, where it has been shown that governments play an important role in supporting domestic industries, particularly in the early phases of the catch-up process.

Ruckman (2008) analysed the US biopharmaceutical industry to understand whether internal R&D and external technology sourcing via acquisition have a complementary or substitutive relationship. Her research confirms complementarity.

The above mentioned recent studies were all implemented in the context of developed countries and all confirm the complementary relationship between indigenous

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[38] Survey analysis

and foreign technology sources. Although these studies have tried to be specific in their discussions, there remains a gap in the literature about developed countries in terms of sector- and firm-specific dynamics. In addition, these recent studies have not been undertaken within the framework of a developing country or a country or industry that is catching up. Therefore, the dynamics of the interaction between indigenous and foreign capabilities, particularly in the context of developing countries, and the influencing factors of these dynamics are still largely missing from the existing literature – the subject to which this thesis intends to contribute.

3.3.2 The Dynamics of Interactions: A New Approach

The broad literature review above on the subject of substitution/complementarity reveals a number of important points. Firstly, the studies in both the contexts of developed and developing countries have paid much attention to exploring the 'type' of relationship between indigenous technological efforts and overseas technology transfer. The proponents of the substitution idea argue that technology accumulation in the countries of the global South may result in falling behind rather than technological catching-up. They raise the concept of dependency in historical literature that perceives foreign technology transfer as a substitute for domestic technological efforts, thus creating a reliance on foreign technology. These discussions were initiated in the 1960s and 1970s when evidence of unsuccessful technology accumulation was observed in Latin America. In contrast, the changing conditions in trade and technology development over the last three decades have led to the perception of overseas technology transfer as something working in combination with indigenous efforts. Thus, scholars since the 1980s, based on empirical observations, have criticised the substitutive view and argue in favour of the complementary relationship. In these circumstances, the studies that focus on specific sectors have employed quantitative methodologies to explore the type of relationship between the two main knowledge sources.

Secondly, recent studies have focused only on specific sectors in developed countries. These studies confirm the complementary relationship between in-house and foreign technology sources. However, the dynamics of interaction and influencing factors are still largely missing from the literature.

Thirdly, the substitution/complementarity literature in the context of developing countries is confined to a small number of developing countries (India: Katrak 1997 and Lall 1985; Brazil: Braga and Willmore 1991; South Korea: Lee 1996, Kim 1998). The majority of these studies[39] aimed to find out the type of relationship between indigenous technological efforts and foreign technology transfer.

Fourthly, all the studies that have been reviewed pay inadequate attention to the dynamics of interaction between indigenous technology development and overseas technology transfer. The majority of researchers have been preoccupied with assessing the correctness of one of the ideas of substitution or complementarity. In other words, they have tried to prove one view and reject the other, while a dynamic perspective on the analysis or interpretation is largely absent. The literature has paid inadequate attention to the complexity of the process, problematic situations, and the coexistence of influencing factors. The extent to which the interaction processes between these two main knowledge sources can be reduced to investigate only the type of relationship is, of course, a controversial question.

Fifthly, in dealing with indigenous and foreign knowledge, the existing literature, in general, assumes two scenarios for a latecomer firm engaged in the technological catch-up process. In the first scenario, the firm is able to choose 'only' one of the two possible sources: develop indigenously, or transfer from abroad. In this option, the two possible sources are substitutes for each other. In the case of in-house development, the firm will face two types of problems. The first problem relates to the cost of technology development in terms of human resources and associated labour costs, infrastructure and physical equipment. The second problem is the time when the firm acquires technology. In these circumstances, the firm is probably a long way away from developing technology, and assuming it does achieve the technology or knowledge, it is uncertain whether the technology can compete in the market because other firms may develop newer technologies, and these newer or upgraded products will be in the markets. However, the

[39] Kim (1998) tries to understand the dynamics of catch-up in the Korean context and his study contributes to providing useful insights on the substitution/complementarity literature, though the influences on the processes have not been analysed.

positive consequence of this path is the building of indigenous technological capabilities. In contrast, if the firm decides to import technology from overseas sources, it is uncertain whether indigenous workers can acquire the transferred technology and catch up, although the firm is able to supply the market. In the long-run, if the firm is not able to acquire knowledge, it will inevitably import new technology in future, and thus the firm will be dependent on foreign sources.

In the second scenario, the firm chooses both of the two knowledge sources. However, it is reasonable to pose the question of whether latecomer firms (or even firms in developed countries) possess endless amounts of money with which it can invest in both indigenous R&D efforts and in transferring technology from abroad. Does it have plentiful human resources through which it can manage both local R&D and international technology transfer?

A closer look at the findings of the substitution/complementary studies and the successful catch-up cases reveals that despite the complementarities between indigenous technology development efforts and overseas technology transfer (based on the absorptive capacity concept), they have an interchangeable role. The studies show that firms tend to choose both of the two knowledge sources (Bell and Pavitt, 1993) but 'partially', because the firm, due to its prior knowledge base and its contemporary efforts, not only is able to absorb the transferred technology but also is able to actively involve itself in the transfer process. This argument is also mentioned by Lee (2005), who believes that Korean firms, in the late stages of catching-up, collaborated with foreign companies in the form of co-development rather than OEM subcontracting. He argues that despite the lack of sufficient capability and a core knowledge base, the Korean firms had some complementary assets, which were created by indigenous R&D efforts. Moreover, at some stages the need for foreign knowledge is much higher than at others (Lall, 1985). Therefore, although foreign knowledge and domestic efforts complement each other and the importance of both sides is emphasised in the literature, the evidence shows that firms often dynamically change the contribution of both knowledge sources in terms of resource allocation (financial and human resources). In some circumstances they may invest more in indigenous capability building than in foreign knowledge sources, and vice versa. The extent of the contribution depends on the dynamics of the process and associated influences. However, this cannot be reduced to a static trade-off between these two knowledge sources (Pack and Saggi 1997). Radosevic (1999) argues that "the optimal trade-off between imported and domestic technological effort cannot be answered in general for any country. It is very much an industry-specific relationship" (p 120). Thus, the extent to which domestic and overseas technology sources contribute to the technological catch-up process depends not only on national level but also on sector and firm level influences. Furthermore, as technological catch-up is a long and dynamic process, the extent of these influences may change. Hence, the dominance of foreign or indigenous knowledge may change depending on influencing factors.

This thesis approaches this issue from a different perspective than that of the traditional literature. It argues that a 'dynamic approach' is needed to study the interaction processes between these two main knowledge sources. This is because technological catch-up is an extraordinarily complex process within which the interaction processes between indigenous and overseas knowledge sources are influenced by various national, industry and firm level factors, and thus it is often necessary to view the issue from different angles for different industries as well as for different countries. These influences may present simultaneously – beyond the will or power of managers and policy makers – and that has to be recognised, analysed and dealt with. Therefore, understanding the interaction processes between indigenous efforts and overseas technology transfer cannot be reduced to examining only the type of relationship. Instead, far more attention needs to be devoted to identifying the influences and understanding how they affect the technological catch-up processes. Therefore, the dynamic approach in this thesis reflects two main characteristics, which originate from the meaning of 'dynamic' in the literature:

- The technological catch-up process is a non-stop and ongoing process in which latecomer firms constantly engage with indigenous and overseas knowledge sources.
- The process is changing over time. There are many influencing factors and latecomer firms face various difficulties and challenges throughout their development. A dynamic view allows one to understand these influencing

factors, complexities and difficulties. It also provides insights to understand how latecomer firms deal with these issues.

The dynamic approach facilitates reaching a deep understanding of the interaction processes between these two main knowledge sources. It helps scholars to approach the cases at hand more competently and to understand their complexities more clearly. The extent to which latecomer firms deal with these challenges and difficulties still remains unclear. Conventional substitution/complementary literature often ignores these aspects of the process. The new approach suggests a method of questioning and a method of thinking by which scholars are able to approach the reality and understand its complexity. This perspective not only embraces economic aspects but also sheds light upon political and social dimensions. It is able to interpret how the interaction processes between indigenous and overseas capabilities are influenced by political, contextual, and other factors. The new approach requires strong qualitative methods to be operationalized, which will be explained in Chapter 4.

However, before any attempt to operationalize this perspective in a specific context is made, it is necessary to scrutinise the literature to discover the findings of previous studies. Although the number of studies focussing on the dynamics of the interaction processes between indigenous and overseas capabilities is limited, their findings can provide useful insights for this thesis, because, in examining the type of relationship, these studies mention a few influencing factors in specific contexts. Therefore, summarising these factors can facilitate the building of a framework specifically for this thesis. The next section will review the literature on influencing factors in the substitution/complementary debate in order to identify the different influences which have been mentioned implicitly or explicitly in the literature.

3.3.3 Influencing Factors

The purpose of this section is to analyse the relevant studies that might be utilised in different contexts in order to develop a preliminary framework for undertaking research in the Iranian context. Further details will be explained at the end of this section and in the methodology chapter. However, at the outset it should be noted that this thesis, as discussed in the above sections, perceives substitution/complementarity literature as one of the main elements of the technological catch-up concept. From this perspective, technological catch-up is the bigger picture and substitution/complementarity is a smaller part of the framework. Thus, in order to explore the influencing factors in the area of substitution/complementarity, the possible candidates for influencing factors should be identified. These factors might not be relevant to the substitution/complementary literature; however, they should be taken into account before examining issues of dynamics in the Iranian case.

One of the first attempts to understand the dynamics of technological catch-up was the research implemented by Bell and Pavitt (1993). In their qualitative study on the industrialisation of developing countries, they emphasise the supportive role of governments in the East Asian newly industrialised countries where international technology transfer was used as a channel for active engagement in the technological learning process. Bell and Pavitt (1993) believe that in the successfully caught-up countries, foreign technology intensively linked into the process of domestic technological accumulation. However, bringing government into the discussions entails many political, economic and institutional factors which have been missing in the substitution/complementary literature.

Hobday (1994), in his study on the electronics industry in four Asian 'dragon' economies,[40] mentions a number of firm-level factors and explains how these factors influence the interaction of in-house and foreign technologies. He maintains that the existence of skilled local entrepreneurs was an essential factor in all of the countries studied, except for Singapore. "In the absence of such entrepreneurs, Singapore chose to rely on foreign TNCs" (1994, p 358). The corollary of this position is that although Singapore has

[40] South Korea, Singapore, Taiwan and Hong Kong

benefited from foreign technology flows, it chose a particular technology transfer method (TNCs) in order to cope with the absence of skilled local manpower. Hobday (1994) also believes that although there have been different industrial structures among these four countries, the existence of a high level of domestic competition played a major role in all four. Furthermore, "at the corporate level, the coupling of technological learning with export demands enabled latecomers in each economy to climb the technological ladder and progressively reduce the technological gap between themselves and the international market leaders" (1994, p 358). Hobday also believes that governmental investment in education and the coupling of the education system with industrial needs was a success factor in these countries. Such a line of reasoning implies an important role for the national/sectoral innovation system in technological catch-up where universities and other educational institutions are well linked with industry. However, Hobday's study was not in a macroeconomic context and hence it has left unanswered a number of questions, which this thesis intends to answer.

Lee (1996) studied some of the influencing factors – mostly relevant to government policies – in the Korean context. He maintains that government policies have played an important role in domestic R&D efforts at the level of the economy through the interplay of three factors, namely tax privileges, tariff reductions for R&D facilities, and access to subsidised credit, which is granted by the Korean government to R&D institutes. Lee also states that "there is no peculiar relationship between firm size and R&D efforts in LDCs such as Korea. Beyond the naturally expected positive relationship between firm size and commitment to R&D efforts among the whole population of firms, firm size does not affect the intensity of R&D efforts" (1996, p 206). Lee's study does not include political or other industry/national level influences, but it sheds light on the details of government policies in the interaction processes between domestic and foreign technology in the Korean context.

Katrak (1997) examined government policies and quantified the variables in the Indian context. He tries to investigate whether an enterprise's decision to use imported technologies depends on it having initially undertaken technological efforts. Katrak's research reveals that there is little influence on this. However, a closer look at the main arguments of the dynamic capabilities of the firm reveals that Katrak's research findings on technological capabilities are superficial. Firstly, he equates technological capabilities with market value and therefore reduces it to measuring the number of patents and similar data. However, in accordance with the resource-based view of the firm (Barney 1991; Nelson 1991; Penrose 1959; Prahalad and Hamel 1990; Eisenhardt and Martin 2000), dynamic capabilities are process-oriented and often relate to a set of processes like product development, strategic decision making and alliancing. Secondly, Katrak's view is in contrast with the necessity of initial technological capability development before entering into international technology transfer contracts for those countries wanting to catch up (Freeman and Hagedoorn 1994; Pack and Saggi 1997).

At the same time, Pack and Saggi (1997) undertook a broad literature review and address some influencing factors in the substitution/complementarity discussions. The addressed factors can be categorised into two different types: internal factors (to the firm), and external factors. Regarding the first type, Pack and Saggi argue that transferring technology to domestic firms requires a threshold level of capabilities otherwise such a transfer will not be successful. As a result, their analysis implicitly emphasises the role of the absorptive capacity of the domestic firm in the interaction processes between indigenous and foreign knowledge sources. This argument renders it similar to Hobday's (1994) argument of the importance of the existence of skilled entrepreneurs, and also Freeman and Hagedoorn's (1994) views, explained above. From this line of reasoning it can be argued that the technological capability of the domestic firm does play a key role in the interaction processes between these two main knowledge sources.

The second part of the study of Pack and Saggi (1997) aims to identify the external factors. They firstly explain the often-cited role of government policies. Pack and Saggi argue that in most African countries, Latin America, and South-East Asia, with the existence of the import substitution policies, importing new products and processes has been discouraged by tariffs and quotas. Consequently, local firms are not in a competition environment, and thus there is not any demand for technology development. In contrast, in the newly industrialised Asian countries, supportive government policies – mostly market protection – have been accompanied by penetration of foreign markets. Since export markets require the acquisition of new knowledge about products and processes, Pack and Saggi argue that such circumstances resulted in a strong demand for technology development. Drawing on Pack and Saggi's research outcomes and also on Hobday's

(1994) study, it would appear that government competition policy plays a key role in the interaction of domestic and foreign technology sources.

The geographical factor is another external factor that Pack and Saggi (1997) discuss. They argue that "some of the most innovative high-tech industries in the world tend to be clustered geographically (e.g., the computer industry in Silicon Valley). This suggests that there are important local externalities in industries that generate modern technology geographical location of R&D matters" (1997, p 82). Drawing on this, they argue that "the context in which technological effort occurs is very important" (1997, p 82). Despite such an insightful argument, their study lacks any evidence in the context of developing countries. Furthermore, their study has left unanswered the role of geographical agglomeration in the interaction processes between the two main knowledge channels in detail. In general, although Pack and Saggi (1997) discuss a few influencing factors, their study is primarily based on literature review rather than on factual cases.

Kim (1998) elucidates in detail the role of government policies in the catch-up process of Hyundai, the Korean automotive company. He argues that the supportive policies of the Korean government included "protection of the local market from new entrants and from new foreign knock-down imports, a significant tax reduction, promotion of vertical integration leading to new business opportunities, preferential financing, tax concessions, and an administrative decree to guarantee a large market share for indigenous model" (Kim 1998, p 511). These forms of support were coupled with step-by-step deadlines for domestic car companies to catch up; that is to say that the government would reduce its supportive policies on certain dates. In these circumstances, the local company tried to enhance its capabilities at each stage of technology transfer through coupling migratory knowledge with its own technological efforts. It succeeded in leaping from assimilation of assembly operations in the 1960s to being an independent innovator in the 1990s. Kim's study was a step forward in unfolding the role of governments in the technological catch-up process.

Confirming the important role of technological capability of the firm, Radosevic (1999) argues that "to understand the relationship between technology imports and 'in-house' R&D, we need also explicitly to take into account the technology capability of a firm (or country)" (1999, p 118). However, this is not possible at the country level because it seems unfeasible to measure, study and analyse a specific country's technological capability. Radosevic recommends understanding context-specific factors (firm-, sector- and country-specific factors), otherwise the complementary/substitution concept cannot be understood. He comments that:

> "In more general terms, the relationship between imported technology and domestic technology effort cannot be correctly understood out of the specific country, industry or firm context. Moreover, host country specific factors should be explicitly taken into account. This leads to a better understanding of the dichotomy between a general acceptance of the complementarity hypothesis and the lack of robust empirical support for it." (1999, p 117)

Two points emerge from Radosevic's argument. Firstly, the substitution/complementarity concept cannot be deeply understood until there is an approach in which influencing factors can be identified and analysed. With respect to this, this thesis introduces the dynamic approach in which the evaluation of factors is considered. This view is also supported by Pack and Saggi (1997), who argue that taking a dynamic viewpoint sheds light on the complexity of the issue. Secondly, influencing factors cannot be reduced to a number of firm level factors because the firm is not separate from its context and thus the external factors are in the dynamics.

Radosevic (1999) also raises a new factor in the discussions, namely the age of technology. He believes that "older technologies are wholly available through licensing and they entail less unfavourable transfers" (1999, p 141). This implies that the age of technology can influence the interaction processes between indigenous and foreign technology sources because new technologies may be difficult to transfer.

Mazzoleni and Nelson (2007) studied the role of public domestic research institutions in the catch-up process and analysed a number of common features in this process. Their study has some important implications for substitution/complementary discussions. Firstly, they argue that although benefiting from cross-border flows of knowledge (people) is as a common feature in all successful catch-up cases, the role of indigenous technological and scientific capabilities is becoming increasingly important. This is particularly the case with regard to today's advanced technologies, which have strong connections with scientific knowledge. This argument also implies that in the interaction processes between indigenous and foreign knowledge sources the importance of the indigenous part in science-based technologies[41] is much higher than in other industries. This interpretation relates to the factor of the nature of technology (the type of relationship between science and technology), which was introduced by Pavitt (1984), and which was explained in the substitution/complementary discussions by Radosevic (1999).

Secondly, they believe that the loose IPR regimes in latecomer countries help domestic firms to replicate and then master the imported technologies. Framed in this way, if a latecomer country does not seriously restrict IPR regimes, there could be a chance for the latecomer firms to replicate, assimilate and internalise imported technologies. This line of reasoning proposes the status of IPR regimes as an influencing factor in the interaction processes between the two main technology sources.

Thirdly, Mazzoleni and Nelson (2007) argue that "research in universities and public laboratories can play a strong supporting role, and one that is likely to take on different connotations at different stages of the process of catching-up" (2007, 1517). They believe that, although not systematically studied, the successful cases confirm the importance of public research institutions and their supportive role for industries in the catch-up process. This line of reasoning is based on an innovation system approach, which was explained in Section 3.2.3. Their study reveals that public research institutions and their supportive relations with industries are factors in the interaction processes between indigenous and foreign technology sources. In other words, if a latecomer firm has access to local supportive public research institutions (e.g. universities), not only may the need for foreign knowledge diminish but also imported technology, based on the absorptive capacity concept, can be better assimilated, and thus technological catch-up will be more feasible.

The most recent and comprehensive work on identifying and analysing influencing factors in the technological catch-up process is the paper of Malerba and Nelson (2007) presented at the Globelics Conference. Malerba and Nelson contextualise the discussions across different sectors and in different countries, thus showing the outcomes to be more specific and reliable. They distinguish two different types of factors across specific countries and sectors, namely common factors affecting catch-up in all sectors, and sector-

[41] Pavitt's taxonomy is illuminating here. However, Mazzoleni and Nelson (2007) believe the science-based industry category includes older fields such as chemical and electrical engineering and modern fields such as computer science, biotechnology, and immunology.

specific factors. However, since their study is still in progress, they mention that their analysis is preliminary and further outcomes will be published in future. The common factors are as follows:

- Learning and the formation of capabilities of domestic firms: confirming the previous studies, they argue that the pattern of capability building across countries and sectors is similar. They state that the first stage is characterised by subcontracting and low cost production for domestic or foreign markets. In the next stages the relationship between domestic and foreign companies evolves to create of partnerships and joint ventures, also moving from low-end products to more innovative products. While Malerba and Nelson maintain the complementary relationship between indigenous and foreign knowledge, they argue that different trajectories of capability development across countries are present for the same sectors.
- The development of advanced human capital: the international mobility of skilled labour from advanced countries is a significant help for catching-up, particularly in high-tech sectors.
- Access to foreign knowledge and international networking: maintaining the variety of channels, Malerba and Nelson argue that "when access to foreign knowledge did not take place, as in telecommunications in India and Brazil, the catch-up process has been seriously impaired" (2007, p 13).
- Government policy: as in former studies, Malerba and Nelson also believe that government policies stimulate capability building and learning in all sectors.

The above findings have some implications for the concept of this thesis. They consolidate previous studies' findings about government policies, the importance of foreign knowledge flows and the variety of foreign technology transfer channels.

Malerba and Nelson (2007) also identify a number of sector-specific factors in the catch-up process, as follows:

- Industry structure: this is one of the most frequently changeable factors across sectors. Some sectors are distinguished by large firms (e.g. the automotive and telecommunications industries), while others by small firms (e.g. software and agro-food).
- Multinationals and channels of networking: in some sectors multinational corporations dominate (e.g. software, pharmaceuticals and semiconductors), while in some others licensing and joint ventures are extensively used (e.g. the telecommunications and automotive industries). Furthermore, some sectors are characterised by vertical networks (semiconductors and software), while others by collaboration in production or mutual R&D (e.g. the telecommunications and automotive industries).
- Demand: this could be oriented towards export markets (semiconductors, telecommunications, pharmaceuticals, software, and automobiles), domestic markets (this depends on the size of the domestic market, e.g. China and India in pharmaceuticals) or segmented [42] (pharmaceuticals and telecommunications in China).
- Universities and public research laboratories: these contribute in two ways: by providing advanced training for domestic firms, and by conducting research in scientific and technological areas.
- Finance: this "has played a particularly relevant role in those sectors in which entrepreneurship needed resources to fund new ventures. This has been the case for software and pharmaceuticals" (2007, p 18).
- Types of government policy: although government policies have played a crucial role in all catch-up cases, the types of policies are notably different from one country to another and from one sector to another. They might be in the form of R&D support, fostering competition, protection of domestic markets via taxes or tariffs, creation of advanced public research institutes and so on.
- Standards, regulations and norms: these "have been important in fostering or in blocking catch-up in various sectors" (2007, p 18).

[42] Malerba and Nelson argue that "sometimes the type of products offered to the domestic market by local firms has been different from the products and production done for exports within the international division of labor" (2007, p 16).

- The systemic and dynamic relationship among these factors: Malerba and Nelson believe that such a relationship exists among factors across sectors in a 'complementary' way. "Often one factor alone cannot trigger catch-up unless other factors are present, and they feedback on each other" (2007, p 19).

The above findings have some implications for studying the interaction processes between indigenous technology development efforts and foreign technology sources, which is the topic of this thesis. Firstly, the size and the orientation of the domestic market influences these processes. In some countries with large domestic markets, like India and China, supplying the domestic market with the support of government policies enhances domestic firms' capabilities. This is recognised as an opportunity through which domestic firms can build initial technological capabilities before their entrance into international competition.

Secondly, universities and public research institutes can provide trained human capital and know-how in the catch-up process. Besides this, the involvement of these institutes in technology acquisition from foreign countries improves the absorption of foreign technologies. Universities and public research institutes often support domestic companies in mastering transferred technologies. Furthermore, the recent evidence in the literature indicates that the role of domestic universities and public research institutes is becoming increasingly important.

Thirdly, the status of IPR regimes in the host country may influence indigenous technology development efforts. In the presence of loose IPR regimes, domestic firms can enhance their technological capabilities by reproducing parts.

Fourthly, in all successful catch-up cases, government policies, although different from one country to another, have played a significant role. Domestic firms with the support of their governments are better able to deal with foreign firms. These policies are important particularly at the early stages of development. However, the successful catch-up cases show dynamic and strategic types of government policies, as long-term domestic market protection leads to technological stultification.

The most recent study on analysing the factors in the technological catch-up of a latecomer firm has been undertaken by Bell and Figuieredo (2010). Emphasising the importance of explaining factors in technological catch-up studies, they propose a framework within which the factors are categorised based on their levels, as follows:

- Firm-specific factors: factors such as age, size, ownership and market-orientation of firms have been commonly examined. Bell and Figuieredo (2010) argue that the studies, so far, have said little about dynamic aspects of innovation capability creation and accumulation.
- Industry specific factors: "there has been little systematic analysis of how inter-industry differences influence the paths of capability deepening in latecomer firms" (Bell and Figuieredo 2010; p 51). They believe that the studies in this area have pervasively relied on quantitative analysis such as patent data, and have overemphasised technological regimes. Thus, inter-industry differences in accumulation of innovation capabilities are still a major challenge.
- Country-level institutions: sets of rules, guidelines, principles and frameworks, such as the Washington Consensus and import substitution policies.
- Economy-wide incentives: trade policy can influence production capacity but not innovation capability. Market protection needs to be matched by incentives for performance and efficiency, and should be complemented by competition policy.
- Global-level factors: global financial, economic, and other multinational organisations such as the World Bank, the IMF, and the WTO influence and shape the context in which latecomer firms operate.

This proposed framework enables researchers to approach the understanding of the complexity of latecomer firms' catch-up processes. It also provides useful insights into analysing the dynamics. Despite this comprehensive framework, however, a clear distinction between influencing factors on different levels is not always possible. For instance, the influencing factors are often found in the vague boundaries between the industry level and the country level, though a rough distinction is feasible provided a specific firm, industry or country is being discussed. There are often no clear boundaries between industrial policies and government policies. Intellectual property rights regimes are recognised as country-level institutions, but they may become much more industry-specific, although they originate from global institutions like the WTO, TRIPS, etc. Similarly, in the analysis of university-industry linkages, the policies are often in a complex relationship between state-level policies and industry-specific dynamism. This thesis would argue that the best way to engage in understanding the dynamics of latecomer firms' technological catch-up process is to contextualise the discussions in a specific country or industry, as discussed in earlier sections.

Moreover, Bell and Figuieredo (2010) leave many questions about the complexity of interactions between indigenous and overseas technology transfer unanswered. Their categorisation of factors largely helps to understand the dynamics; however, the complexity of factors, the type of their influence on latecomer firms, the interrelationships between the factors and the interaction processes between knowledge sources remains unclear in Bell and Figuieredo's study.

Drawing on the preceding literature review, Table 3.2 summarises and categorises the influencing factors discussed, explicitly or implicitly, in the technological catch-up literature. However, as explained at the start of this section, it should be noted that these factors have been elicited from the technological catch-up literature and not all the factors in the table may necessarily be relevant to the dynamics of interactions between indigenous and overseas knowledge sources. Nevertheless, this thesis consciously applies those factors to this sub-section of technological catch-up literature. With respect to this, Table 3.2 provides a preliminary framework by which this research is operationalized. Through this framework, this thesis will examine the possibility of engaging these factors in the Iranian context and will explore other possible engaged factors.

Table 3.2: Influencing Factors That Affect Technology Catch-up

	Influences	Literature
Internal Influences (Firm Level)	Technological capability and absorptive capacity	▪ Initial technological capabilities development (Freeman and Hagedoorn 1994) ▪ Existence of skilled local entrepreneurs (Hobday 1994) ▪ Absorptive capacity (Cohen and Levinthal 1989; Kim 1998; Lee 2005) ▪ Threshold level of capabilities and absorptive capacity (Pack and Saggi 1997; Radosevic 1999) ▪ Production experience (Katrak 1997)
	Continuous interactions with foreign players	▪ Cross-border flows of knowledge (Bell and Pavitt 1993; Freeman and Hagedoorn 1994; Pack and Saggi 1997; Radosevic 1999; Lee 2005; Malerba and Nelson 2007; Mazzoleni and Nelson 2007)
External Influences (Industry, National, and Global Level)	Government policies	▪ Investing in learning in international technology transfers (Bell and Pavitt 1993). ▪ Investment in education (Hobday 1994). ▪ Tax privileges, tariff reduction, public procurement (Lee, J., 1996; Lee, K., 2005) ▪ Substitution policies (Pack and Saggi 1997; Katrak 1997) ▪ Financing, tax reduction, protection of the local market (Kim 1998) ▪ New regimes after the 1980s (Radosevic 1999) ▪ Stimulating capability building and learning (Malerba and Nelson 2007)
	Size and orientation of markets	▪ Export-led growth, high degree of domestic competition (Hobday 1994). ▪ Competition environment and penetration of export markets – the case of new Asian industrialised countries (Pack and Saggi 1997) ▪ The size of domestic market (Malerba and Nelson 2007) ▪ Domestic market can be important (Whang and Hobday 2010)
	Geographical agglomeration	▪ Clustered geographically (local externalities) (Pack and Saggi 1997; Lee 2005)
	Type of technology	▪ The nature of the technology – age of technology (Radosevic 1999) ▪ Pavitt's taxonomy of innovations (Pavitt 1984; Bell and Pavitt 1993). ▪ Type of technology – connections with scientific knowledge (Mazzoleni and Nelson 2007)
	Universities and public research institutes	▪ Coupling of the education system with industry needs (Hobday 1994; Lee 2005) ▪ Universities and public research institutions (Mazzoleni and Nelson 2007) ▪ Universities and public research laboratories (Malerba and Nelson 2007)
	Intellectual property rights regimes' status	▪ Loose IPR regimes (Mazzoleni and Nelson 2007) ▪ IPR may have different effects on different sectors (Malerba and Nelson 2007)

This matrix provides multiple levels of insights. Firstly, it reflects the possible important factors involved in the interaction processes between indigenous and overseas capabilities. These factors – implicitly or explicitly – have been discussed in the technological catch-up literature, and rarely in the substitution/complementarity literature, through different studies in different contexts. They are the possible relevant factors for the specific purpose of this thesis.

Secondly, the matrix categorises the influencing factors based on a latecomer firm perspective. From this perspective, the technological acquisition process of a latecomer firm is influenced by intra-firm factors as well as by other external influencing factors. The external factors are on a broad range of industry, national and global levels and a clear distinction between them, as argued above, is not always possible. For instance, gas turbine technologies (as will be explained in Chapter 5) are highly advanced and sophisticated and the international market for these products has an oligopolistic structure. In these circumstances, the type of technology is a global level factor. It means that acquiring gas turbine technologies is a challenging process around the globe. Furthermore, the IPR regimes are industry-, country- and also global-level factors. Thus, any exclusion of these issues in the categorisation of the factors will be an *ad hoc* view. With respect to this, the matrix above categorises all industry-, national- and global-level factors as factors external to the firm.

Thirdly, which is very important, this matrix incorporates the development of a structured framework for the operationalization of the study. It provides a platform from which the study can approach the case with more readiness, and allows the influences of the Iranian context to be better explored. The details of the framework, as well as its operationalization, will be discussed in the methodology chapter (Chapter 4).

3.4 Conclusions

This chapter began with the investigation of the basic concepts associated with the idea of interaction processes between indigenous technology development efforts and overseas technology transfer. Targeting technological catch-up, this chapter elucidates the different conceptual dimensions. It has explained how two other important concepts, namely the national/sectoral innovation system and the international technology transfer, have contributed to the evolution of the technological catch-up literature. The national/sectoral innovation system literature sheds light on the role of indigenous technology development efforts, learning systems, institutions and engaged organisations. On the other hand, international technology transfer has contributed to the technological catch-up concept by highlighting the role of foreign knowledge sources and various technology transfer channels. This chapter elucidates how in the successfully caught-up countries overseas technology transfer flows underpin local technological capabilities.

The corollary of these basic concepts is the emergence of the substitution/complementarity literature, to which this thesis intends to contribute. The literature tries to understand the relationships as well as the interactions between indigenous and overseas technology sources. Based on a comprehensive literature review, this chapter analyses the previous studies and contributes to the literature with a new perspective. This thesis contends that technological catch-up through indigenous R&D and/or technology import embeds contradictory influences that are present simultaneously – beyond the will or power of managers and policy makers – which have to be recognised, analysed and taken into account. This chapter shows that the majority of the previous studies examining the type of relationship and the reviewing the frameworks have paid inadequate attention to the dynamics and the associated factors, challenges and difficulties.

This thesis introduces a different mode of thinking to that of the traditional literature. This thesis suggests the 'dynamic approach' to study the interaction processes between the two main knowledge sources. It argues that technological catch-up is an extraordinarily complex process within which the interaction processes between indigenous and overseas knowledge sources are influenced by various national-, industry- and firm-level factors, and thus different industries and different countries often require examination from different angles. In this way, understanding the interaction processes between indigenous efforts and overseas technology transfer cannot be reduced to examining only the type of relationship. Instead, far more attention needs to be devoted to identifying the relationships and understanding how they influence the processes. The dynamic approach facilitates reaching a deeper understanding of the interaction processes between these two main knowledge sources. It helps scholars to approach the cases at hand more competently and to understand their complexities more clearly.

The most recent few studies have perceived the importance of the dynamic analysis of latecomer firms' technological catch-up processes. They have attempted to understand the different levels of factors and have tried to explain why they are important. In spite of these insights, these studies have been confined to the general context of developing countries rather than concentrating on specific countries or industries. Furthermore, they have not focused on the influencing factors in the interactions between indigenous and overseas technology sources. As explained above, this thesis intends to understand this issue by focusing on a specific country and sector. The next chapter explains in detail how this thesis approaches the question.

Chapter 4 : Research Methodology

4.1 Introduction

In reviewing the relevant literature, the previous chapter aimed to define the theoretical and analytical framework that guides this thesis by determining what is known about the dynamics of interaction between indigenous technological efforts and overseas technology transfer. It draws on concepts from discussions of technological catch-up and substitution/complementarity, supplemented with arguments stemming from the national/sectoral innovation system literature and that on international technology transfer. All the reviewed concepts will be contextualised in the gas turbine industry in Iran. The purpose of this chapter is to outline the research methodology and explain the methods employed to address the research questions. It elaborates how the research was designed and implemented.

The initial plan for this research was to run a pilot study to understand the general characteristics of Iran's gas turbine industry and to explore the general trend of the concepts of technological catch-up and international technology transfer in this industry. After generic data collection, the research focused on an extensive and comprehensive literature review to locate the research in the literature and to identify the existing gaps. Such a comprehensive literature review resulted in building the theoretical framework for the case study. Having established the background and the analytical framework, the research moved on to design the research method.

This chapter is organised as follows. Section 2 illustrates how the research, including the fieldwork and data gathering, was designed. It explains the methodological principles through which it relate the theoretical framework to the empirical research. In fact, it constructs a logical connection between the theoretical framework and the research questions on one side, and the employed methods on the other. Based on this, the section will then explain which methods have been specified and designed for the research.

Section 3 elaborates the research process and explains how the data gathering processes were implemented during the fieldwork. The interviewed companies and organisations, as well as the collected documents are explained in detail. Section 4 presents the conclusions to this chapter.

4.2 Research Design

"A research design describes a flexible set of guidelines that connect theoretical paradigms first to strategies of inquiry and second to methods for collecting empirical material" (Denzin and Lincoln 2003, p 36). The term 'flexible' in the above definition is very important as it represents research in qualitative studies in the social sciences as an evolutionary process. A research design generally involves a clear focus on the research question(s), the purpose of the study, thinking about what type of information is most appropriate to answering the research question(s), and which strategies are most effective for obtaining it (Denzin and Lincoln 2003, p 36). Although this thesis would argue research as an evolutionary process, it emphasises clarity and lack of ambiguity in each stage of the research. According to Denzin and Lincoln (2003), one of the main functions of research design is that it situates researchers in the empirical world and connects them to specific sites, persons, groups, institutions and bodies of relevant interpretive material, including documents and archives. Therefore, a research design may help to clarify how the researcher addresses issues such as data gathering methods, reliability of data and triangulation.[43] It may also help to clarify the research agenda and endow a readiness as well as preparation for the researcher to consider the important issues *ex-ante*, during and after the implementation period of the fieldwork.

In this thesis, the first step in designing the research was to understand the methodological principles that have been elicited from the theoretical framework (Chapter 3). These principles construct a logical connection between the theoretical framework and the associated research question(s) and methods of data gathering. The following sections will explain these issues.

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[43] Comparing the responses of individuals to ascertain areas of common agreement.

4.2.1 Methodological Principles

The main objective of this thesis is to understand the dynamics of interaction between indigenous technology development and overseas technology transfer in the technological catch-up process. This includes identifying, analysing and interpreting intra-firm as well as external influences. Furthermore, this thesis will investigate how these influences affect the catch-up process. Have they had positive or negative impacts on technological catch-up? As explained in the theoretical framework (Chapter 3, Section 3.3.2), in contrast to previous studies which were often based on quantitative analysis, mostly survey analysis, this study is interested in exploring the dynamics and gaining an in-depth understanding of the influences. The case study method, by going into great depth in a single case, enables the researcher to understand the dynamics present within one setting (Eisenhardt, 1989). This method also enables the researcher to investigate important topics not easily covered by other methods, and can illuminate a particular situation, to get a close (that is to say, in-depth and first-hand) understanding of it (Yin, 2006).

This thesis aims to clarify how influences affect the interaction processes between indigenous and overseas knowledge sources, and why. These influences are not necessarily under the control of latecomer firms' management or even industrial policy makers. However, as argued in Chapter 3, these influences should nevertheless be recognised and managed. The case study method has a distinctive advantage when "a how or why question is being asked about a contemporary set of events, over which the investigator has little or no control" (Yin, 2003; p. 9).

Furthermore, studies that have investigated the complementary and substitutive relationships between indigenous technology development and overseas technology transfer have been confined to a small number of developing countries (India: Katrak 1997 and Lall 1985; Brazil: Braga and Willmore 1991; and South Korea: Lee 1996 and Kim 1998). There have been no detailed studies of these relationships with respect to Iran. It is well worth studying in the Iranian context, as another developing country, in order to shed light on the concepts and to provide further insights.

Beyond this, the land-based gas turbine industry is recognised as a very complex and highly advanced industry. The existence of few suppliers throughout the world is one of the main characteristics of this industry (Watson 1997; Watson 2004a; Magnusson et al, 2005). As will be explained in Chapter 5 (Section 5.4.3), the global market for these products is in an oligopolistic form in which there are often two or three lead suppliers and the others are followers. Similarly, Chapter 8 shows that in India, as in Iran, there is only one state-owned company which undertakes the manufacturing of gas turbines. Likewise, in China there are only three state-owned companies which are in the same business. These are the only companies in Asia (except Japan) which are involved in the gas turbine industry.

The above discussion puts forward the theoretical rationale of using a case study method in this thesis. However, the case study method is often criticised based on traditional prejudice about case studies' limitations in generalising their research findings. Yin (2003) argues that the short answer to this question is that "case studies, like experiments, are generalizable to theoretical propositions and not to populations or universe. In this sense, the case study, like the experiment, does not represent a sample, and in doing a case study, your goal will be to expand and generalize theories (analytical generalization) and not to enumerate frequencies (statistical generalization)" (p. 12).

Although this thesis is justified that, due to its research objectives, such as the importance of exploring the dynamics, the case study method must be used, it takes a strategic approach to substantially contribute to the literature of the gas turbine industry. This thesis aims to understand insights into gas turbine industries in other developing countries, particularly China and India. However, according to a broad literature review as well as to the Sussex Energy Group database, the gas turbine industries of developing countries have not been systematically examined to date. This could be because of the specific industry characteristics which will be discussed in Chapter 5 (Section 5.4).

Obviously undertaking the same level of research with regard to India and China as Iran is not possible in one PhD thesis. Therefore, this thesis strategically focuses on what documentary evidence exists for China and India (primarily reports, such as those produced by the IEA, journal papers, and reliable websites) and on conducting secondary interviews, which will be explained in detail in the following sections. This provides a limited opportunity to compare the findings from the Iranian context with the experience of two other developing countries. It also helps to understand the similar and different features of the gas turbine industry in Iran when compared to the two largest emerging economies.

This comparison will include technological capabilities and associated influences as well as policy drivers. Thus, the essential principle of this research is to operationalize the theoretical framework via a case study and compare the findings with the Chinese and Indian contexts. However, the case study method is applicable in a broad context, as a case might address a country, an industry, a firm, a programme or a project. Therefore, the case and its scope must be clarified before specifying the details of the methodology and assigning the methods.

Based on all the above considerations, the following criteria can be identified for the methodology:

I. It must be able to interpret the process of combination of indigenous expertise and imported knowledge in a dynamic manner; that is to say, how the two parts of this tango interact with each other to produce richer expertise.

II. The case of this thesis is the gas turbine industry; however, data collection methods should be able to reveal the firm-, the industry-, the national- and the global-level influences on the interaction between domestic and foreign technology sources. In order to 'operationalize' this part of the theoretical framework, Table 3.2 is reproduced. It provides a platform for the design of the data collection methods. Based on the categorisation criteria, explained in Chapter 3 (Section 3.3.3), the influences in this thesis are considered internal or external to the firm.

Table 4.1: Conceptual Framework for Exploring Influences

	Influences in Theory	Contextualised in Iran
Internal Influences (Firm Level)	Technological capability and absorptive capacity	Investigation of the level of technological capabilities of the Iranian firms and understanding of their prior knowledge base and the intensity of their efforts in their interactions with domestic and foreign knowledge sources.
	Continuous interactions with foreign players	Foreign sources of knowledge to be identified and the type of their interactions to be explored. How have Iranian firms tried to continuously benefit from overseas knowledge?
External Influences (Industry, National, and Global Level)	Government policies	How have Iran's governmental policies supported (or not supported) the growth of the gas turbine industry? What types of policies?
	Sanctions	Iran has been under US-led sanctions since 1996. How has this sanction regime influenced the industry?
	Size and orientation of markets	Iran's domestic electricity market is a large and growing market. How has such a market influenced the industry? Is the industry's growth based on the domestic market or on exports?
	Geographical agglomeration	Is geographical agglomeration the case in Iran's gas turbine industry? If so, how does it influence the interaction processes between domestic and overseas technology sources?
	Type of technology	Gas turbines are technologically advanced products. How this has influenced the evolution of the Iranian firms?
	Universities and public research institutes	How do Iranian firms interact with domestic universities, and do these interactions contribute to the industry's evolution?
	Intellectual property rights regimes' status	Has the status of the IPR regime in Iran influenced the industry?

Source: Author

Note: The influence of sanction regimes has not been discussed in the technological catch-up literature to date. However, they should be considered and analysed in the Iranian context. International sanctions are global-level influences.

III. As discussed in the theoretical framework, in the technological acquisition process, benefiting from indigenous capabilities and transferring foreign technology constructs a problematic situation for policy makers, in which they should manage influencing factors and considerations. The methods must be able to allow one to recognise how policy makers deal with these issues and how they cope with the associated tensions and challenges.

The above considerations render specific methods able to respond to the concerns of dynamics, offer great in-depth analysis and reveal the influences.

4.2.2 Specifying Data Collection Methods

The previous discussions result in the need to search for highly qualitative data, which are able to reveal how Iran's gas turbine industry has combined indigenous technological efforts and overseas technology transfer, and how policy makers have dealt with problematic situations and influences. The interviews carried out needed to be designed in a way that would enable them to reveal challenges, difficulties and influences. These data should also be able to reveal the technological development process in detail. Furthermore, supporting documents are needed to underpin the perception of the industry development processes and to unfold the historical evolution in detail. The interview data will provide an in-depth understanding of the process, but documents will help to fill the possible gaps in the interview data, particularly where precise details are needed.

Therefore, to answer the research questions, interaction with the parent enterprise authorities, the managers of the subsidiaries and state-level policy makers is crucial. This study planned to conduct multi-level interviews and document collection.

4.2.2.1 Designing the Interviews: Interview Protocol

According to the above requirements, an interview protocol was designed to gather the data. This protocol incorporates some important guidelines or principles that are outlined in this section.

The first principle in this protocol clarifies the levels of interviewees.

- Interviews with the parent state-owned enterprise (MAPNA) authorities. This group of people can help to understand the firm-level as well as the industry-level influences. On one hand, they are connected to state-level authorities and hence they can reveal the consequences of government policies on technological catch-up. On the other hand, they manage the parent enterprise and its subsidiaries and thus they can expose the challenges faced by these companies. Furthermore, they can connect the interviewer to the relevant subsidiaries, those manufacturing gas turbine components and parts.
- The second level of interviewees is subsidiaries' managers. This group of people firstly consists of company managers including managing directors, board members and technology transfer project managers who have been responsible for acquiring technological knowledge through the two main knowledge sources. These project managers on one hand interact with foreign companies, and on the other they interact with indigenous organisations to acquire technical knowledge. Hence, these key informants could help to understand how the industry deals with those two technological sources and what factors influence their pathways. By understanding the influencing factors at this level, the thesis is able to interconnect between the firm-level and industry-level influences which seem vital in answering the research questions.
- The third level of interviewees is the state-level authorities, including deputies and managers in the Ministry of Energy. This group of people reveals the concerns and understanding of the state-level authorities of Iran's gas turbine industry. They can also reveal the state policies in the development of the industry.

The second principle in the protocol is to conduct the interviews in a 'trusting context'. This thesis intends to reveal the dynamics and associated challenges in the interaction between indigenous and foreign knowledge sources. Accordingly, as argued in the sections above, in-depth qualitative data are required. Experienced managers and other informants are rich sources of data. Interviews with these people require building a trusting context in which the interviewee feels comfortable and will therefore aim to fully share his or her knowledge, experience and feelings about the issues. For this purpose, the thesis planned to explain to the interviewees that this thesis is a non-commercial piece of research and that the company managers can benefit from its findings. Furthermore, prior personal relationships between the interviewer and a number of managers helped to build a trusting context for the research.

The third principle is to conduct the interviews in a 'flexible and dynamic way'. With the aim of conducting purposeful interviews, a preliminary framework was prepared before conducting the interviews. However, due to the need for in-depth qualitative data, the interviews were planned to be conducted in a flexible way, by which the interview is guided along particular paths depending on the expertise of the interviewee and on emerging issues. This enables the research to capture unknown areas that the theoretical framework may not have considered. Furthermore, it seems that such flexibility is mandatory because the Iranian context is un-trodden territory in science and technology policy studies. Therefore, flexibility is a matter of degree in the interviews. Moreover, the questions were designed in ways that would be able to reveal the challenges, influences and considerations, and to show how the managers dealt with these issues.

4.2.2.2 Document Collection Strategy

The fieldwork aimed to collect any documents relevant to the research topic including managerial board reports, technology development reports, international technology transfer reports, conference papers and relevant archival documents. These documents provide evidence of the industry's efforts and challenges during the technology acquisition process. Besides this, the reliability and validity of documents are significant criteria.

4.3 Research Process

Building the theoretical framework and designing the research methods provided a readiness and purpose for fieldwork implementation. The pilot case study also provided background knowledge about the industry and its structure. The next step was to implement the field study. This section elaborates the case study phase in detail.

4.3.1 Interviews

According to the theoretical framework and methodological principles, the interviews were classified and conducted at the three levels of government, industry and firm. These three levels of interviews were conducted concurrently. The first level was the state-level authorities who could explain state policies, their perspective on the gas turbine industry and past and future trends. It was possible to conduct interviews with Ministry of Energy managers. The managers in the deputy section have worked for many years in Iran's power plant industry and were therefore able to reveal many aspects of it. However, the main focus is on the industry level, where the MAPNA Company and its subsidiaries are developing and transferring technologies. On this level the main interviews focused on the CEOs, the boards, and the deputies. Furthermore, in order to access the details of how these companies have acquired technologies and how they have combined transferred technologies with in-house capabilities, the interviews extended to each company's project managers, technology transfer offices and R&D managers.

In the pilot study, the interviews were conducted as open-ended interviews because the objectives were to explore general aspects of the industry, to acquire some insights for the research, and to make connections with informants to be interviewed again in future. In contrast, during the main fieldwork the interviews were conducted as semi-structured interviews[44] because the use of strictly structured interviews might lead to some important aspects of influences vital to this thesis being missed, while open-ended interviews might have been difficult to manage and might have raised many unrelated issues. After being asked the major questions, the interviewees were encouraged to explain other relevant issues in a conversational manner. In total, 22 interviews were conducted, of which four were in the pilot stage and 18 were during the main fieldwork. Furthermore, I was allowed to participate in ten formal meetings in MAPNA Group and its subsidiaries. These meetings were great opportunities to become familiar with the industry dynamics. Table 4.2 illustrates and summarises the detail of the interviews, their main scope, and the companies involved.

[44] In semi-structured interviews a respondent is interviewed for a short period of time after which the interview may remain open-ended and assume a conversational manner, but in which the interviewer is more likely to be following a certain set of questions derived from the case study protocol (Yin 2003).

Table 4.2: Conducted Interviews at a Glance

Interview Level	Company Name	Interviewed Sections	The Core Topics
National	Ministry of Energy	Deputy of Energy	Addressing all government policies (including national energy policies) in the evolution of Iran's gas turbine industry (can reveal political, economic, environmental and IPR factors)
Industry and Firm	MAPNA	Board, Vice President, R&D, Engineering, and System Deputies	Influential factors, technology acquisition trends, challenges, university-industry linkages, technological capabilities, strategies, contrasts between in-house and foreign technology sourcing
	TUGA	Engineering Deputy, Technology Transfer Office, Project Managers	Characteristics of gas turbine models, technology transfer sources, indigenous technology sources, level of capabilities, strategies, challenges, contrasts between in-house and foreign technology sourcing
	PARTO	Board, CEO, R&D, Sales Managers, Engineering Deputy	Characteristics of gas turbine blade models, technology transfer sources, indigenous technology sources, level of capabilities, strategies, challenges, contrasts between in-house and foreign technology sourcing
	MECO	Board, Engineering Deputy, Project Manager	Electrical systems of domestic gas turbines, technology transfer sources, indigenous technology sources, level of capabilities, strategies, challenges, contrasts between in-house and foreign technology sourcing

Note: The table generally shows the interviewees' roles. The interviewees requested individual names not be disclosed.

The interviews had some key features, as follows:

Firstly, some people interviewed were not only active in the industry, but were also affiliated to universities and other R&D institutions. This offered an opportunity to ask about university-industry issues and to understand what types of technologies have been developed through these relationships.

Secondly, although difficult to arrange, all interviews were organised as face-to-face interviews rather than telephone conversations. This enabled me to build a more trusting context and helped me to follow up subsequent issues more easily.

Thirdly, some of the more important interviews were organised as two or three sessions. Although difficult to arrange, this enabled the researcher to focus on the themes of the first session, find the gaps, and pursue these issues in the following interview sessions. Furthermore, this helped establish a trusting context. In these cases, the first session was conducted as a semi-structured interview and the following sessions (the second and the third sessions) were conducted as open-ended interviews.

Fourthly, I did not follow the procedure of conducting a number of interviews and then attempting to analyse the data. After each interview, I tried to understand the key points and then attempted to validate the information provided in relation to other interviews and my own experience. I have a mechanical engineering background and am familiar with design and manufacturing processes. In conjunction with my working experience in international companies, this substantive knowledge of the technological domain not only helped me to validate the data but also facilitated my access to detailed technical and managerial documents. In some instances, I tried to access original documents such as project reports to understand the accuracy of claims in the interviews. This was particularly the case when respondents claimed the contribution of their own indigenous efforts in acquiring a specific technology. Among the interviews, there was only one instance in which the degree of indigenous efforts in developing a specific technology had been overestimated. In this case, two different opinions emerged regarding the assimilation of one specific procedure of manufacturing technology. One respondent claimed the totally indigenous development of this technology, while another interpreted it as combining significant indigenous efforts with consultancy from foreign firms. Post-interview activities and accessing the original technical reports revealed the accuracy of the second claim.

In fact, technological evaluation by the interviewer and post-interview activities increased the verisimilitude of this study and helped in reaching reliable data rather than simply an account of the opinions of those interviewed. This was particularly the case in identifying the manufactured gas turbines in Iran and comparing them with the international leaders' products. Distinguishing between the technological requirements of the different vintages of gas turbine needs a detailed technical knowledge. Comparisons of these different vintages should take into account efficiency, availability, price, reliability and repair-ability parameters. Similarly, the comparison between Iranian and Chinese and Indian companies, in terms of technological capabilities, requires a broad basis of technical knowledge. For instance, assembling a new and advanced product does not necessarily reflect a firm's technological capabilities. Manufacturing some gas turbine parts, such as blades and vanes (Chapter 5), requires the assimilation of highly sophisticated manufacturing knowledge. Likewise, manufacturing one model of gas turbine does not necessarily imply having design knowledge. In spite of the close interconnectivity between design and manufacturing knowledge in the gas turbine industry, they are very distinct features of technological knowledge. Design knowledge reflects the capability of a company in designing and perhaps manufacturing a variety of products while manufacturing knowledge reflects the capability of producing specific products. Therefore, if one company claims in its documentation the manufacturing of the latest version of a gas turbine, or if an interviewee claims to have all aspects of gas turbine technology, these statements should be validated by supplementary research activities.

The above characteristics led to the gathering of reliable and in-depth qualitative data. It is worth mentioning that although there were some contacts with lead suppliers (particularly with Siemens) in the wider gas turbine market, the study did not aim to conduct interviews with the foreign partners – those who had technology transfer agreements – of MAPNA Group. This is because this thesis aims to understand the influences and the dynamics of technological catch-up of an Iranian firm in the Iranian context. However, it is evident that accessing the foreign partners of MAPNA Group could provide further information concerning the two sides' interactions. Interviewing these foreign companies would enhance the likelihood of understanding the Iranian firms' challenges in acquiring the technologies as well as their degree of contribution to the development of some specific technologies. However, time and resource limits prohibited gathering this additional evidence. Nevertheless, the lack of these interviews does not invalidate the findings of this thesis because of the salient features of data gathering undertaken in this research.

4.3.1.1 Secondary Interview Data

MAPNA Company compares its position with technological leaders as well as with follower companies, e.g. in China and India. The managers have carried out some benchmarking studies and comparative reports. They often compare their technological capabilities as well as their markets with those of other developing countries' enterprises, and have undertaken some visits to these countries and visited the plants. Hence, the pragmatic way – with respect to research limits on time and resources – to gather data on the situation in China and India was to conduct interviews with these people. This thesis planned to conduct interviews with those MAPNA managers who had visited Chinese and Indian sites. Such data would not only provide some insights into Chinese and Indian enterprises, but also reveal how the MAPNA managers think about other followers and potential rival companies. Furthermore, people affiliated with SPRU have also had experience in the Chinese and Indian contexts and therefore interviews were conducted with these people. In parallel, a number of connections with Siemens Company were made. These contacts helped to build an understanding of cutting edge knowledge of the gas turbine industry.

4.3.2 Document Gathering

Further to the interviews, many documents have been gathered in order to complement the interview data. These supporting documents can reveal technological development processes in detail. The main data sources are described below:

- Technology transfer projects between the parent enterprise and its subsidiaries and overseas partners. These documents are typically in the form of North-South contracts; however there are other salient features which will be described in Chapter 6.
- Technology development projects between the parent enterprise and its subsidiaries and domestic universities and R&D institutions. These documents reveal the level of industry-university linkages and mutual collaboration in detail (elaborated in Chapter 6).
- Internal engineering, R&D and managerial documents. These documents can help to understand intra-firm technological efforts in the parent enterprise and its subsidiaries (elaborated in Chapter 6). Furthermore, these documents helped to understand the complexity of technologies as well as the companies – domestic or foreign – who are engaged in the business of gas turbine manufacturing (elaborated in Chapter 5).
- Ministry documents and reports, which can help to understand government policies (including national energy policies) and industrial development strategies. These documents are also important in explaining the research context (see Chapters 2 and 8).
- Conference attendance: the First National Conference on Thermal Power Plants was held on May 16-17 2009 at the University of Tehran. It was organised by MAPNA Company and the University of Tehran, and was sponsored by the Ministry of Energy. This was a great opportunity to be involved in the latest discussions about the power plant industry in Iran. The conference had two main topics: strategic and management discussions, and technical papers. Conference proceedings include many useful papers in

terms of the Iranian power plant and power equipment industry (detailed in Chapter 2). Furthermore, the conference was the first national conference on the power plant industry, and hence the majority of managers and policy makers participated; the event therefore provided an opportunity to have face-to-face discussions with top-level MAPNA managers as well as with state-level policy makers (see Chapter 7). It also facilitated subsequent interview arrangements.

In addressing comparative objectives, two types of documents were used in the thesis. Firstly, MAPNA managers have written a number of reports about the position of Chinese and Indian firms. These archival reports are in the form of visit reports or benchmarking reports which include many useful materials. Secondly, the SPRU database (in the Sussex Energy Group) has a number of reports which explain the Chinese and Indian contexts, particularly in the sense of policy drivers. This literature provides useful insights for this thesis and helps to compare the findings with these two developing countries' enterprises. Moreover, IEA reports contain reliable data about energy policies in developing countries as well as the power generation industry. These reports help to connect the evolution of the industry in each country with its energy policies and hence provide a platform for comparing it with other developing countries that also have gas turbine industries. Since the companies in Iran, India and China are all state-owned and their numbers are very limited, this comparison can be framed in a reasonable manner.

Another important part of the documentation is related to the necessary technical and market data which facilitates the understanding of the challenges of the gas turbine companies in acquiring different technologies and competing with rivals. In fact, before any attempt to analyse Iran's gas turbine industry can be made, the technological requirements of gas turbines, the evolution of the technology and the structure of the market and of suppliers should be clarified. It should be set out which technologies can be distinguished as the main technological areas in the gas turbine industry, what are the technical specifications of these main areas and how they evolved, and how the companies compete in such an oligopolistic market.

Answering the above questions requires a huge literature review both in engineering as well as in policy studies. In order to understand the technical dimensions, various engineering documents such as gas turbine handbooks and published technical papers were gathered and studied. Simultaneously, the existing policy literature (which is limited in number), including journal papers and well-known global magazines (such as *Turbomachinery*) were gathered and studied during the research. The output of this investigation will be demonstrated in Chapter 5.

4.4 Conclusions

This chapter has clarified the research design, the research process and the methodology of this thesis. Drawing on the theoretical framework and the new perspective which this thesis introduces (Chapter 3), this chapter has specified the methodological principle that can bridge the theoretical framework and the empirical research. Based on these principles, the chapter has elaborated the research design. The interview protocol that was designed in order to provide interview guidelines was elaborated; this facilitated the undertaking of purposeful interviews and the gathering of rich data. Similar guidelines were applied with regard to document collection.

The research process has been explained in detail, and the interviewed organisations and companies have been described in this chapter. As explained, the thesis employed multi-level interviews. All the interviews were organised as face-to-face interviews. Although organisation of this was difficult, in some interviews it was organised to carry out the interview over more than one session, because some interviewees were more knowledgeable than expected and could greatly contribute to different aspects of the research. In these cases, the first session was conducted as a semi-structured interview and the next sessions (the second and third sessions) were conducted as open-ended interviews. Furthermore, in order to provide useful insights for other contexts, the secondary data for India and China were gathered. These data enable the study to compare the findings for Iran with other similar developing countries and help the thesis findings to become more generalizable.

Chapter 5 : Gas Turbine Industry: Technological Requirements and Industry Characteristics

5.1 Introduction

This chapter aims to clarify the gas turbine industry both in terms of its technological and market dimensions. Before any attempt can be made to analyse Iran's gas turbine industry and examine the interaction processes between indigenous and overseas technologies, the technological requirements of gas turbines, the evolution of technologies, and the structure of the market and the suppliers should be clarified. Such an illumination prepares the way to scrutinise the Iranian case and analyse its technological growth, the level of its capabilities, its sources of technological knowledge and its market. Therefore, this chapter will analyse the gas turbine industry in three main sections.

Section 2 explains the technological requirements for the gas turbine industry. It responds to the question of which technologies can be distinguished as the main technological areas in the gas turbine industry. What are the technical specifications of these main areas and how did they evolve? Deep understanding of the technical knowledge and its categorisation is necessary in order to understand the industry's dynamics and processes at the global level and subsequently locate the Iranian case. Section 2 also provides a background from which to analyse the challenges and difficulties of the Iranian case during technological catch-up. Gathering these valid and up-to-date technical data was based on my working experience and fieldwork data gathering, and benefits from the relevant technical papers.

Section 3 charts the evolution of land-based gas turbine technologies. It summarises the historical developments of these technologies. Such an analysis helps to understand the industry dynamics and the stages of each technology, demonstrated in the previous section.

Section 4 illuminates the structure of the gas turbine industry in terms of market, product and supplier dimensions. Nowadays, gas-fired power plants and in particular CCGTs have increasingly become the predominant choice in fossil fuel power plants, both globally and in Iran. The advantage of CCGTs over other types of thermal power plants typically relates to the advancements in gas turbine technology. The gas turbine is the main machine of the CCGT (Islas 1997) and is recognised as the most technologically advanced part of the CCGT (Watson 2004*a*). Therefore, the key specifications of CCGTs – such as high levels of technology, complexity and efficiency – are generally attributable to the gas turbine. This section will show that while the market for gas turbines has become large and will increase in future, the lead suppliers, as well as the latecomers, are confined to a small number. It will also explain why and how government policies have played an important role in this market. Section 5 draws conclusions regarding the technological and industrial structure of gas turbines.

5.2 Technological Knowledge Requirements

The gas turbine is often recognised as the main machine and the most technologically advanced part of a gas-fired power plant. The required technologies for manufacturing gas turbines for electricity power have incrementally evolved over the last 50 years. The formation and utilisation of gas turbine technology in power generation is attributed to an increase in demand in the 1960s and 1970s (Watson 2004*a*) when engineers became convinced that aircraft jet engines were an important technological opportunity for electricity generation (Islas 1997). All manufacturing technologies have progressed over the last decades, and companies have strived to manufacture efficient, durable and less fuel-consuming gas turbines in a rapid time and with less wastage.

Computerisation of manufacturing technologies (such as CAD/CAM[45] and CNC[46] machines) have enabled manufacturers to manufacture highly accurate parts and

[45] Computer Aided Design (CAD) is the use of computer systems and software to design two- or three-dimensional virtual models of products for the purposes of visualisation, analysis and testing. Computer Aided Manufacturing (CAM) is the use of computer-based systems including software and hardware to assist the manufacturing processes. When both terms CAD and CAM are used simultaneously, e.g. CAD/CAM, it implies that the output of CAD is translated into manufacturing instructions and hence is the input of CAM.
[46] Computerised Numerical Control (CNC) is a method of programming used in modern manufacturing processes. The programming, which includes a sequence of actions as well as the geometry and duration of

components. Similarly, design technologies have greatly benefited from computer simulations and new material sciences. Both design and manufacturing technologies are closely interrelated to each other and the interaction between design and production units seems vital in designing advanced parts that are able to be manufactured. Gas turbines, as sophisticated, systematic and multi-disciplinary products, are a set of various interrelated subsystems. This section elucidates the technological requirements for gas turbines based on a process-based approach, which implies the explanation of a set of interrelated technological activities required to design and manufacture gas turbine components and parts. The data has been gathered through an in-depth fieldwork study of MAPNA and its subsidiaries, as well as through the author's engineering background and knowledge.

5.2.1 Casting Technologies

The first stage of the manufacturing process of gas turbine parts typically involves the production of rough parts through casting or forging raw materials. The basic geometry and material characteristics are shaped in the casting process. Any existence of mocks or other imperfections in the cast parts can lead to catastrophic failures of machines when the parts are subjected to working loads. Aside from turbine blades, other gas turbine parts are often produced through typical casting processes. Turbine blade casting involves sophisticated techniques, advanced high temperature alloys, and the incorporation of a network of tiny holes within the hottest blades for cooling (Watson 2004*a*). The blades are also the most consumed parts in gas turbines, as they are subjected to very high temperature loads and therefore should be renewed more often than other parts.

Turbine blades are mounted by vanes on the turbine shaft. Vanes are recognised as the roots of turbine blades. Turbine blades are differentiated into two groups: stationary blades and rotary (or moving) blades. The stationary blades accelerate and conduct hot fired gases into the rotary blades. The rotary blades convert the kinetic energy of the gases into

each action, enables machines to manufacture products accurately and rapidly. Programmers often import CAD models as inputs.

the shaft rotating energy. Due to the rotation of the rotary blades and the temperature of the gases, the stationary blade temperature is higher than that of rotary blades and thus should have a high melting point. However, rotary blades are subjected to centrifugal forces and hence should be strengthened against both thermal and mechanical loads.

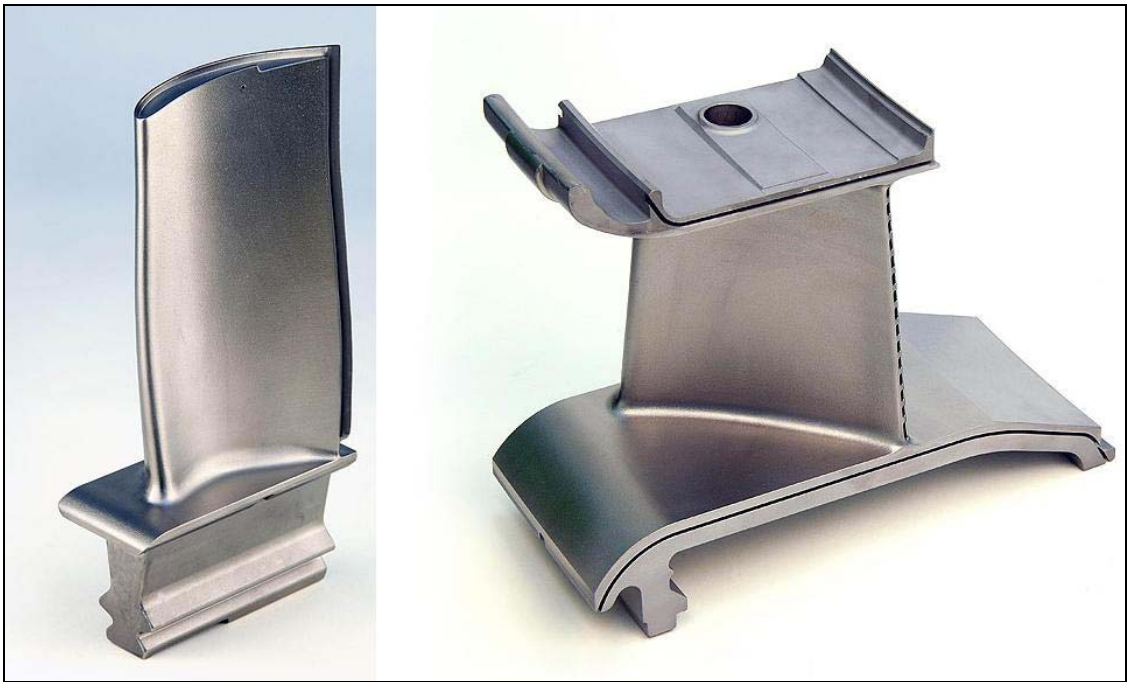

Figure 5.1: Siemens V94.2 Gas Turbine Blade (left) and Vane (right)
Courtesy of PARTO

For casting turbine blades, the first step is to make conceptual wax patterns of the blades. The wax patterns are used to make different layers of ceramic moulds after slurry coating and staco coating processes. The ceramic moulds are then subjected to a dewaxing process and are then put in the furnace. The output will be ceramic dies ready to be used for melt pouring which should be implemented in vacuum furnaces. The final process is solidification.

What demarcates the casting of gas turbine blades from other gas turbine parts can be summarised as follows:

- Gas turbines rotate due to the flow of hot fired gases through blades. The kinetic energy of the gases causes the rotation of the rotors and thus electrical power is generated. The efficiency of output power relates to the temperature of the gases. Higher temperatures of inlet gases leads to higher efficiency and higher output power (Giampaolo 2006). Turbine blades must be able to resist high-temperature working conditions and thus should have a very high melting point.
- They should be resistant against corrosion and oxidation in high-temperature working conditions.
- They should be strong and stiff under high-temperature working conditions.
- They should have reasonable production costs.

The above specifications are not achievable using basic metals and require the use of advanced metal alloys. At the same time, in order to increase durability and the creep-fatigue life cycle of the blades, cooling airflow should be employed at least for the first series of blades. This is realised by including very tiny holes in the blades through which the cooling air is circulated.

The alloys of gas turbine blades are mostly based on nickel or cobalt alloys, called 'superalloys'. Superalloys (or high performance metal alloys) are generally defined as metal alloys that have the characteristics below:

- The base metal is one of the three elements: nickel, cobalt, or iron.
- They should be able to maintain their corrosive resistance, failure strength and material structure while they are subjected to high temperature loads in a highly corrosive atmosphere.

The evolution and development of superalloy technology has its roots in aircraft jet engines. However, earlier aircraft engines had many problems in relation to their fatigue life cycle and efficiency. The main reason was the oxidation of two important elements, titanium and aluminium, in the air once the melted alloys were poured into the moulds. The oxidation process causes the formation of imperfections in the material structure and thus will shorten the life cycle. Engineers understood that vacuum casting can prevent oxidation and they therefore tried to adapt and develop vacuum casting technology in gas turbine blade manufacturing. Consequently, vacuum induction melting processes were developed.

Superalloys' material characteristics, vacuum induction melting and casting procedures coevolved in such a way that superalloys are now widely used in aircraft engines as well as in power generating gas turbines. Table 5.1 shows the share of superalloy application across different industries.

Table 5.1: Share of Superalloy Application in Different Industries

Industry	Application	Share (%)
Aircraft Industry	• Gas Turbines • Aeroplane Structure	72 8
Electric Power Generation	• Gas Turbines • Nuclear Power Plants • Other Fossil-fuelled Power Plants	10 2 1
Chemical Industry	-	6
Other	-	1

Source: Sims et al (1987); Tien and Caulfield (1989)

In addition to the past incremental technological developments in turbine blade casting, two recent technological innovations have recently been introduced to the electric power generation industry. The first innovation is directional solidification (DS). As cast turbine airfoils are typically polycrystalline, it is always possible that unwanted imperfections at grain boundaries, such as void formation, increased chemical activity, intergranular cavitation and slippage under stress loading will occur. These imperfections will gradually result in the catastrophic failure of the blade. DS technology was developed by Pratt and Whitney in the aircraft jet engine industry and was patented in 1966. However, it has recently been applied to land-based gas turbines and has been commercialised over the last decade. It allows lateral grain boundaries in the gas turbine blades to be eliminated, thus improving thermal fatigue life and increasing durability.

The second innovation in gas turbine blade casting was also introduced by Pratt and Whitney, namely 'single crystal' blades which were developed in the aircraft jet engine industry in the 1970s. This was an effort to eliminate grain boundaries from turbine blades and hence help to increase creep strength, thermal fatigue life and corrosion resistance. Similarly, single crystal blades allow for increased working temperatures from 150 to 200 degrees Celsius, thereby contributing to engine efficiency. In 1982, for the first time, single crystal technology passed the certificate flight tests by Pratt and Whitney and was then installed in the jet engines of the Boeing 767 and the Airbus A310.

The two innovations discussed above originally emerged in the jet engine industry. However, land-based gas turbines have a number of differences compared to aircraft jet engines. The main problem in land-based gas turbines is the size of the blades which are larger than jet engine blades and thus incur high numbers of imperfections and the difficulty of directional solidification in the blade material structure during the casting processes. Furthermore, the favoured material characteristics in aircraft jet engines and land-based gas turbines are different. Therefore, chemical and metal alloy specifications in aircraft engines are different than in land-based gas turbines. Considering these dissimilarities, the technological development of industrial gas turbines is generally a decade later than that of aircraft jet engines.

Both directional solidification and single crystal technologies are now maturing in land-based gas turbines. In 2003, General Electric, when demonstrating its new CCGT, stated that the gas turbine blades and vanes were made of single crystal materials. However, single crystal technology is expensive and the blades manufactured with single crystal materials have a low level of repair-ability. Thus, companies prefer the directional solidification process, as with recent advancements in coating technologies they are now able to achieve similar specifications at a lower cost.[47]

[47] Interview with the head of R&D, PARTO Company (20 June 2009).

5.2.2 Machining Technologies

Gas turbines are the product of various interrelated components and parts with different geometrical and material specifications. A number of those parts have accurate geometrical tolerances and some of them have very tight tolerances which are not achievable using ordinary machines and techniques. For instance, turbine blades typically have machining tolerances lower than 0.025mm. In addition, the machining of some specific parts is not as simple as with ordinary metals because of their ultra-stiffness and extra hardness. Turbine blades are manufactured with superalloys which are often recognised as difficult machine-able materials. The machining lines of gas turbine parts are often among the rarest and most specific orders for machining line suppliers. Besides this, in gas turbine manufacturing technology 'selection of machines' is perceived as a valuable knowledge as it is recognised as a mix of academic and practical knowledge. Understanding the fundamentals of manufacturing technologies, being up-to-date in terms of the latest manufacturing advances, and having profound knowledge of manufacturing processes are vital to design and the establishment of efficient and cost-effective manufacturing lines. Selection of machines and equipment, as knowledge of production lines design, is a 'tacit intensive knowledge'. The knowledge is accumulated through long manufacturing experience and in-depth knowledge of manufacturing processes. Machining line designers and process planners are capable of designing a number of machining sequences, the details of each sequence, and the integration of these sequences in order to optimise the whole process in terms of efficiency and cost-effectiveness.

Another important aspect of gas turbine machining is the extent to which all sophisticated manufacturing knowledge and experiences must be codified into clear, recognisable and programmable procedures by which the operators should be able to perform manufacturing processes. The operators are often working with codified instructions by which they perform a specific stage of the machining process. Due to the existence of high accuracy and tight tolerances in gas turbine parts, the complex machining procedures should be controllable and manageable. Thus, these codified instructions play a significant role in machining processes.

Further to these codified instructions, there are some specific procedures in gas turbine machining which cannot be codified and are very much dependent upon workers' skills. In other words, tacit knowledge of machining is characterised as an essential element for gas turbine machining, particularly for a number of parts such as turbine blades. Edges of the turbine blade should be manually deburred even when advanced and efficient machine tools together with the codified machining instructions are employed in the process. This complex task requires a very high level of skill which can only be transferred through training and face-to-face interactions. This implies that despite the recent advances in the computerisation of manufacturing processes, there are still some critical processes that should only be performed manually. These processes require a very high level of skills, which are difficult to transfer.

Figure 5.2: Deburring Gas Turbine Blade Edges, Which Can Only Be Performed Manually
Courtesy of Siemens Presspicture

The machining of gas turbine parts can be categorised into three major steps:

- Heavy machining: this step includes the main inner and outer casings and shafts which are usually performed by large CNC boring, milling and turning machines.
- Medium-small machining: this process includes machining of medium and small sized parts such as blade rings, bearings, discs and nuts. The machining process includes broaching, grinding, milling, machining centre and turning machines.
- Blade machining: this process is one of the key machining sequences which mainly includes STEM drilling, [48] creep feed grinding, electro discharge machining and milling.

The challenges and difficulties of machining processes for the first two groups are explained above. However, turbine blade machining has a number of unique features which demarcate the process from ordinary machining processes, although they are not as highly sophisticated as casting. The turbine blade machining process can be ascribed by two main characteristics:

- Superalloys are stiff and resistant to thermal loads and corrosion, and thus they are recognised as materials which are 'difficult to machine'. Due to lower thermal conductivity and intensive hardness, the cutting and milling machines are not as the same as for ordinary steels. Furthermore, the machining process of such stiff materials results in residual stress on the blades which incurs the lower strength of the blade or blade bending.
- Turbine blades have long and tiny holes to circulate cooling air through the blades. These holes are typically 300 millimetres in length and 1.5 millimetres in diameter, but could be different based on the blade size. As superalloys are

[48] In order to machine the cooling holes, a specific method namely, 'Shaped Tube Electrolytic machining (STEM)' is used. In this method drilling process is accomplished electrochemically. An electrolytic fluid is passed through a conductive tube to the workpiece while a DC current is passed and thus the material from the workpiece 'deplate' into the electrolyte and hole is formed.

recognised as difficult to machine, none of the ordinary milling methods are able to make these holes.

Figure 5.3: Blade Holes in GE Gas Turbine (Frame 9E)
Courtesy of PARTO

For the above reasons, specific machining methods are used for machining the turbine blade. The manufacturers use the ‘creep feed grinding’ method which is a highly accurate and efficient method in complex machining. In this method, the depth of cut is increased while the feed rate is decreased in comparison with normal grinding practices. All the above processes require expensive and technologically intensive equipment.

5.2.3 Coating Technologies

Coating systems are the last line of defense to protect equipment such as heat exchangers and gas turbines against corrosion, oxidation, and fouling (DeGaspari 2004). Many of the ordinary materials used in engineering are not strong against corrosion in high-temperature atmospheres. For example, under these critical conditions, carbon-alloyed steels decompose into iron oxides and eventually fail. In most nickel and cobalt alloys, it is not possible to achieve both optimised mechanical properties and corrosive resistance, hence the parts are often coated by a layer of materials that have corrosive resistance properties.

Coating technology is recognised as one of the key complex technologies in gas turbines. In land-based gas turbines over the last 20 to 30 years alloy improvement, directional solidification and single crystal technology have significantly contributed to the development of the industry, but arguably the emphasis has shifted to coating systems (Sourmail 2003). All types of gas turbines – including aircraft engines, land-based gas turbines, and marine engines – contain materials that should be resistant to high-temperature conditions; however, they should also be resistant to oxidation and corrosion. As explained above, manufacturers often use superalloys to achieve strong materials. The drawback of using such materials in the base alloys is that these parts are often become weaker against oxidation and corrosion. Therefore, coating techniques are usually used in order to strengthen these materials against oxidation and corrosion.

5.2.3.1 Different working conditions, different coatings

A gas turbine is a system of many complex and interrelated parts within which the working conditions are extremely variable in terms of temperature and pressure. Their values vary greatly from the combustion chamber (hot section) to other areas. These different conditions require different materials and different coatings. Turbine blades are subjected to high temperatures and high pressure loads and thus require strong materials as well as coatings resistant to oxidation and corrosion. In contrast, other parts, such as the drive shaft, work in a low temperature and low pressure environment but under extremely high mechanical loads which necessitate the use of strong and hardened materials. Similarly, there are some static parts such as air inlet housing which are subjected to static loads and thus there is no need to make them with very strong materials. Therefore, low pressure and low temperature parts are often manufactured from titanium which is ideal for strength and density. The parts operating at high temperatures and under high pressure should be manufactured from nickel-based superalloys. The static parts of the compressor are typically manufactured from ordinary steel alloys. These different areas are coated with different materials and using different techniques, which will be explained in the following section.

5.2.3.2 Coating Types

Coatings in the gas turbine industry can be categorised into two general types, as follows (Pomeroy 2005; Sourmail 2003):

- Diffusion coatings: these coatings are based on the principle of element (mostly aluminium) diffusion on the surface of the part by which it can be protected against corrosion and oxidation. "Diffusion coatings are formed by a chemical vapour deposition type processes such as aluminising or chromising or indeed codeposition of both Al and Cr" (Pomeroy 2005, p. 225).
- Overlay coatings: in contrast to diffusion coatings, overlay coatings provide more independence from the substrate alloy. They also have more flexibility in design through which the coating composition can be optimised for best protection (Sivakumar and Mordike 1989).

Each of the two methods above includes many other techniques which can be differentiated in terms of materials and processes. However, today, two main coatings are well-recognised and widely used in the gas turbine industry, as explained below.

MCrAlY

This coating is a type of overlay coating. The M of MCrAlY stands for either nickel (Ni) or cobalt (Co) elements, or a combination of both (when applied to steels, it can also be Fe), depending on the type of superalloy. Co-based alloys appear to have superior resistance to corrosion. The presence of a significant amount of chrome (Cr) gives these coatings excellent corrosion resistance combined with good oxidation resistance (Sourmail 2003). The Al of MCrAlY stands for aluminium content which is typically around 10-12 wt%. There is a trade-off in Al amount in the process because although it essentially improves the resistance against oxidation, it significantly decreases the ductility (Sivakumar and Mordike 1989). The Y of MCrAlY shows the presence of yttrium. Its main role is to combine with sulphur and prevent its segregation to the oxide layer, which is otherwise detrimental to its adhesion (Sourmail 2003). Nowadays, MCrAlY coatings have been increasingly used in gas turbines and are superseding diffusion coatings, particularly in heavy gas turbines (Okazaki 2001).

Thermal Barrier Coatings

In land-based gas turbines, the inlet temperature is normally higher than 1100 degrees Celsius and in modern gas turbines it is close to 1500 degrees Celsius (in aircraft jet engines the temperature is even higher). A thermal barrier coating is a type of overlay coating and is widely used in gas turbine hot section parts such as burners, transition ducts and blades in order to provide thermal insulation. The earliest TBC coatings were used in aerospace applications in the 1960s. They were used to coat the exhaust nozzle of the X-15 manned rocket plane and were developed by the National Advisory Committee for Aeronautics (NACA) (Cao et al, 2004). "The use of TBCs (100 to 500 mm in thickness), along with internal cooling of the underlying superalloy component, provide major reductions in the surface temperature (100° to 300°C) of the superalloy" (Padture et al, 2002, p. 280). TBC coatings can be used to reduce the need for blade cooling by about 36% while increasing the creep life of the blade. (Strangman 1985). The benefits of TBCs in terms of engine efficiency are comparable to those brought about by the replacement of directionally solidified alloys by single crystal ones (Strangman 1985). The important point in the application of TBC coatings is that although they insulate the parts against high temperatures, they are brittle and thus they can be easily cracked. Therefore, manufacturers often use MCrAlY coatings as an intermediate layer with TBC coatings over them. Figure 5.4 shows a schematic microstructure of a TBC coating. Bond-coat could refer to MCrAlY or other coatings which adhere to TBC coatings. However, thermally grown oxide (TGO) causes failure in the part after its fatigue life has occurred.

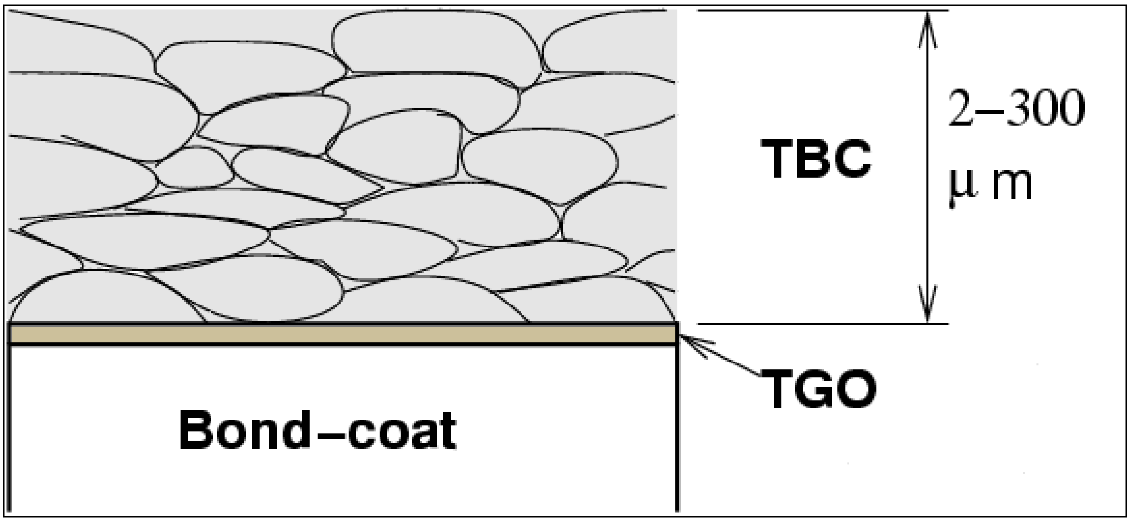

Figure 5.4: Schematic Microstructure of a Thermal Barrier Coating (TBC)

Source: Sourmail (2003)

5.2.4 Control Technologies

The control system, as a sub-system of the gas turbine, is recognised as the intelligence of the whole gas turbine system. It enables the system to operate efficiently, smartly, safely and manageably. “Without a proper control system: the compressor can go into surge in less than 50 milliseconds; the turbine can exceed safe temperatures in less than a quarter of a second; and the power turbine can go into overspeed in less than two seconds. Furthermore, changes in ambient temperature and ambient pressure, deviations that may not even be noticed, can adversely affect the operation of the gas turbine" (Giampaolo 2006, p. 71). The control system is a complex, intelligent and multi-functional system by which a variety of influencing parameters (such as fuel flow, compressor inlet pressure, compressor discharge pressure, shaft speed, compressor inlet temperature and turbine inlet or exhaust temperature) are constantly monitored and controlled. It has a number of major functions such as controlling the gas turbine during steady state operation, and starting, stopping, increasing and decreasing the power. Figure 5.5 shows a simplified gas turbine control system and demonstrates the major influencing parameters on the system.

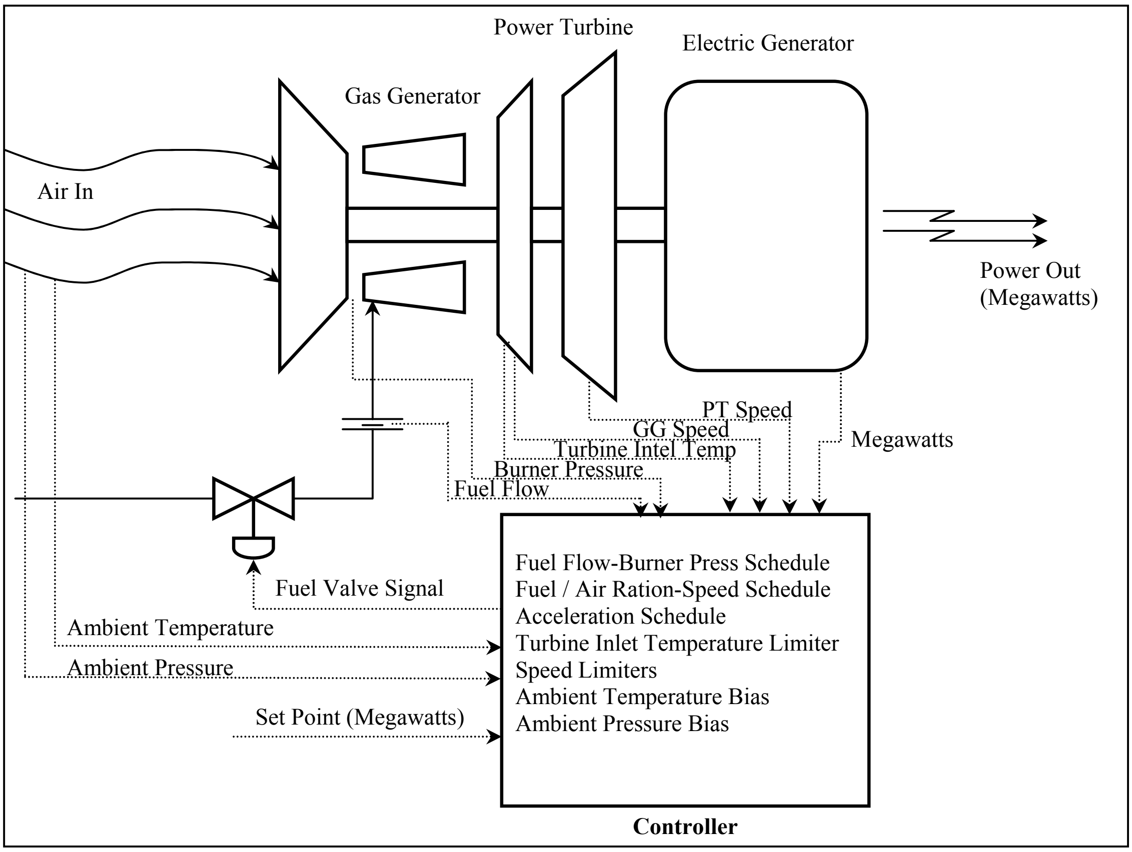

Figure 5.5: Simplified Gas Turbine-Generator Control System

Source: Giampaolo (2006)

Depending on the gas turbine's application (aircraft engine, land-based power generator, marine engine, etc.) the control system has different operational conditions and different tasks. However, gas turbine control technologies have had three major evolutionary stages, as follows:

- Hydromechanical control: This type of control system is frequently based on mechanical displacement, pneumatic or hydraulic mechanisms mainly consisting of cams, servos, speed (fly-ball) governors, sleeve and pilot valves, metering valves and temperature sensing bellows. In general they manage and control the mechanical parts of the system based on mechanical engineering rules. Hydromechanical control systems were common control systems in the 1960s. However, they have a number of limitations (Giampaolo 2006). Firstly, they have to be calibrated frequently (weekly in some applications) and are subject to contamination and deterioration due to wear. Secondly, they inherently embed a compromise between accuracy and response time (i.e. they are not quick to respond). Thirdly, many of their tasks have to be performed manually which decreases accuracy and increases duration.
- Electrical control: In this type of control,[49] all control functions (start, stop, load, unload, speed and temperature) are generated, biased and computed electronically (Giampaolo 2006). Electrical control systems were substituted for hydromechanical controls and were widely used in the 1970s and 1980s. Despite their agility to respond, they often took the form of independent control loops and did not operate as multi-functional controlling systems.
- Computer control: This type of control system is a programmable logic controller or microprocessor which incorporates many electrical functions such as amplifiers, relays, switches and timers within the central processing unit (CPU) (Giampaolo 2006). In the 1990s, the advent of programmable logic controllers and microprocessors and their application in gas turbines facilitated multi-functional control in the gas turbine industry. Computer controls have a number of advantages over the two control types detailed above. Firstly, they

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[49] Hard wired relay logic

are flexible because they are reprogrammable and the user can easily modify the program based on the system's working conditions. Secondly, they have a multi-functional controlling ability by which the system is much smarter to respond and thus the efficiency as well as the accuracy will be much higher.

5.2.5 Computational Simulations

Over the last two decades, technological advances in computer technologies have resulted in a radical change in the engineering sciences as well as in industrial processes and procedures. The advent of efficient and fast computers has fuelled considerable progress in numerical calculations in ways that enable engineers to calculate very complex and lengthy calculations, which has generated a real boom of engineering computational simulations. This trend has a number of advantages by which all industrial sectors, and particularly the gas turbine industry, have benefited from these technological advances. Firstly, full-scale prototype manufacturing is unusual since it is too expensive in terms of both capital and operating costs (Magnusson et al, 2005). However, computer-based simulations facilitate testing mechanical parts before any manufacturing takes place. This enables engineers to simulate machines' functionality before any manufacturing and thus facilitates numerous trials and errors in the design process. Therefore, a huge amount of manufacturing and testing costs can be eliminated. Secondly, computational simulations allow the calculating and running of very complex and lengthy engineering calculations which have never before been feasible. Such a facility assists engineers to optimise their designs in terms of accuracy, cost-effectiveness, rapidness and functional efficiency.

Industrial companies also benefit from computer-based simulations in re-engineering activities. In some circumstances, it is possible to optimise a specific part or upgrade or redesign it. Computer simulations assist in diagnosing the problems and redesigning the equipment in an efficient manner. These capabilities are design capabilities which require the mastering of academic applied sciences as well as an understanding of manufacturing procedures. These capabilities are necessary for technical change and are typically added to technological capabilities rather than to production capacity (Bell and Pavitt 1993).

Gas turbine suppliers have benefited from engineering computational simulations over the last 20 years to optimise gas turbines in weight, cost and efficiency. Through a knowledge management perspective, engineering computational simulations in the gas turbine industry can be categorised into the following types (this articulation is based on interview data and author's seven years' experience in advanced engineering simulations):

<u>Stress and fatigue analysis</u>:

The ultimate goal of this type of knowledge is to calculate the applied stresses on mechanical parts under working conditions, through which the possibility of failure and strength of material can be estimated. Further to static loads, the whole structure (components and parts) is subjected to complex cyclic working loads during the operation. These cyclic loads will eventually lead to catastrophic failure. Although engineers often try to design lightweight mechanical parts with less material, companies prefer to sell reliable components, with fewer warranties and recall costs. Software techniques enable researchers to integrate mechanical engineering concepts and material science with mathematical calculations in order to predict the parts' life-cycles. This helps companies to test the life-cycle of products before expending high manufacturing and testing costs. These calculations are implemented using Finite Element Analysis (FEM) which is a numerical technique for analysing the stress, strain, and distortion of working structures. Integrating advanced mathematical techniques with mechanical engineering concepts allows the visualisation of bending, twisting and displacement of the whole part of the structure and hence assists in optimising the structures in terms of weight, volume and material specifications. This helps to test the structure under different working loads and facilitates the optimisation of the design before manufacturing is attempted, which reduces manufacturing costs. In the gas turbine industry, companies often use one of the following software packages: Fe-safe, Fe-Fatigue, MscFatgiue, MscNastran and ANSYS.

Computational Fluid Dynamics (CFD):

This is a part of computational mechanics which employs numerical techniques to analyse, explain and simulate the dynamics of flows of gases and liquids, heat and mass transfer and fluid-structure behaviour. In the gas turbine industry, CFD methods are frequently used to simulate the speed, temperature and direction of fired gases in order to optimise the output efficiency and reliable design of working parts. This technique enables engineers to implement numerous trials and errors to find the optimum conditions of operating (temperature, pressure, etc.) and thus helps to reduce the manufacturing costs. In the gas turbine industry, companies often use one of the following software packages: Fluent and ANSYS.

Combustion Analysis:

The ultimate goal of this type of analysis and simulation is to understand the combustion phenomena and optimise the output power. Calculating and optimising internal pressure, temperature and velocity variations within the gas turbine is a very complex process. Combustion of fuel in the combustion chamber of a gas turbine is performed in a milli-scale of a second; however, controlling the influencing parameters does play a key role in the output power. Optimisation of the combustion process not only has a direct effect on the output power but also mitigates pollutant gases. Environmental regulations have forced gas turbine manufacturers to decrease pollutant gases and eliminate unburned hydrocarbons such as carbon monoxide which is the product of incomplete combustion. Furthermore, combustion simulation assists engineers to design stable combustion processes in which knocking and other unfavourable consequences are eliminated. Fluent, KIVA and Star-CD are the most popular software packages for combustion simulation in gas turbines.

Noise, vibration and harshness (NVH):

These types of studies and simulations aim to understand and modify the noise and vibration characteristics of gas turbines. NVH investigation in gas turbines requires a comprehensive knowledge of mechanical and control engineering together with experience with these systems. “Noise from combustion turbines can cause a dramatic change to the environment, particularly in rural settings and communities if adequate noise control or mitigation is not incorporated” (Giampaolo 2006, p. 146). Noise levels should be investigated in the design stage, otherwise post-installation of noise control equipment frequently proves to be very expensive and may also negatively affect turbine performance (Giampaolo 2006). Simulation advances over recent years have enabled designers to make noise control breakthroughs in gas turbines. In fact, gas turbine designers often harness simulation techniques in order to understand noise levels and diagnose the noisy parts. They then try to mitigate the noise levels by designating auxiliary systems such as silencers. Similarly, vibration simulation helps to understand the sources of imbalances and misalignments in the gas turbine and enables the designer to improve system vibrations through which the system durability will be enhanced. ADAMS is one of the popular software packages in NVH studies.

5.3 Evolution of Land-Based Gas Turbine Technologies

Technological requirements for land-based gas turbines have had evolved over the past decades. Although gas turbines have nearly a century of history, the evidence suggests that the commercialisation of land-based gas turbines started in the 1960s. This section charts the evolution of land-based gas turbines over the last 50 years. It is based on interview data, in-depth literature review and extensive searches in relevant magazines. However, the first four phases of the historical evolution closely mirror those put forward by Watson (1997).

5.3.1 The 1960s: Realised by Jet Engine Technologies

By the early 1960s, the main improvements to the old gas turbines were implemented to increase the flow of air through the machine through the use of more efficient compressors with higher compression ratios (Watson 1997). The four main incumbents were GE, Siemens, Brown Boveri and Westinghouse. The companies were able to manufacture land-based gas turbines with a maximum temperature of about 850 degrees centigrade, a maximum efficiency of 28% and maximum power of 25 MW (Watson 1997). The hot sections, mostly blades, were coated using an old version of diffusion coating (aluminising) which was not resistant enough against hot corrosion (PARTO 2002*a*). By the late 1960s, the two companies which had direct access to jet engine technologies – GE and Westinghouse – started using nickel-based superalloys and some titanium alloys for turbine and compressor blades and thus succeeded in manufacturing more efficient gas turbines (Watson 1997). Furthermore, cooling technologies, particularly internal cooling passages for the stationary blades and vanes, were adapted from jet engines (Watson 1997). In the late 1960s, land-based gas turbines demonstrated their ability to generate power.

5.3.2 The 1970s: Scale-up

The 1970s involved what is referred to as 'scale-up' in which manufacturers increased the size of gas turbines in order to meet customer demands (Watson 1997). By the mid 1970s, manufacturers had sold industrial gas turbines which were capable of generating over 50 MW with an efficiency of 31% (Watson 1997). In 1974, GE implemented a modified version of diffusion coating known as RT-22. This version was more resistant to hot corrosion than the previous coating, though it was brittle and sensitive to cracking (PARTO 2002*a*). Furthermore, in the 1970s, for the first time R&D activities started work on TBC coatings.

In the 1970s, manufacturers started to sell their first batch of larger CCGTs. ASEA Stal (a Swedish Company), LMZ (Soviet Union), and Mitsubishi had joined the manufacturers in the market. However, the oil crisis of the mid 1970s brought a sudden end to the 'boom' in gas turbine orders that had commenced in the 1960s (Watson 1997). Despite this, the market for land-based gas turbines began to recover in the late 1970s as real oil and gas prices began to fall again (Watson 1997). Furthermore, the Middle East demand in the late 1970s and early 1980s helped the recovery of the land-based gas turbine market (Watson 1997). In 1978, GE introduced its new gas turbine known as GE-Frame-9E with power of 105MW. It has incorporated numerous improvements over the years and has been one of GE's most successful large size gas turbines. It is able to burn a variety of liquid and gaseous fuels, and provides reliable operation with minimal maintenance at a competitively low installed cost (GE 2006).

5.3.3 The 1980s: Incremental Improvement

In general, the 1980s was a recession period for gas turbine manufacturers. In this period, manufacturers undertook two distinguished activities: incremental improvement of their production, and increasing gas turbines' operational reliability (Watson 1997). Incremental improvements included the areas of material, coating type and cooling systems.

In 1981, three years after the introduction of GE's new gas turbine (Frame 9E), Siemens introduced its new product, namely V94.2 with power of 112MW, efficiency of 31%, and a maximum temperature of 930 to 1000 degrees Celsius (Bohrenkämper et al 2004). Since then there have been many improvements to this model as it has been one of the most highly-demanded products of Siemens. In the first version of the V94.2 gas turbine the cooling system was designated only in the first row of blades. In 1986 Siemens introduced the second version of V94.2 with a maximum temperature of 1000 to 1050 degrees Celsius, in which the cooling system for the blades extended to the second row (Bohrenkämper et al, 2004).

GE also made similar improvements to gas turbine technologies, mainly focused on coating technologies as well as new materials. In 1983 GE upgraded the RT-22 coating to a new coating known as GT-29, which was a MCrAlY coating with greatly improved resistance to cracking (PARTO 2002*a*). In the mid 1980s world oil prices fell and the World Bank supported CCGT power plants due to their high levels of efficiency (Watson 1997). Subsequently, some developing countries, such as Malaysia, Thailand and Egypt ordered CCGT power plants (Watson 1997). GE benefited from its access to aircraft jet engine technologies and introduced a new efficient gas turbine known as Frame 7F, thus maintaining its dominance in gas turbine technology (Watson 1997). The maximum temperature of this model was about 1250 degrees Celsius, whereas in the 1960s only 850 degrees Celsius was attainable. The main innovation in this new land-based gas turbine model was the use of directional solidification (DS) technology in blade materials, thereby improving thermal fatigue life and increasing durability. GE transferred this technology due to its access to aircraft jet engine technologies. Thus, after nearly two decades from the introduction of DS technology in the aircraft engine industry, it was commercialised in land-based gas turbines. In addition, the new F class of gas turbine from GE had the advantage of a new coating type on its blades. In 1989, GE improved on the previous coating technology and introduced GT-29 Plus. GT-29, which had been commercialised in 1983, was not strong enough against oxidation, though its resistance to cracking had been greatly improved. In contrast, in GT-29 Plus, both oxidation and cracking problems were improved (PARTO 2002*a*).

5.3.4 The 1990s: Back to Jet Engine Technologies

This period is known as the success period of CCGTs, and in particular of gas turbines. The technological changes in the 1980s confirmed that gas turbines were able to produce more output power with high efficiency and less pollutant gases. In the 1990s, there was a dramatic increase in demand in the North American and Asian markets for gas turbines (Watson 1997). The manufacturers made further efforts to supply the markets with advanced and efficient gas turbines. Following GE, other manufacturers perceived that they had to make direct links with the aero-engine technology supermarket in order to acquire advanced technologies and thus they started to make strategic alliances with jet engine companies (Watson 1997). This helped manufacturers take advantage of spillover effects from advanced military technologies. In 1988, ABB signed a technology transfer agreement with Rolls Royce;[50] in 1990 Siemens signed a similar contract with Pratt and Whitney, and in 1991 Westinghouse made a tri-lateral alliance with its long term licensees, Mitsubishi of Japan and Fiat Avio of Italy[51] (Watson 1997).

In 1990, Siemens introduced the third version of the V94.2 gas turbine with 163 MW power and a maximum temperature of 1050 to 1060 degrees Celsius. In tandem with improvements on the cooling system, the previous diffusion-type chromium coatings of the blades were replaced by MCrAlY-type overlay coatings and thus their strength were greatly improved against corrosion and cracking (Bohrenkämper et al, 2004). At the same time, due to the previous advancements in coating technologies, GE improved the coating of Frame 9E blades and succeeded in reaching 126 MW and efficiency of 33% in simple-cycle mode, and over 52% in combined cycle mode (GE 2006).

By the mid 1990s, GE had introduced the new version of the Frame 9 gas turbine in F class, called the GE Frame 9F, with 255.6 MW power, in which the blades were manufactured based on DS and single crystal technologies. Therefore, 15 years after the introduction of single crystal alloys in aircraft engines (in 1982, as explained in Section 5.2.1), land-based gas turbines were equipped with this advanced material technology. Due to the high cost of single crystal materials, only the first and second stages of blades were made of single crystal materials with subsequent stages incorporating directionally solidified or equiaxed[52] components (Gerybadze and Stephan 2006).

In 1996, Siemens introduced its new F class of gas turbines, namely the V94.3A with 292 MW power. The main differences between V94.2 and V94.3A relate to the blades and the combustion chamber. While the blades in V94.2 are made of superalloys, V94.3A was manufactured using DS and/or single crystal materials. Furthermore, the size of the combustion chamber in V94.3A was significantly reduced. The main reason for this change

[50] The relationship stopped one year later as each company held a different view of the way forward. ABB then switched to using Russian jet engine expertise via its strategic alliance with Saturn (Watson 1997).

[51] However, one year later Westinghouse made a two-way technology transfer and marketing agreement with Rolls Royce (Watson 1997).

[52] Equiaxed investment casting is a process in which molten metal is poured into a ceramic mould in a vacuum, to prevent the highly reactive elements in the superalloys from reacting with the oxygen and nitrogen in the air. Thermal fatigue life of directionally solidified blades is ten times that of equiaxed blades (Boyce 2006; p. 442).

was the desire to allow higher firing temperatures in order to increase unit efficiency (Watson 1997).

The Siemens database shows that V94.3A had an older version, namely V94.3. However, it was quickly succeeded by V94.3A. There is little information about V94.3 but the evidence suggests that Siemens was offering V94.3A to its customers instead of V94.3. The main difference is that V94.3A had an annular combustion chamber while V94.3 had some kind of silo combustors. V94.3A has been one of the most successful units.[53]

In 1997, GE improved the coating of the GE Frame 9 and Frame 7 gas turbines with its new version, known as GT-33IN-Plus, which is enormously strong against oxidation and cracking as well as against corrosion. This type of coating includes both the overlay and diffusion coatings (PARTO 2002*a*).

5.3.5 The 2000s: Software Boom and New Cycles

The 2000s is distinguished by three main technological developments in land-based gas turbines. The first is the boom in software simulation techniques in gas turbine design and manufacturing. With the advent of software simulation techniques and following the swift growth of computer technologies in the 1990s, gas turbine manufacturers started to benefit from these techniques in the optimisation of their products. Since the late 1990, there have been a number of types of software developed to analyse and optimise gas turbine parts, as explained in Section 5.2.5. The use of efficient aerodynamic codes is recognised as the biggest contributor to gas turbine advancements and is responsible for considerable performance gains (Gerybadze and Stephan 2006). For instance, to design and analyse blade configuration, manufacturers take advantage of advances in computer-aided design, finite element analysis and desktop computing power (Gerybadze and Stephan 2006). Furthermore, as explained in Section 5.2, the recent advancements in simulation software have computerised the manufacturing process and introduced CAD/CAM

[53] This paragraph is based on the information received from the Siemens Company (from May to July 2010). The contact person was Daniel Tuex, Energy Sector, Fossil Power Generation Division Products.

techniques which enable the manufacturers to manufacture highly accurate parts in short times.

The second technological change in land-based gas turbines in the 2000s was the introduction of ceramic materials to be used in the hot sections of gas turbines. Combustion liners, blades and vanes are the possible candidates for ceramic materials. Ceramic materials are capable of withstanding high thermal loads. However, long-term mechanical reliability is of critical importance to the use of ceramics. Because industrial gas turbines are expected to operate continuously for 25,000 hours or more between overhauls, and they are thus riskier than single crystal metal materials (Gerybadze and Stephan 2006). In addition, advanced ceramic materials entail manufacturing problems. Producers have difficulties in making reliable and reproducible parts, since ceramic materials cannot be cast and require elaborate manufacturing methods to produce shapes that are more intricate (Gerybadze and Stephan 2006). The series production of turbine blades using ceramic materials is in its infancy. Therefore, today, manufacturers use alternative ways of using structural ceramic parts in the design and manufacture of metal ceramic bonds or TBC coatings (Gerybadze and Stephan 2006), as explained above. “TBCs have a long, successful history in the aircraft industry and a growing experience base in the power generation turbine industry” (Gerybadze and Stephan 2006, p. 19).

The third essential technological change in the 2000s has been the designing of new cycles in CCGTs which are much more efficient than the previous vintage. The success of CCGTs was confirmed in the 1990s and advanced gas turbines were introduced to the market. Since the 2000s the competing manufacturers have tried to introduce new CCGTs with higher thermal efficiency. In 2003, GE unveiled the world’s largest CCGT at Baglan Bay on the south coast of Wales with thermal efficiency of 60% and 530 MW output power. It is called MS9001 H and it has a first-stage single crystal turbine vane with a characteristic length of 30 cm and a first-stage single crystal blade of 45 cm, for which both vane and blade are cooled by steam (from the unit’s combined-cycle operation) (Langston 2006). The new cycle is known as the H System. To date, information about the details of its cycle and gas turbine specifications are sketchy. However, the evidence suggests that the blades are manufactured from single crystal materials and coated using the TBC technique.

In 2005, Siemens introduced a prototype of its new version gas turbine called SGT5-8000H with an actual rated output of 375 MW[54] and 40% efficiency. In 2009, Siemens completed the required test run. The evidence suggests that it is the world's largest and most efficient fully air-cooled gas turbine. The first stage of blades and vanes are made of single crystal materials and the first to third stages are coated using TBC coatings. In combined cycle gas turbine operation, Siemens's new system will achieve an output of over 570 MW at an efficiency of more than 60%. Siemens claims that with the introduction of the SGT5-8000H model, Siemens forged ahead of GE and crossed the 60% efficiency barrier. Complementary tests are underway and Siemens plans to supply the market in 2011. The SGT5-8000H is the first new frame developed after the merger of Siemens and Westinghouse (Gerybadze and Stephan 2006).

Today, manufacturers offer a variety of land-based gas turbines in accordance with customer needs. Table 5.2 shows the most highly demanded land-based gas turbines in the market offered by the two lead manufacturers, GE and Siemens. The numbers are based on standard climatic conditions as well as fuel types, and thus there will certainly be minor changes under different conditions. Furthermore, it should be mentioned that GE's gas turbine specifications in the new H system are not given and GE produces the numbers based on combined cycle operation. Moreover, the gas turbines in Table 5.2 are selected based on the 50 Hertz frequency of electricity which is popular in Europe and Asia.

[54] Siemens states that such an amount of electricity is enough to supply a city like Hamburg, with two million inhabitants.

Table 5.2: Technical Specification of Most Recent Land-based Gas Turbines

Specifications	Siemens V94.2	Siemens V94.3 A	Siemens SGT5-8000H	GE Frame 9E	GE Frame 9F
Normal output (MW)	168	288	375	123.4	255.6
Frequency (Hz)	50	50	50	50	50
Efficiency (%)	34.7	39.5	40	33.8	35
Exhaust-gas temperature (C)	536	580	625	543	602
Compression ratio	11.7	18	19.2	12.6	17

Source: Company literature

Note1: Siemens gas turbines have new names. SGT5-2000E is the new naming for V94.2 and SGT5-4000F is for V94.3A.

Note2: The numbers vary according to climatic conditions and fuel type.

5.4 Market Structure

Gas turbines are widely used in different industries such as large building complexes, the oil and gas industry, and power plants. In contrast to the technological similarities between all types of gas turbines which are based on the same technological principles, market characteristics are dissimilar to each other, though the suppliers of all markets have had connections and in recent years have sometimes been the same.

The market for gas turbines is classified by power output. They often recognised as microturbines, industrial gas turbines, and mid and heavy duty gas turbines. Microturbines are typically assumed to be in the range of 30 to 400 kW (Smith 2002). Although they operate on similar principles to large gas turbines, their working temperatures are significantly lower[55] and thus the mechanical design and manufacturing is simpler (Magnusson et al, 2005). They can be used in buildings, vehicles, onshore and offshore operations or as a back-up to a utility grid. Compared to CCGTs, microturbines have a substantially lower unit cost as they are less complex, standardised, easy to install and account for mass-produced goods (Magnusson et al, 2005). Despite these advantages, other technologies such as fuel cells and internal combustion engines are seen as alternatives in the automotive industry. The technologies have been vying with each other in terms of cost, environmental friendliness, efficiency and operability. The competition may increase further as the market for microturbines is subject to growth in the future because governments intend to make policies to foster microturbines in individual households (Watson 2004*b*). However, the major concern of such initiatives is the environmental impacts and thus gas-fired microturbines are a less favourable choice in households compared to solar and wind technologies. In contrast, they are preferred in large buildings and complexes.

Industrial gas turbines[56] are typically identified as having a capacity from 1 MW to 50 MW. They are primarily used in the oil and gas industry[57] including upstream, midstream and downstream, as these applications require considerable amounts of electrical power. Supplying such power is not feasible through the ordinary electricity grid and thus oil and gas companies designate a small part of the power plant to supplying the energy. Industrial gas turbines are also frequently used in power generation for small cities, standby power, marine propulsion, hospitals, universities and other building complexes. They are more complex than microturbines as they operate under relatively high temperature conditions. In addition, when they operate in a severely corrosive atmosphere, such as in marine gas turbines, the materials should be strong enough to withstand corrosion. These complexities have confined the suppliers of industrial gas turbines to a small proportion of companies compared to microturbines. The market for industrial gas turbines is subject to growth in the future due to the decentralisation trend in power plants. In recent years

[55] In microturbines there is no need to use superalloys, advanced coatings or advanced cooling systems.
[56] They are also known as mechanical drives.
[57] Industrial gas turbines provide power upstream onshore and offshore for pumping crude oil into oil wells, gathering and compression of natural gas, natural gas injection, boosting pipeline pressure for natural gas transport and other similar activities. Furthermore, they are used to change natural gas into liquefied natural gas (LNG) for storage and they also supply the power for the transmission of oil and gas through pipelines. Downstream, they are used in refineries and petrochemical plants.

distributed power generation has been growing (Watson 2004*b*; Magnusson et al*,* 2005) and thus this trend may influence the market for industrial gas turbines. The main rationales for developing distributed power electrical generators are their functionality in peak-shaving,[58] the enhancement of the security of supply, and the elimination of electricity transmission costs.

Medium and heavy duty gas turbines are assumed to be those above 50 MW output power, of which medium size are often those below 100 MW. As explained in the first section of this chapter, these gas turbines are advanced technological systems and their manufacturing requires advance casting, machining and coating technologies. Technological requirements for these gas turbines are much more advanced than those for microturbines and even for industrial gas turbines. The scope of this thesis includes those gas turbines that are applicable to power plants, in particular mid and heavy duty ones.

The evolution of gas turbine technology is attributed to its origin in multi-billion dollar military and civil programmes and other public R&D budgets (Mowery and Rosenberg 1982). However, both demand pull factors (e.g. demand for peaking/backup plants in the US and the UK in the 1960s, or the PURPA Act plants in the US in the 1980s) and supply push factors (e.g. military R&D support) have been important in the evolution of technical skills, knowledge and innovation in the gas turbine industry. Until recently, many gas turbine technologies have been readily available in the multi-billion dollar military jet engine programmes of the US Department of Defense and its European counterparts (Watson 2004*a*). The trend of gas turbine technology evolution and its application in the power plant industry highlights governments' intervention in the processes. In the 1970s, utility companies intended to invest in gas-fired power plants when advantages such as cost, quick build time and relatively low emissions became clear. However, this investment was strongly discouraged in many places such as the EU, the UK and the US following the first oil shocks. Despite the restrictions[59] there were two direct government-funded R&D programmes in the 1970s: the American High Temperature Turbine Technology (HTTT) project, and the Japanese Moonlight project. Both

[58] Peak-shaving means offsetting differentiated electricity pricing regimes in periods when the price of grid electricity exceeds the variable cost of operating the back-up generator (Magnusson et al 2005).
[59] A 1975 European Directive to discourage gas-fired power plants was followed by a similar US Power Plant and Industrial Fuel Use Act in 1978 (Watson 1997, p. 329).

programmes were started after the first oil shock in 1973 and both aimed to improve gas turbine efficiency (Watson 1997). Both projects were unsuccessful as the Japanese experience stopped at prototype stage and the American project did not even reach the prototype stage (Watson 1997). However, the Japanese project enabled Mitsubishi Heavy Industry to acquire key areas of technology such as high temperature materials and blade cooling techniques, and the American project enabled GE and Westinghouse to acquire steam cooling systems technologies which were important in their 1990s efforts (Watson 1997).

After the 1980s, restrictions were relaxed and governments did not object to the development of gas-fired power plants; rather, they tried to support R&D programmes. In the US the Department of Energy (DoE) funded some programmes to research advanced materials for gas turbines. For instance, the Advanced Gas Turbine Programme, funded by the DoE from 1979 to 1987, aimed to develop ceramic materials in gas turbines (Richardson 1997). In the same way, in 1992 the US Advanced Turbine System (ATS) was incepted which aimed to enhance the international competitiveness of the American gas turbine industry (Watson 1997). Companies like GE started to develop new CCGTs with higher rates of thermal efficiency (the target was 60%) whilst reducing atmospheric emissions and capital costs (Watson 1997).

In Germany, public-sponsored research efforts in the field of advanced materials for gas turbine applications were organised through the New Materials for Key Technologies of the 21st Century (MaTech) programme of the German Federal Ministry for Education, Science, Research and Technology (BMBF) (Gerybadze and Stephan 2006). This ten-year programme, initiated in 1994, aimed to develop metals, ceramic materials, composites and related processing technologies with the overall goal of increasing the efficiency of stationary gas turbines (NMT 1998).

Likewise, in the UK, land-based gas turbines became a target of public funding. Watson (1997) provides evidence showing that the close links between the land-based gas turbine and the aircraft jet engine have yielded a large amount of publicly funded technology, though it came about in a complex interaction between privately funded research projects. He argues that in the case of CCGTs and in particular land-based gas turbines, government R&D funding programmes have operated indirectly in the UK. He also argues that these programmes have had a high profile in the USA, Japan and Germany.

In the UK, utilities have invested a lot in gas-fired power plants, including the development of efficient gas turbines. Accordingly, public R&D was supportive of the case as the 'dash for gas' manifested itself in the UK in the 1990s. The dash for gas emphasised CCGTs' development and deployment in the UK's power generating industry instead of traditional fossil fuel and nuclear power plants (Winskel 2002; Watson 2004*a*). This was influenced by privatisation policies in the UK. In fact, awareness of CCGT technology was ahead of privatisation in the UK (Winskel 2002), and the dash for gas was not a government policy; instead, it was a result of policies to privatise and liberalise the power sector. Furthermore, the scale and speed of the shift to CCGTs in the UK was influenced by the long-standing animosity between the Conservative Party and the main coal mining trade union (Watson 2004*a*). Therefore "government interventions encouraged the tentative efforts of marginalized groups to mobilize around a radical technology" (Winskel 2002, p. 587).

The USA has experienced the deregulation of its electricity markets in a similar way to the UK. Once the Public Utility Regulatory Policy Act (PURPA) was ratified in the USA in 1978, gas turbines emerged as the most popular technology for independent power generators (Watson 2004*a*). In spite of deregulation in the USA and the UK, the majority of electricity supply companies are still managed and regulated by states. For example, in South Korea, India, Mexico, Thailand and Turkey electricity buyers are state-owned monopolies (Watson 2004*a*). Similarly, in India and China, which have power equipment industries, the gas turbine manufacturing companies are still subject to significant state oversight. In Iran, the electricity suppliers as well as the equipment manufacturers are state-owned companies, even though the industry is in a long and controversial privatisation process (see Chapter 2, Section 2.4.3). Furthermore, as will be explained in Chapter 8, Iranian, Indian and Chinese energy policies have had different impacts on the evolution of each country's gas turbine industry.

The above analysis indicates that the market for land-based gas turbines has had connections (direct or indirect) with each country's industrial and energy policies. It has been heavily influenced by state policies in all countries, though the strength or weakness of influence might be different depending on whether the industry is privatised or state-owned. The customers of this type of product have been or still are states. Although electricity markets as well as power plant equipment manufacturers in the US and the UK have been privatised and liberalised over the last two decades, in the majority of countries the electricity generation market structure is either a private monopoly or a state-owned company. Therefore, 'politicised markets'[60] can still be distinguished for land-based gas turbines, particularly in some developing countries like Iran, India and China.

Market demand for land-based gas turbines is also attributed to governments' environmental policies. Environmental and climate change issues are nowadays amongst the challenges at state level. Today, natural gas is recognised as a much cleaner type of fuel compared to other types of fossil fuels and consequently CCGTs are often favoured over power plants using other fossil fuels. Furthermore, their short construction times and low capital costs (in comparison with other types of fossil fuel power plants and also nuclear power plants) add to the above demand pull factors. Thus, where natural gas is available, governments tend to support the construction of gas-fired power plants in their national energy policies.

These characteristics fit well with liberalised electricity markets. However, CCGTs can also be popular without liberalisation for various reasons. Firstly, their speed of construction meets rapid growth in electricity demand particularly in developing countries such as China, India and Iran. Secondly, although some countries need to import natural gas to supply gas-fired power plants, the efficiency of CCGTs in comparison with other types of fossil fuel power plants, makes them an economic choice. Moreover, "the discussion shows that liberalising reforms such as those implemented in the UK are neither a necessary nor a sufficient condition for the success of the CCGT. Instead, it is more accurate to conclude that there is a tendency for new entrants in competitive markets to choose the CCGT in countries where natural gas is available" (Watson 2004*a*, p. 1077).

Another salient feature of the market for gas turbines is its increasing size not only over the past two decades but also in the future. According to an International Forecast press release,[61] the gas turbine-powered electrical generation market is projected to

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[60] Sometimes the term 'monopsony' is used to show that the state is the only buyer of such products.
[61] International Forecast press release, 31 May 2005,
http://www.forecastinternational.com/press/release.cfm?article=67

generate $118.4 billion in revenues in the decade 2005-2014 with the production of 7,550 machines, and will be projected to peak in 2010-2011. Meanwhile, heavy duty gas turbines will dominate the market. According to the International Forecast, of the 7,550 machines projected to be manufactured from 2005 to 2014, machines of 125 MW and larger should account for more than 30% of unit production and over 70% of the value of production. The evidence suggests that these numbers were 14.5% and 35% for unit production and value production respectively from 1996 to 2005.[62] Therefore, it can be argued that the unit production as well as the value of production of gas turbine machines of 125 MW and over will double in 2005-2014 compared to 1996-2005. Similarly, the Siemens database shows that the number of gas turbines in units was 220 per annum in 2002-2007, while it will be projected to be 300 from 2008 to 2013 (Suss 2008). These data confirm the large and growing global market for mid and heavy duty gas turbines.

5.4.1 OEM Market

The market for gas turbines is also distinguished based on the OEM concept. Such a distinction allows an understanding of the supplier's orientation in the market, the supplier's relationship with foreign companies, and the supplier's products' global competitiveness.

According to Hobday (1994), Original Equipment Manufacturer (OEM) has three main characteristics. Firstly, as a specific form of subcontracting, it requires a close connection with a foreign partner. The foreign partner assists the domestic firm in the selection of equipment and the training of managers, engineers and workers. Secondly, under OEM deals, the local firm produces a good to the exact specification of the foreign company. This could be in the form of licensing or joint venture contracts. Thirdly, the foreign firm under its own brand name markets the product through its own distribution channels. This is particularly the case for foreign markets. This line of reasoning focuses on

[62] The data has been extracted from the Turbomachinery Handbook (1996, Vol.37, No.6).

the contractual terms and relationships between the leader and the follower companies. However, in the context of the gas turbine industry the OEM concept primarily delineates the type of manufacturer. OEM manufacturers are those lead manufacturers that supply gas turbines as well as after-sales and maintenance services to their customers. These manufacturers – such as GE, Siemens and Mitsubishi Heavy Industry – mainly supply gas turbines under their own brand names. OEM manufacturers are well-known for their advanced and cutting edge technology. They are the main competitors in the introduction of new products.

Besides this, there are other suppliers in the market, namely OEM licensees. In some circumstances, OEM companies sell the license of a gas turbine or a specific part of it to another company. For example, Ansaldo Energia (an Italian company), MAPNA (an Iranian company), and BHEL (an Indian company) are manufacturing gas turbines under the license of Siemens.

5.4.2 Non-OEM Market

This group of companies often manufactures gas turbine parts via reverse engineering and supplies after-sales markets. In 2009, OEMs held a 57% share of maintenance spending, and the remaining 43% was split between independent service groups including OEM licensees and non-OEMs (Gas Turbine World 2009). The evidence[63] also suggests that non-OEM participation in the service market will likely increase over time (Gas Turbine World 2009).

Supplying turbine blades for power plants is a substantial part of the after-sales market. The MAPNA database suggests that the share of the gas turbine after-sales market for hot section parts is about 70%, of which more than 65% is specifically blades. Therefore, supplying a new set of blades for a new gas turbine is not the whole story of the business. Rather, supplying the blades over the subsequent 30 to 50 years (the life cycle of a gas turbine in operation) is a bigger market which generates considerable revenue for the

[63] The study was implemented by AeroStrategy Company published in Gas Turbine World (2009 Vol.39 No.6)

suppliers. Consequently, one focus of interest here is the way in which, and the extent to which the gas turbine after-sales market, in particular the blades, works, what kinds of suppliers supply these markets and how they compete with OEM manufacturers.

Until the 1970s, the gas turbine market was an oligopoly in which only a few OEM companies did business. The evidence suggests that after the 1970s, due to the development of the gas turbine industry and the rapid growth of demand, the OEM companies were not able to respond to the whole market demand and thus they were not able to supply gas turbines and their equipment on time. This was an opportunity for other non-OEM companies to enter into the market. For instance, Turbine Services Limited, which is now one of the largest non-OEM suppliers of GE gas turbines, started its business in the 1970s. Turbine Blading Group of the UK, a leading company in the design, re-engineering, manufacture and repair of gas turbine blades, also started its business in the 1970s. Similarly, Stewart and Stevenson entered into the land-based gas turbine market in the 1980s and became a competitor for GE in the gas turbine parts market. The evidence shows that after the 1980s, these non-OEM companies started to manufacture gas turbine parts and supply after-sales markets. In order to speed up technological knowledge acquisition, these companies tried to absorb and hire experts from OEM companies. On some occasions, they succeeded in accessing the documents and drawings of these companies. In the 1980s, OEM companies legally challenged newcomers and non-OEM companies. Nevertheless, in accordance with international laws, each company is allowed to manufacture parts similar to OEM parts provided that they do not directly use the OEM's documents and drawings. The evidence suggests that in most cases the courts delivered verdicts in support of non-OEM companies.

The strategy of non-OEM companies is 'cost leadership'. They try to supply the parts to the market at lower prices than OEMs. Meanwhile, the strategy of OEM companies is diversification of their business and customers in order to alleviate the risks of their portfolio and use their credit and brand in selling other products. OEM companies have recently developed a new policy in order to keep their superior position in the market. They try to acquire competent non-OEM companies and if they have already sold a license to other companies they are now reluctant to renew the agreement and occasionally terminate these licensing agreements altogether. For instance, GE terminated the license of GE Frame

9 gas turbines from Alstom. Likewise, in 1998, GE acquired the gas turbine unit from Stewart and Stevenson. Similarly, in 1999, GE acquired the Turbine Blading Company which had become the main competitor for GE gas turbine blades. The acquisition caused a dramatic increase in gas turbine blade prices as in 2000 prices nearly doubled compared to 1999. Figure 5.6 demonstrates the price for a set (92 blades) of GE Frame 9 blades from 1996 to 2000. The prices are shown for the first stage of blades for both stationary blades and rotary blades.

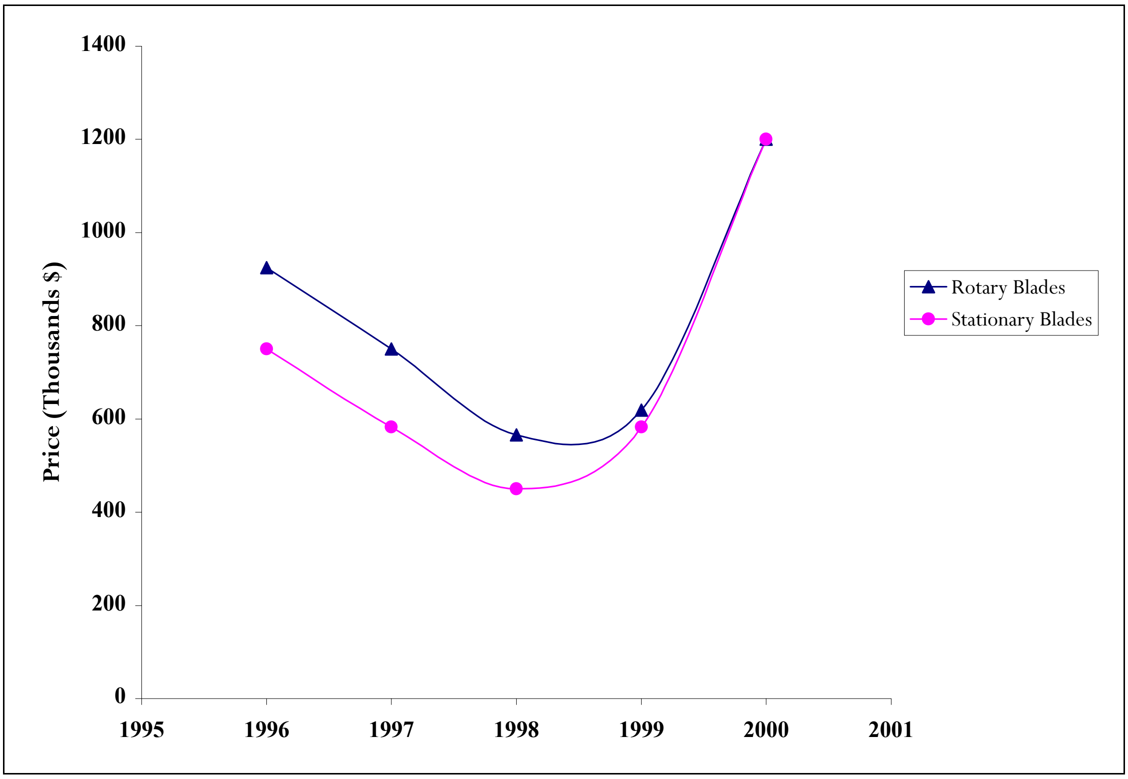

Figure 5.6: Price Changes for a Set of GE Frame 9E Gas Turbine Blades between 1996 and 2000

Source: Author's elaboration on PARTO (2002*b*)

The trend discussed above does not only include the acquisition of non-OEM companies by OEMs but also includes the merging of a number of OEMs. Recent merger activities have been Siemens's acquisition of Westinghouse's fossil power generation business in 1997, Alstom's acquisition of ABB's large-scale power generation unit in 1999, and Siemens's acquisition of Alstom's small and medium-sized gas turbine operations in 2003 (Magnusson et al, 2005). These acquisitions led to Westinghouse and ABB's shakeout from the mid and large size gas turbine market (Bergek et al, 2008). Today, the lead suppliers in the mid and large size gas turbine market are GE and Siemens and possibly Alstom and Mitsubishi Heavy Industry, though the first two are the strongest. This acquisition within the OEMs can be interpreted in two ways. Firstly, by acquiring non-OEMs they can better maintain their leadership position while also enhancing their competitiveness in the market. This is realised by accessing other OEMs' technologies and complementing their organisational capabilities with those acquired knowledge sources. Secondly, these mergers, willing or unwilling, lead to companies becoming oligopolies in the market, thus making entry very difficult for newcomers.

Non-OEM companies usually do not have access to the drawings and technical specifications of OEM parts and thus at the start they reproduce drawings and technical documents. In the gas turbine market, it is also common that a non-OEM company will manufacture some parts for OEM companies and some other parts in the form of non-OEMs. In these circumstances, these companies should supply OEM parts with OEM labels and non-OEM parts with their own or their customers' labels.

The quality of manufactured parts is always a controversial issue. OEM companies often claim that non-OEM parts do not have the same quality as OEM parts and the customers should not endanger their gas turbines by using non-OEM parts as their failures lead to the catastrophic failure of other gas turbine parts. Their argument is that OEM parts are manufactured based on original drawings and documents while non-OEM parts are manufactured through reverse engineering. In the reverse engineering method, the exact specification of the part is reproduced through accurate measurement techniques and, nowadays, via CAD/CAM instruments. The process highly depends on the experience and skills of the company. In some circumstances the non-OEM company is so capable that not only can it reproduce part specifications but it can also contribute to their improvement (re-engineering). Therefore, it can be argued that while OEM parts always have an adequate quality, non-OEM parts have the potential to outperform OEM parts – but their quality may be more variable than that of the originals.

5.4.3 Suppliers' Characteristics

Due to high development and manufacturing costs, advanced technology and complex manufacturing procedures, land-based gas turbines, particularly at the mid and heavy duty level, are typically manufactured based on customer orders in terms of technical specifications, guarantees and cost. Product characteristics are typically identified with regard to a specific project and consequently both design and manufacturing processes are highly dependent on customer orders. However, in recent years the manufacturers have tried to standardise the general specifications and have introduced different models of gas turbines with different ranges of power output. Nevertheless, they often change some features based on customer orders. In general, limited production numbers, complex and advanced technology, customisation and systems integration[64] are the main features of gas turbines which demarcate them from mass-produced goods (Magnusson et al, 2005).

In the specific market and technological circumstances described above, it can be argued that suppliers have evolved in a particular form, as follows:

Oligopolies

Land-based gas turbine technologies have mainly been evolved and developed through aircraft jet engine technologies. Over most of the past two decades, the number of suppliers has been limited to a few multi-billion dollar companies. However, in recent years, and within an atmosphere of competition, the market has been entered by newcomers which have either transferred technologies from the lead companies, or which have been working as their licensees. Today, amongst those countries that have a gas turbine industry (which are limited), the number of suppliers in each country is confined to one or two. According to an International Forecast press release,[65] the overall market leaders (outside the Russian

[64] Hobday et al (2005), based on the nature and processes involved in the systems, define systems integration based on four typologies of technological systems. In the gas turbine industry, they argue that "systems integration is likely to pose difficulties and require new types of capabilities both within the prime contractor or lead integrator and between the latter and other suppliers and users. Governments, standards, and regulatory bodies may also play a direct role in the systems development, including approaches to integration" (pp. 1115-1116).

[65] International Forecast press release, 31 May 2005, http://www.forecastinternational.com/press/release.cfm?article=67

Federation) in terms of the production of gas turbine machines (excluding microturbines) are projected to be GE, Siemens and Kawasaki Heavy Industries. However, in contrast to GE and Siemens, which manufacture gas turbines in a variety of ranges, Kawasaki Heavy Industries only manufactures industrial gas turbines (sub 50MW). Siemens's position has strengthened dramatically due to its acquisition of a large part of Alstom's small and medium-sized gas turbine operations in 2003 (Magnusson et al 2005). Alstom is also a competitor with GE and Siemens in the range of mid and heavy duty gas turbines. Therefore, the existence of few lead suppliers in the market for these high-tech products has made the market oligopolistic.

Pyramid Shape

The evidence indicates that there are often two or three lead suppliers globally, and other suppliers are recognised as followers or latecomers. In the global market, GE and Siemens have more than 60% of the total value share of gas turbines in all power output ranges. Other OEM suppliers, such as Alstom and Mitsubishi Heavy Industries, are behind these two lead suppliers. The rest of the suppliers worldwide tend to be followers which work under the licenses of these lead suppliers (as OEM licensees). For instance, Iranian, Indian and Chinese companies have had technology transfer agreements with Siemens and GE.

Focused Sub-suppliers in Vast Numbers

Since gas turbines are the product of many technologically advanced systems, there are many focused and specialised sub-suppliers for the parent companies. The parent companies integrate the vast majority of components and parts. The sub-suppliers are normally in the form of subsidiaries of the parent company, spin-offs, or private high-tech firms.

The above discussions distinguishes the market for land-based gas turbines from that of mass-produced goods in terms of there being few buyers, few suppliers, a politicised market, a pyramid shape of suppliers, small batches of products, complexity, interrelated and advanced technology of products, and a high degree of customer involvement.

5.5 Conclusions

This chapter has clarified three issues. First, it analysed the technological requirements for gas turbines and explained the technical specifications in detail. It showed that gas turbines are the product of many technological advances and interrelated technologies, some of which have evolved from their roots in aircraft jet engines. This chapter has also analysed the historical development of land-based gas turbines' technologies and showed the dynamics of their evolution.

Finally, this chapter has analysed the market structure for land-based gas turbines. It can be argued that the industry has had connections with individual countries' energy and industrial policies. Government policies in all countries have had direct or indirect connections with the market. The industry has been supported by government-funded programmes over the last decades. Although the industry in some countries has recently been privatised, it remains state-owned in the majority of countries. Therefore, a politicised market can be recognised for land-based gas turbines.

The analysis has also shown that the market for land-based gas turbines is a large and growing market. Meanwhile, the number of suppliers is limited. In general, two suppliers, GE and Siemens, are the leaders, while other suppliers are followers. Thus, the majority of suppliers are working under the licenses of the two lead suppliers.

High technology, complexity, technological interrelation and a politicised market distinguish the gas turbine industry as a favourable choice for the proposed theoretical framework, which intends to shed light on the dynamics and influencing factors in the interaction processes between indigenous development and overseas technology transfer. Drawing on this, the next chapter will analyse Iran's gas turbine industry and demonstrate its dynamics.

Chapter 6 : Iran’s Gas Turbine Industry: Its Evolution and Technology Acquisition Processes

6.1 Introduction

This chapter elaborates the products and markets for Iran’s gas turbine industry. It aims to explain the development phases, the evolution of capabilities, technological acquisition processes and associated challenges. Focusing on the processes, it will show how the various areas of gas turbine technology were acquired in various circumstances.

Section 2 explains when and how Iran’s gas turbine industry was formed. As it will be explained, MAPNA and its subsidiaries are the main actors in Iran’s gas turbine industry. Section 3 introduces product specifications, and Section 4 goes on to explain the market for MAPNA’s products. Based on the distinctions set out in Chapter 5, this section will locate MAPNA’s products in domestic and overseas markets. Section 5 depicts the evolution of MAPNA’s technological and structural development phases. It provides a historical and analytical background for the analysis of the evolution of technological capabilities.

Section 6 scrutinises the formation and development of Iran’s gas turbine industry and explains how capabilities were formed step-by-step in the MAPNA Group. It sets out the capabilities and their evolution.

Section 7 explains how MAPNA has dealt with indigenous and overseas knowledge sources. It explains the challenges of the parent enterprise and its subsidiaries in these processes, and goes on to show how indigenous technological development efforts and overseas technology transfers have been synthesised. It compares the findings with the substitution/complementarity literature. Finally, Section 8 draws the conclusions of the chapter.

6.2 Formation of Iran's Gas Turbine Industry: MAPNA as the Main Actor

As discussed in Chapter 2, Iran's net electricity generation has dramatically increased over the last 25 years. This trend is predicted to grow faster as industrial managers seek to increase national installed capacity by roughly 10% annually, in line with the projected 7-9% annual growth in national demand (EIA 2010). The huge amount of underdeveloped households' energy demands, as well as industrial/economic growth are the main reasons for this increase (see Chapter 2). Meanwhile, gas-fired power plants – with higher efficiency, lower emissions and rapid construction time compared to other fossil fuel technologies – are at the core of power plant industry development in Iran. In the late 1980s, the energy policy makers in Iran paid much attention to prioritising the power plant industry to satisfy the growing national energy demands. Their agenda was to respond such an energy demand with an organised and long-term plan. The document analysis of this period shows that the policy makers had well perceived the vital role of the energy sector and energy policy issues. On one hand there was a huge electricity demand which was mostly related to the development of household access to electricity, investment and development in the oil and gas industry, and the growth of other industrial sectors. On the other hand, the policy makers recognised the country's electrification as an opportunity to create a domestic industry and underpin its technological capabilities. Last but not least, shaping the industry was recognised as a remedy for the unemployment of indigenous people. Documents and interviews with experienced managers reveal that a multi-objective plan was developed.

In the 1990s, the intention of Iranian electricity generation policy makers to develop an in-house power plant industry was contemporaneous with the globally emerging gas turbines in the electric power industry, which resulted in a paradigm shift (Islas 1995; Watson 2004*a*). The UK's 'dash for gas' in the 1990s was part of the same global trend (Winskel 2002; Watson 2004*a*). In these circumstances electricity industry policy makers in Iran, while monitoring the global trend, prioritised the construction of gas-fired power plants. Iran's huge natural gas reserves, the need to satisfy growing national electricity demands, and global trends have been the major drivers in the shaping of Iran's gas turbine industry. Nevertheless, shaping and growing a power equipment industry, as a complex and high-technology industry, is not an easy or a short-term process. The policy makers therefore envisioned the establishment of a domestic industry that was capable to respond to domestic electricity demands as well as to supply relevant technological equipment. The fieldwork data reveals that the aim was to acquire three major capabilities:

- Satisfying the growing national electricity demand
- Development of capabilities for management of power plant projects
- Development of technological capabilities for power plant equipment manufacturing

The objectives of managers and policy makers reflect the importance of the domestic market, not only for electricity supply but also for technological equipment. Interviews and document analysis in this research show that these authorities were not concerned only with economics and a market-based approach which prioritises short-term objectives and cost/benefit analysis. In contrast, they were concerned with technological development in power plant equipment, and envisioned technological catch-up in addition to infrastructural building in electricity supply.

After MAPNA's establishment in 1992, the company was the focus of policy makers in terms of economic and technological growth. In the early phases of MAPNA's establishment, all design and manufacturing of power plants and the main pieces of power equipment were procured through outsourcing, but MAPNA initiated its learning phase through cross-border technology transfer contracts. Over the last 18 years MAPNA has acquired different types of capabilities which will be explained in the following sections. Its technological development has been connected with various challenges, trade-offs and difficulties. MAPNA Group is now a conglomeration of a parent enterprise and its 29 subsidiaries. However, Iran's gas turbine industry[66] is often defined by MAPNA and its three subsidiaries, below, as described in Chapter 2:

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[66] For electricity generation

- MAPNA Turbine Engineering and Manufacturing Co. (TUGA)
- MAPNA Turbine Blades Engineering and Manufacturing Co. (PARTO)
- MAPNA Electric and Control Engineering and Manufacturing (MECO)

The MAPNA Group has held a monopoly in Iran and industrial managers have been reluctant, particularly in the early phases, to establish any competitor for MAPNA. The main reason has been to support the growth of the company and the consolidation of its capabilities. Whilst national authorities have tried to respond to national electricity demands, at the same time they have paid much attention to gradually promoting MAPNA in terms of technological capabilities. According to MAPNA's database, since its foundation, MAPNA Group has constructed, or has under construction, more than 60 projects, valued at €17 billion, among them power projects covering more than 45,000 MW, having a share of 86% of the country's total grid capacity.

Interview data with MAPNA managers reveals that during the first decade of its establishment, MAPNA perceived gas turbines as one of the most strategic parts of power plants for several reasons. Firstly, the global trend in the power plant industry introduced gas-fired power plants as an environmental friendly choice compared to other types of fossil fuel power plants, with a rapid time of construction and high efficiency, particularly in conjunction with steam turbines (CCGTs). Secondly, political conflicts between Iran and the US resulted in US-led sanctions against Iran. US companies hesitated to sell gas turbines to Iran. This conflict highlighted the independent production of gas turbines (or self-reliance) as a significant factor for industrial policy makers. Thirdly, in-house manufacturing of gas turbines – the main high-tech and most expensive part of gas-fired power plants – has cost advantages for MAPNA and is also able to create jobs. All these factors led to the establishment of special subsidiaries by MAPNA to focus on gas turbine technology, through which technologies are assimilated, localised and developed in MAPNA Group.

Despite the fact that the core business of MAPNA is power plant construction and power generation equipment manufacturing, it has diversified the business into other areas. According to the MAPNA database, MAPNA's business scope can be categorised as follows:

Power plant industry

MAPNA is capable of designing and constructing fossil fuel based power plants. The company is now sufficiently skilled and experienced to organise, schedule and integrate all elements in order to design and manufacture fossil fuel based power plants and in particular CCGTs. Further to management and construction, MAPNA has acquired technological capabilities to design and manufacture gas and steam turbines and their ancillary equipment, turbo-compressors, turbine blades and vanes, power generators, heat recovery steam generators and conventional boilers, and power plant electrical and control systems. The capability of MAPNA in manufacturing power equipment has recently opened a new market for the company, namely after-sales services and operation and maintenance. The details of these capabilities will be discussed in the following sections.

Oil and gas and petrochemical projects

MAPNA has been engaged in the execution of utility projects for the oil and gas industry such as refineries, petrochemical complexes, pipelines, cogeneration plants (utilities) and liquefied natural gas (LNG) plants.

Railway transportation

MAPNA broadened the extent of its business to the rail transportation market in late 2004. The company now has a number of projects in manufacturing cargo and passenger locomotives and implementing railway transportation projects through close cooperation with worldwide partners.

MAPNA is now the biggest power generation equipment manufacturer in Iran, the biggest private investor[67] in power plant construction projects in Iran, and the biggest

[67] As explained in Chapter 2, MAPNA is in the process of privatisation and its assets are being divested to other companies. It is not under government regulation, but state-owned companies still hold the majority of the stock share.

power plant constructor in Iran and the Middle East. Today, MAPNA has 29 subsidiaries, and Iran's gas turbine industry is identified by MAPNA Group.

6.3 Product Specifications

Since the scope of this thesis is the gas turbine industry, it will focus only on gas turbines amongst MAPNA's products. MAPNA mainly manufactures the Siemens V94.2 gas turbine, which is a heavy duty gas turbine. The Siemens database shows that the V94.2 gas turbine has technologically evolved over the last three decades. In the 1970s when demands for heavy duty gas turbines arose, Siemens responded to these demands and introduced the first V94.2 gas turbine in 1981 (see Chapter 5, Section 5.3.3). Incremental technological development has improved the efficiency and reduced the pollution (air pollution and noise pollution) of this model of gas turbine. "These applications include single- and multi-shaft combined cycle, simple cycle, cogeneration and integrated coal gasification combined cycle. In the case of the V94.2 gas turbine, incremental design improvements have increased output and efficiency from initially 112 MW/31% to 163 MW/34.5%" (Bohrenkämper et al 2004, p. 3). The Siemens V94.2 model is also capable of running on a variety of fuels – from caloric gaseous and/or liquid fuels to treated heavy oil, with extremely low emissions (Bohrenkämper et al 2004). Availability, reliability, and low specific operating cost are major salient features of the Siemens V94.2 gas turbine. Further to these factors, its long market history and proven maturity make the V94.2 highly attractive for simple or combined-cycle processes, with or without combined heat and power, and for all load ranges, particularly peak-load operation (Bohrenkämper et al 2004). All these features have resulted in the V94.2 being an important and strategic product in Siemens's heavy duty gas turbine portfolio, and Siemens has presented this model in the market as a proven machine for a wide range of demands. MAPNA manufactures the V94.2 model of Siemens's gas turbine under the license of Siemens. MAPNA is a licensee of Siemens for manufacturing two distinct versions of V94.2, namely version three with 157

MW power output and version five with 162 MW power output.[68] Versions higher than the third version have been developed after 2001. The evidence shows that V94.2 is the highest-sold product among Siemens gas turbines, as Siemens has sold more than 390 units since 1981.[69] Beyond this, MAPNA has manufactured more than 100 V94.2 Siemens gas turbines in Iran. To date, MAPNA does not manufacture V94.3A gas turbines, although it is working hard to acquire the technologies. The main differences between V94.2 and V94.3A are the blade technologies (single crystal and directional solidification) and the combustion system (See Chapter 5, Section 5.3.4).

MAPNA also manufactures different types of GE Frame 9E gas turbine blades.[70] This type of GE gas turbine has 123.4 MW power output and was originally introduced in 1978 at 105 MW, since when it has incorporated numerous component improvements (see Chapter 5, Section 5.3.2). Its efficiency is approximately 33% in simple-cycle mode and over 52% in combined-cycle mode (GE 2006). Other auxiliary components of gas turbines like air intake, exhaust systems and boilers are manufactured in MAPNA's subsidiaries. MAPNA does not manufacture class F gas turbines; therefore, it can be argued that V94.3A and GE Frame 9F are the main technological gaps of MAPNA in mid and heavy duty gas turbine manufacture, compared to GE and Siemens, the two lead suppliers in the market. The main characteristics and differences between various vintages of GE and Siemens gas turbines are discussed in Chapter 5, Section 5.3 and Table 5.2 .

MAPNA also manufactures Siemens type E steam turbines with power output of 160 MW under license of Siemens. The analysis of these turbines is not in the scope of this thesis; however, it is worth mentioning that MAPNA has recently combined its technological capabilities in gas and steam turbines in order to operate as a turnkey for the mid and heavy range of CCGT power plants.

[68] Interview with TUGA Technology Transfer and Licensing Manager (16 July 2009).
[69] Daniel Tuex, Energy Sector, Fossil Power Generation Division Products. Contact on 20 May 2010.
[70] Although after the D'Amato Act in 1996, when US-led sanctions were legislated against Iran, GE did not sell gas turbines to Iranian companies, the previously-installed GE gas turbines always need repairing and maintenance. Therefore, domestic companies have made serious efforts to acquire GE gas turbine parts technologies and supply the domestic market. This will be discussed in detail in Chapter 7.

6.4 MAPNA's Market

Focusing on gas turbines, this section explains the market for MAPNA's products and services. The core business of MAPNA, as explained above, is the management and construction of fossil fuel power plants as well as manufacturing power generation equipment. However, in power plant industry the design, management and construction of power plants are typically differentiated from power plant equipment manufacturing. In the first case, companies construct power plants based on customer orders (capacity, fuel type and other specifications), procure the equipment often through outsourcing and then integrate the vast number of components and parts, while the latter case includes the companies that work on design and manufacturing of power plant equipment, which can be differentiated based on the OEM concept, as explained in Chapter 5. Drawing on these notions, the market for MAPNA's products and services can be distinguished into three main areas, as follows.

6.4.1 MAPNA as an EPC

EPC stands for Engineering Procurement and Construction. It is a common form of contracting in the power plant industry in which the contractor designs and constructs a power plant based on a customer's order. This mainly includes designing the power plant, procuring the required equipment – in-house or through outsourcing – and finally installing the equipment and completing the construction stages. In this type of contract, the contractor carries the project risk for the schedule as well as the budget in return for a fixed price, called a lump sum turnkey (Loots and Heniche 2007). However, the contractor may only undertake engineering and procurement, which is called an EP contract. In these contracts, construction is excluded when the construction risk is too high for the contractor or when the customer does not want to outsource the construction.

The salient feature of EPC projects is the project management and planning skills involved. In power plant construction projects, which are normally budget-intensive, the project may overrun the budget and fail to meet the schedule and technical specifications if the project not managed through modern planning and control systems. Therefore, EPC companies should be capable of organising, scheduling and integrating all the individual elements of a project.

MAPNA has a particular division for EP and EPC power plant projects, namely its engineering and construction division, which is in charge of controlling and directing all EP and EPC power plant projects. MAPNA has managed some of the largest and most complex projects in the Iranian and Middle East[71] power industry. MAPNA constructs power plants under BOO[72] and BOT[73] schemes. According to the MAPNA database reviewed for this thesis, since its foundation (over the last 18 years), MAPNA has constructed, or has under construction, more than 60 projects valued at €17 billion, among them power projects covering more than 52,000 MW, having a share of 86% of the country's total grid capacity. Today MAPNA is the main investor and main contractor of independent power and industrial projects (IPs) in Iran as it has ventured into projects to generate over 9000 MW of electricity under BOT and BOO schemes, corresponding to a total contract value of more than €4 billion. Therefore MAPNA counts as an EPC company, its market being mainly Iran and the Middle East.

[71] MAPNA has had power plant construction projects in Iraq, Syria and Lebanon.

[72] BOO (Build-Owned-Operate) is a form of project financing in which a private investor constructs a power plant and then sells the electricity to the government or to other utility companies. The ownership of the power plant belongs to the investor. In the context of Iran's power plant industry, the government takes the responsibility for providing the fuel for the power plant. Furthermore, the investor must inform the government of the power plant's thermal efficiency throughout its operating years and if it is below the agreed value, the investor is charged.

[73] BOT (Build-Operate-Transfer): Similar to BOO, this is also a form of project financing; however in this case the investor will return the power plant to the private or public sector after a lease period once it has covered the expenses and agreed benefits. In both BOO and BOT schemes, a private sector undertakes public sector infrastructure projects under agreed terms and conditions. These two types of contracts are commonly used in developing countries' capital intensive sectors, like the power plant industry, in order to provide the required investments.

6.4.2 MAPNA in the OEM Market

MAPNA shares some characteristics of OEMs. As explained in Chapter 5 (Section 5.4.1), in the context of the gas turbine industry, the OEM concept primarily delineates the lead suppliers and their licensees (OEM licensees). MAPNA manufactures Siemens V94.2 gas turbines under the license of Siemens. The Siemens Company assisted MAPNA in the selection of equipment and the training of managers and engineers. However, there are three distinct differences between the case of MAPNA and the general understanding of OEM contracting in the literature. Firstly, the degree of MAPNA's involvement in the establishment of the production sites and the degree of indigenous efforts have been much higher compared to other typical types of OEMs. MAPNA installed more advanced casting and machining lines than Siemens because at the time of the installation of MAPNA's sites there had been advances both in machines and manufacturing procedures and hence the domestic firm intended to establish advanced plants which imposed additional challenges for the Iranian managers. Secondly, the majority of MAPNA products are sold in Iran's domestic market, which is a big and growing market (see Chapter 2). Although MAPNA has penetrated the Middle East market, its share of the domestic market is much higher than that of export markets. Thirdly, export marketing has been implemented by MAPNA independently rather than through Siemens's marketing channels. The interviews with MAPNA managers shows that MAPNA has intended to market its manufactured products based on its own channels and without the restrictions of foreign companies. The reason for this is that the MAPNA Company intends to function as an EPC company in which it can make use of its own produced goods.

6.4.3 MAPNA in the Non-OEM Market

In addition to Siemens V94.2 gas turbines, MAPNA manufactures GE gas turbine parts via reverse engineering. This is particularly the case for GE Frame 9E blades which are some of the most high-tech and expensive parts of a gas turbine. Technological capabilities have been acquired through intense indigenous technological development efforts; the matter will be explained and analysed in the following sections. MAPNA supplies the after-sales and maintenance market for Iran and the Middle East.

As explained in Chapter 5 (Sections 5.4.1 and 5.4.3), OEM companies are at the cutting edge of technological knowledge. These companies are not in the business of EPC and they are specifically focused on the development and manufacturing of gas turbines. EPC companies procure the required gas turbines from OEMs or OEMs' licensees. However, MAPNA is an EPC company, which manufactures some models of gas turbines itself. The evidence suggests that in 2009 there was a very limited number of companies in the world that were involved in both the EPC and the power generation equipment (such as gas turbine) manufacturing businesses. This thesis was able to investigate three of these companies: BHEL, MAPNA and Ansaldo Energia. However, this does not mean that these three companies manufacture all the power generation equipment themselves; rather, they construct power plants in which they undertake partial or perhaps all the manufacturing processes of power generation equipment. For instance, BHEL, as will be explained in Chapter 8 (Section 8.2.1), undertakes only machining for some models of gas turbines. Table 6.1 compares these three companies in terms of turnover, products and electricity capacity installation in 2007.

Table 6.1: Companies in both EPC and Gas Turbine Manufacturing Businesses in 2007

	BHEL	**MAPNA**	**Ansaldo Energia**
Capacity (installed or under installation)	90000 MW	50000 MW	38415 MW
Turnover	5 billion ($)	1.45 billion ($)	1.2 billion ($)
Mid and heavy duty gas turbine models	V94.2, V94.3A,V64.3 Fr.6FA, Fr-9E, Fr-9FA	V94.2, GE Frame 9E (some spare parts)	V64.3A,V94.2,V94.2K, V94.3A

Source: Documents gathered in the fieldwork; company literature

Note: This table demonstrates only mid and heavy duty gas turbines for power plants – industrial gas turbines are excluded due to the scope of the thesis.

6.5 Evolution of MAPNA

This section analyses MAPNA's development phases from its inception in 1992 to 2010 and elucidates the growth of its technological capabilities over the last 18 years.

Before the establishment of MAPNA, foreign companies, in turnkey schemes, implemented all of Iran's power plant projects. However, due to the long history of establishment of power plants in Iran, indigenous workers were able to acquire two kinds of basic knowledge in the power plant industry, as follows:

- Knowledge of power plant operation: technicians were trained how to use the power plant and its equipment. This type of basic knowledge enabled the workers to understand the general characteristics of gas turbines and their compatibility with other equipment.
- Knowledge of basic repairs and maintenance: technicians were also trained to repair some power generation equipment. Knowledge of repairs provided skills and capabilities for indigenous workers.

After the foundation of MAPNA, the company tried to absorb these trained and skilled technicians in order to help the company's capability building. MAPNA Group's evolution can be summarised into five stages, detailed below. This analysis is based on a technology development approach rather than on the economic development of MAPNA Group.

All Outsourced, Only Manufacturing of Ancillary Parts (1992-1996):

In the first phase, MAPNA ordered the establishment and construction of power plants from foreign companies. All design, engineering and construction of power plants were implemented by way of outsourcing; however, MAPNA started to locally procure and manufacture a number of ancillary types of equipment of power plants.

Only Main Equipment Outsourced (1996-1999):

The experience of the first stage as well as close interaction with foreign partners in domestic projects and learning-by-doing on one side, and domestic human resource development on the other side, enabled MAPNA to develop its capabilities in power plant construction and design. Similarly, procurement of ancillary equipment from domestic suppliers developed MAPNA's manufacturing capabilities. However, the main pieces of equipment of power plants, such as gas and steam turbines and boilers, were still imported.

All Insourced (1999-2004):

There have been many factors (which will be discussed in Chapter 7) that played an important role in guiding MAPNA towards main equipment manufacturing. In 1999, MAPNA established TUGA, PARTO and MECO to assimilate and master the main pieces of power plant equipment. After the end of this phase, MAPNA acquired knowledge of the manufacturing of gas and steam turbines, and the company was able to design and construct a power plant while manufacturing the required and capital-intensive parts.

Entrance to the After-Sales Market (2004-2007):

The establishment of particular and expert companies to acquire knowledge of the manufacturing of complex and high-tech parts consolidated MAPNA Group's technological capabilities. The companies became able not only to supply the main equipment for power plant projects but were also able to offer quality after-sales guarantees. Thus, they entered into the non-OEM market. MAPNA's subsidiaries succeeded in gradually switching from solely the domestic market to a mix of domestic and overseas markets within the Middle East. Furthermore, in this stage, MAPNA started to invest in the developments and construction of power plants under BOO and BOT schemes and to solicit foreign investment cooperation.

Diversifying The Business (2007-2010):

Mastering gas turbines and other complex technologies enabled MAPNA to diversify its business into other project-based businesses. MAPNA is currently manufacturing passenger and cargo locomotives. One of the current MAPNA projects in this field is the production of 150 units of diesel electric locomotives. The company is also involved in the oil, gas, and petrochemical industries. One of the current projects of MAPNA in this field is the Mobin Petrochemical Complex, the largest utility package in the Middle East.

6.6 Analysis of Gas Turbine Technology Evolution in MAPNA

Since its inception, MAPNA managers have increasingly recognised gas turbine technology as one of the core and most capital-intensive businesses in power plant construction. A variety of factors, which will be explained in Chapter 7, motivated them towards acquiring gas turbine technology. However, technological acquisition occurred over a long, dynamic process. Analysing the industry's evolution and focusing on the processes will help to understand the dynamics and associated influences. Drawing on MAPNA's historical development, the gas turbine industry's evolution can be explained in a number of stages.

6.6.1 Assimilation of Repairing and Assembling Knowledge

At the early stages of establishment, MAPNA was able to develop its capabilities in power plant construction and design through close interaction with foreign partners and active involvement of indigenous capabilities. Construction of domestic power plants in this phase had 'learning-by-doing' benefits for MAPNA. However, these power plants always needed maintenance and repair. This was particularly the case for the main pieces of equipment such as gas turbines, which require advanced knowledge and skills. MAPNA often needed to call foreign companies to take over repairs and re-operation of the power plants. This process had three main disadvantages for MAPNA. Firstly, it usually took a long time for MAPNA to be able to contact foreign suppliers in each case of failure, while growing domestic electricity demand and a shortage of power supply sites could not bear this situation. Secondly, MAPNA had to cover all the expenses and thirdly, which was crucial in the Iranian context, a lack of repair knowledge and skills negatively affected MAPNA managers' credibility among government officials. Since MAPNA was the main contractor, the government always saw MAPNA as responsible for newly constructed power plant issues. Thus, the failure of mechanical or electrical parts of power plants led to demands that MAPNA should be able to keep the power plants and their equipment in working order. In these circumstances, MAPNA made serious efforts to learn repair and maintenance know-how from foreign suppliers. MAPNA tried to acquire gas turbine repair and assembly knowledge through cooperation with foreign suppliers in both the repair of damaged power plants and the construction of new power plants. Therefore, two types of similar knowledge gradually accumulated and coevolved in MAPNA: repair and maintenance of gas turbines, and assembling of gas turbine parts. This phase took place between 1992 and 1999.

6.6.2 Development of Manufacturing Capabilities

MAPNA managers increasingly recognised the gas turbine as the core high-tech and capital intensive component in gas-fired power plants. There were also a number of factors pushing MAPNA managers to initiate the building of gas turbine manufacturing capabilities (see Chapter 7). MAPNA was able to assimilate basic manufacturing knowledge and skills through the manufacturing of ancillary parts from 1992. Furthermore, assimilation of repair and assembly skills for gas turbines in the first phase had prepared the basic knowledge about gas turbine technologies. When MAPNA managers were assured of the existence of further potential, they embarked on developing manufacturing capabilities and envisioned the localisation of manufacturing of power plants' main equipment, especially gas turbines. In these circumstances, the government supported MAPNA in establishing subsidiaries which would specifically focus on gas turbine manufacturing technologies, as this closely matched the government's doctrine[74] of self-reliance.

In 1999, MAPNA Turbine and Manufacturing Company (TUGA) was founded as a MAPNA subsidiary. TUGA started close interactions with foreign suppliers such as Siemens and Ansaldo Energia to learn and assimilate gas and steam turbine manufacturing and design. Concurrently, TUGA started to build indigenous capabilities through engaging and activating universities in technology transfer processes and human resource development strategies. The company was able to absorb talented graduates from universities and then send them to foreign companies in order to be trained. These people were actively involved in the technology transfer processes and hence they had the opportunity of learning-by-doing. Similarly, the company involved domestic universities in absorbing and developing manufacturing knowledge. University scholars and experienced people advised on purchasing production lines and devising manufacturing procedures. In 2001, TUGA delivered its first batch of gas turbine parts, and in 2002 the first gas turbine was manufactured in the plant. In 2003, TUGA acquired the license to manufacture Siemens V94.2 gas turbines from the Siemens Company. In 2009, TUGA celebrated the manufacturing of the 100th locally manufactured gas turbine.

Since the establishment of TUGA, the company had perceived turbine blade manufacturing as a high-tech, complex and expensive[75] part of the process which required special attention. Based on TUGA's feedback, MAPNA decided to establish another subsidiary to specifically focus on turbine blade technology. In 2000, MAPNA Turbine Blade Engineering and Manufacturing Company (PARTO) was founded with the aim of mass production of heavy duty gas turbine blades and vanes for industrial and power generation applications. MAPNA and TUGA were the main shareholders of the PARTO

[74] This influence together with other influences will be explained in Chapter 7.

[75] Gas turbine blades account for 30% of the total value of a gas turbine. In the case of more advanced technologies such as single crystal or direct solidification, blades account for about 50% of the price of a gas turbine (interview with PARTO R&D head, 20 June 2009).

Company. In 2003, the machining plant, and in 2004 the whole site, including casting equipment, were ready to operate. Meanwhile, during the years of the plant's establishment the company tried to absorb basic knowledge, identifying potential foreign partners, evaluating indigenous capabilities and studying the feasibility of overseas technology transfer. At the first stage of operations, PARTO succeeded in localising GE- Frame 9E gas turbine blades. The whole process was implemented through transferring machining and casting technologies from foreign companies and coupling these capabilities with indigenous efforts such as reverse engineering. The main driver for reverse engineering was the US-led sanctions and the need for maintenance and after-sales services for existing GE plant parts in Iran which had been installed before sanctions. Before enacting the US-led sanctions, GE gas turbines were used in Iran's power plants. After the legislation of sanctions (see Chapter 7, Section 7.4), GE was not able to sell its products to Iran. However, the previously installed gas turbines needed maintenance and after-sales services. Therefore, domestic companies strived to acquire these technologies through reverse engineering (this will be explained in Section 6.7.2), enabling them to supply the domestic market. PARTO Company has always prioritised the training of its personnel. Subsequently, PARTO acquired a Siemens license to manufacture V94.2 gas turbine blades.

6.6.2.1 Casting Technologies in MAPNA

The TUGA Company outsources the casting of gas turbine parts. They generally require typical casting techniques which casting companies are able to produce. However, as discussed in Chapter 5, the casting of gas turbine blades includes sophisticated techniques and the employment of advanced alloys, namely superalloys. PARTO, which specifically focuses on gas turbine blades, performs the casting of the blades. Before the establishment of PARTO, gas turbine blade casting technology did not exist in Iran, and MAPNA managers planned to localise this technology by establishing and supporting the PARTO Company. The casting shop was inaugurated in 2004. It is equipped with facilities for investment casting in both vacuum and atmospheric conditions. The shop floor is equipped with advanced equipment and machinery, including wax injection-assembly, automated ceramic shell processing, automated handling systems, advanced cutting, water jet, core leaching and finishing equipment, and grain etching, along with highly advanced quality systems. At the time of its establishment MAPNA managers tried to employ the latest casting machines and procedures and hence this workshop is supported by state of the art technology in the form of vacuum and air melt furnaces. PARTO castings are based on poly-crystal materials and not on single crystals. The managers did not plan to acquire the techniques for manufacturing single crystal blades due to the non-economic characteristics of these materials. Instead, PARTO has established R&D projects to acquire direct solidification (DS) in the near future.

Casting knowledge of gas turbine blades can be classified into two parts, as follows:

- General know-how: This mainly includes superalloy specifications, melt pouring techniques, specifications of ceramic dies and other general know-how. PARTO mostly acquired this knowledge through accessing academic knowledge as well as through licensing agreements with Siemens.
- Specific know-how: This mainly includes designing of a 'process sheet' in which the exact pressure and temperature conditions are described. All the processes such as melt pouring are codified in detail. PARTO mostly developed this know-how through in-house R&D and by recruiting specialists.

6.6.2.2 Machining Technologies in MAPNA

Machining processes are amongst those activities that OEM companies implement in-house. Although it amounts to manufacturing knowledge, machining processes involve designing complex manufacturing procedures. These procedures should then be codified in a way that workers become able to perform the manufacturing processes, as explained in Chapter 5. However, the complexity and required accuracy of gas turbine parts make machining a core activity in OEMs. Since the inception of TUGA, the company managers have striven to establish state of the art machining lines in association with domestic consultants and foreign partners on one hand, and through assimilation of machining knowledge by close interaction with domestic and overseas experts on the other. TUGA has had technology transfer contracts with Siemens and Ansaldo Energia. TUGA was able to establish a heavy machining plant with large CNC boring, milling and turning machines to prepare main gas turbine casings (inner and outer) and shafts. The company also has a medium and small machining plant with broaching, grinding, milling, machining centre and turning machines to manufacture small and mid sized parts such as blade rings, bearings and discs.

However, blade machining has unique features with regard to machining, as explained in Chapter 5. The PARTO Company's machining lines were ready to operate in 2003 and now include STEM drilling (see Chapter 5, Section 5.2.2), Creep Feed Grinding (CFG), Electro Discharge Machining (EDM) and milling.

The evolution of machining technologies in MAPNA shaped two kinds of capabilities in machining: firstly, they allowed for the assimilation and internalisation of machining knowledge, thus enabling MAPNA to implement the machining for different gas turbine parts, and secondly, they enabled MAPNA to build the capability to design machining processes and procedures.

6.6.2.3 Coating Technologies in MAPNA

Siemens coating technologies have mostly been developed through collaboration with US companies and hence Siemens did not help PARTO in transferring the technology. The strategy of PARTO was to develop these technologies by maximising domestic knowledge and materials. However, the company benefited from high-tech companies which are often the providers of technology for large firms. This method of acquisition will be explained in the following section. PARTO now performs MCrAlY coatings on gas turbine blades and is developing its capability to perform TBC coating within the next year. The coating workshop also includes ultrasonic cleaning and overspray removal.

6.6.2.4 Control Technologies in MAPNA

Since 2004, MAPNA has been able to localise the manufacturing of most gas turbine parts; however, electric and control systems were still imported. MAPNA established a new subsidiary, MAPNA Electric and Control Engineering and Manufacturing Company (MECO), to focus on designing and manufacturing instrumentation, electrical and control systems for gas and steam turbines. The initial capability had been built through repairing and assembling activities in the 1990s. In general, control and electrical systems in gas turbines include hardware manufacture and software development.

MECO, similar to the other subsidiaries, started to work closely with foreign partners and mobilised domestic teams to learn during the MAPNA projects. MECO succeeded in acquiring Siemens and ABB licenses in electrical and control systems. Localisation of V94.2 gas turbine control systems has taken place in three main stages. At the first stage, while MECO was manufacturing the systems, it was allowed to localise 20% of the system. At the next stages, MECO was able to increase localisation to 40% and finally to 80% in 2009.

MECO has simultaneously been trying to reopen technological know-how in the components and assimilate embedded knowledge. This was particularly the case for the existing systems of gas turbines, as MECO decoded the software and investigated the electrical hardware in order to use this knowledge in after-sales and design activities. MECO is now able to change, improve and design software logics. MECO is also planning further R&D programmes.

The above sections illustrate the evolution of manufacturing technologies in MAPNA. The consolidation of manufacturing capabilities in MAPNA occurred between 1999 and 2005. Two major capabilities were formed in this period. Firstly, MAPNA developed the capability of manufacturing gas and steam turbine parts based on product specifications, available drawings and available process plans.[76] In this phase, MAPNA was able to install manufacturing lines and assimilate manufacturing knowledge which mainly included mastering the manufacturing processes and assembling procedures. The second phase almost amounts to designing manufacturing processes. This capability mainly includes devising process planning and designing plant layout, based on final product material and geometrical specifications.

At the end of this phase, MAPNA extended its business into after-sales services and operations and maintenance in order to respond to market demand. MAPNA is now able to offer quality and performance guarantees for its customers.

6.6.3 Product Engineering

As explained in Chapter 5, ambient temperature and pressure affect gas turbine performance. A gas turbine might work efficiently in one geographical place but not efficiently in another geographical position with different atmospheric pressure and ambient temperatures. Altitude, temperature and moisture are the geographical and climatic factors that influence gas turbine performance. Geographical and climatic conditions differ vastly across Iran. The western and north-western parts of Iran are mountainous areas. The northern part of Iran is covered by dense rain forests. The eastern part consists mostly of desert basins. The only large plains are found along the coast of the Caspian Sea and at the northern end of the Persian Gulf. The difference between the warmest and coldest regions in Iran can reach 50 degrees Celsius. Similarly, the humidity and altitude pressure dramatically differs across the country. MAPNA needs to consider these important factors when it constructs power plants in different regions of Iran. These circumstances directed MAPNA to optimise its products based on geographical and climatic conditions and hence required re-engineering activities. In this period (the period of product engineering), MAPNA developed its capability to respond to customer order design, in which the

[76] Process plans explain manufacturing and assembling processes.

company improves the design and manufacturing of gas turbines, including air filtering systems and cooling systems, in order to optimise their functionality based on temperature, humidity and pressure parameters in accordance with customers' orders. Furthermore, in this phase MAPNA standardised its products, services and procedures. Therefore, MAPNA initiated the development of its re-engineering capabilities and applied different standards in different places as needed. The NYAM project was one of the large projects of the MAPNA Group in this period.

6.6.3.1 NYAM: A Forward Step

MAPNA has evolved to become the main contractor for the construction of power plants in Iran. However, the major issue for MAPNA in the years between 2005 and 2007 was the adaptation of power plants to different geographical and climatic conditions on one hand, while shortening the construction time on the other. In the power plant industry, utility construction companies such as EPC companies and also main equipment manufacturers often standardise their services and products in order to shorten the construction and production times, and to respond quickly to market demands. Companies like Ansaldo Energia, Siemens and Alstom had similar projects in the 1990s to standardise the design and manufacturing of power plant equipment. Along these lines, in 2005 MAPNA set up the NYAM plan. NYAM stands for MAPNA Standard Power Plant. MAPNA aimed to reach the following goals through the NYAM plan:

Promoting Technological Capabilities

Standardisation of power plant design and power equipment manufacturing provides a common language in MAPNA Group by which people can interact simply with each other. Through the NYAM plan, MAPNA and its subsidiaries embarked on the codification of transferred and created knowledge with an integration approach within the Iranian context. MAPNA staff learned how to standardise technical and managerial knowledge through which all MAPNA staff can interact with each other. For instance, MAPNA performed Overall Interface Engineering within the Group in order to release its own drawings and documents. The plan also helped MAPNA subsidiaries to get feedback from other departments. These discussions helped managers and engineers to reconsider possible technological gaps.

Shortening of Project Times

MAPNA annually constructs 3000 MW of power plants across Iran, and forecasts project that with the implementation of the NYAM plan this capacity will be enhanced to 5000 MW. This will help to remove the diversity of power plants' ancillary parts. Through the implementation of the NYAM plan, power plants' construction times shorten in two ways. One is the pre-engineering (or planning) stage in which the company participates in tenders, negotiates with customers and competes with other companies. During this stage, the company has a robust estimation of the costs and benefits as well as the duration of the project. The second stage is manufacturing power equipment and the construction of power plants. The projects therefore do not start from zero, as there is a standard form of power plant and equipment characteristics for which engineering drawings and documents are already prepared. Some equipment, such as electrical and control systems, is prefabricated and can be quickly installed. The company only needs to adjust the design and equipment to geographical and climatic conditions or in accordance with customer orders. Following the traditional method, power plant construction takes 30 months, of which five months are allocated for pre-engineering and 25 months for the construction of the power plant and the manufacturing of power plant equipment. However, following the NYAM project MAPNA is able to construct power plants in 20 months, of which only two months are for pre-engineering. Similarly, the time for manufacturing and installing gas and steam turbines used to be 13 months, but after the NYAM project this time has been reduced to only five months.

Increasing Productivity

Standardisation is not just about minimising the duration of project implementation. Rather, robust estimation and preparation reduces labour costs as well as manufacturing and construction costs, and hence productivity and benefits will grow.

Enhancing Agility and Competitiveness

Shortening the planning, pre-engineering and implementation stages enables MAPNA to respond quickly to market demands. The company is also able to participate in tenders with more accurate, feasible and economic proposals. Furthermore, customers now have a clearer picture of power plant specifications.

6.6.4 Design Capabilities

Once MAPNA managers had assured the consolidation of manufacturing and product engineering capabilities in 2007, they decided to develop the R&D area. MAPNA's Senior Vice President commented that:[77]

"Design should be step-by-step. This means that we have to move onto design after the consolidation of the manufacturing phase, otherwise we don't even know what we are looking for!"

The establishment of MAPNA's R&D division coincided with the diversification of MAPNA's business scope into other project-based businesses, in particular the oil and gas industry. In this phase there was a need to diffuse accumulated technological knowledge into these new areas. Therefore, MAPNA aimed to reach two main objectives: firstly, the company envisioned improving existing products and developing new products and secondly, the company intended to transfer technological knowledge into other newly

[77] Interview with MAPNA's Senior Vice President and Member of the Board (25 June 2009).

established business areas. However, in the early phases MAPNA did not set unachievable targets. Instead, the company pursued the promotion of its knowledge to the extent to which in the medium-term it would be able to respond to customers' requests for the modification and improvement of products. In other words, the design stage began with re-engineering activities and parts optimisation rather than with designing new products. In contrast to the previous phases, in which the centre of gravity in the combination of indigenous and overseas technology sources was more inclined to the foreign side, in the design phase, MAPNA strategy turned more to the fertilisation of indigenous capabilities and the engagement of domestic universities than before. MAPNA's Head of R&D commented that:[78]

> "MAPNA entered into the design phase after it was assured of the dominance of the previous prerequisite phases. … In the design stage, technology transfer is not appropriate because the lead companies are not interested in transferring it. Transferring of manufacturing technologies is a different matter, though nowadays companies are even reluctant to transfer manufacturing know-how because they believe in a limited number of gas turbine suppliers."

MAPNA's R&D division motivated the other subsidiaries to establish R&D sections in their own specific fields. The whole R&D strategy for MAPNA Group was developed through the interaction of R&D departments in the subsidiaries, and is formed as an integrated plan. All projects, both in the parent company and in the subsidiaries, are confirmed and funded by the R&D headquarters.

Design capabilities are currently under development in MAPNA and it is difficult to evaluate the level of capabilities. However, MAPNA managers envision a long-term plan. Recent activities show some positive signs. MAPNA's R&D Head commented that:[79]

> "The ultimate goal of R&D establishment in MAPNA was to build indigenous capacities to acquire and to create design knowledge. Of course, the department is young now and it is too early to expect much after three years of R&D. However, the momentum is increasing and the current expectations of this department are now more reasonable than before, expecting a miracle! The senior managers are determined enough and this is the

[78] Interview with MAPNA R&D Head (2 August 2009).
[79] Interview with MAPNA R&D Head (24 August 2009).

only department which is directly chaired by the chief of the board and the CEO. In general, we are optimistic in this department."

MAPNA Group defined a number of R&D projects in which the R&D headquarters tried to include R&D departments from the subsidiaries to acquire and consolidate design knowledge and capability. In the early stages, MAPNA's strategy was not to undertake R&D projects in-house; instead, it aimed to outsource them mostly to domestic universities and research centres. During the implementation of these projects, the R&D staff have been able to learn through collaboration with universities and academic agents. However, R&D headquarters aims to develop the core technologies in MAPNA Group through these collaborations.

6.6.5 MAPNA's Model

The above four stages show the details of the gradual promotion of technological capabilities in MAPNA. The process has included complex and dynamic interactions between indigenous technology development efforts and overseas technology inflows, which will be discussed in the next section. Figure 6.1 depicts the gas turbine technology development phases in MAPNA. The last phase of MAPNA's development (design capabilities) is shown with a dashed arrow because, as explained above, this phase only started in 2007 and the evidence indicates an ongoing process rather than fully-established capability.

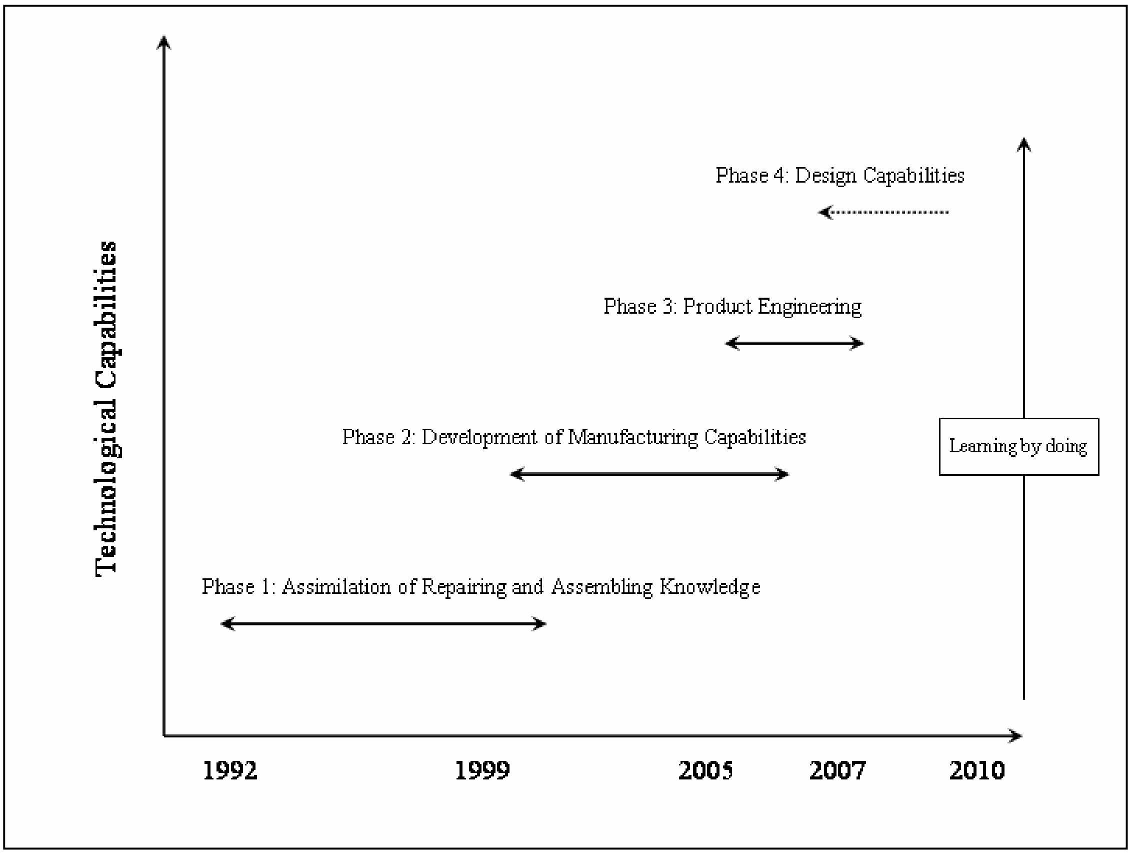

Figure 6.1: Development of Gas Turbine Technological Capabilities in MAPNA

Source: Author's Elaboration (see text)

Figure 6.1 is the outcome of an in-depth analysis of MAPNA and its subsidiaries. The analysis has been implemented independently to the extent that the model shown in Figure 6.1 has not been inspired by any other previous studies. However, the comparison of the Iranian case with other models in the context of latecomer firms provides useful insights for this thesis. The comparison can be made to the Korean model (Lee and Lim 2001; Lee 2005), which is well-known in the literature. Lee and Lim (2001) and Lee (2005) tried to articulate patterns and stages of catching-up in the Korean context, which they call the Korean model. The Korean model for catch-up is led by a few large firms who are nationally-owned and independent from the MNCs in terms of financing, production, and marketing Lee (2005). Below, I discuss the similarities and differences between the case of Iran's gas turbine industry and the Korean model.

- Similarities: firstly, both in the Iranian case and in the Korean model, the main driver to engage in the acquisition of design capabilities was the reluctance of forerunner firms to transfer design knowledge to the host firms. It should be noted that, in the Iranian context, the reluctance of foreign firms was empowered by the special characteristics of the gas turbine industry (see Chapter 5, Section 5.4.3) as well as the existence of US-led sanctions (see Chapter 7, Section 7.4.1). Secondly, the technological capabilities of the Iranian and Korean firms evolved in such a way that the starting point was assembling knowledge, ultimately reaching design capabilities. This path is, however, opposite to that of forerunner firms, which started with the design stage and reached assembly later (Lee and Lim 2001; Lee 2005). Thirdly, in both contexts, the government played a significant role. The details of government intervention will be explained in Chapter 7 (Section 7.3).
- Differences: firstly, the Korean firms have achieved higher levels of technological capabilities in sectors characterised by newer technologies. This is not the case in the gas turbine industry. As explained in Chapter 5 (Section 5.3.3), the Siemens V94.2 gas turbine was introduced in the early 1980s and today it is still a predominant choice in the market. Secondly, most of the Korean cases were oriented towards export markets and the domestic market did not play an essential role in technological evolution. In contrast, in the Iranian case, supplying the domestic market has greatly enhanced local firms' capabilities (see Chapter 7, Section 7.5).

Beyond the similarities and differences between the Iranian and Korean models, the analysis demonstrated in this chapter delves deeply into the processes and details, and thus reveals other insightful points. The model presented by Lee and Lim (2001) and Lee (2005) does not highlight the importance of manufacturing capabilities. This is because in the sectors[80] they studied, there are significant differences between the levels of manufacturing and design knowledge. In these industries, the knowledge requirements for designing are

[80] D-RAM, automobile, mobile phone, consumer electronics, personal computer and machine tool industries.

much more advanced than those for manufacturing. In contrast, the gas turbine industry is characterised by the complexity of its manufacturing technologies (see Chapter 5, Section 5.2). In fact, in the model of Lee and Lim (2001) and Lee (2005), manufacturing knowledge is confined to operational skills (at the first stage of catching-up) and to assembly processes (at the second stage of catching-up). They argue that acquisition of technologies at the first two stages is relatively easy and thus it happens in most developing countries. Conversely, the manufacturing of gas turbines requires the acquisition of highly sophisticated knowledge. Due to the complexity of manufacturing technologies in gas turbines, assembling and operational skills are totally different from manufacturing skills, as explained in Chapter 5. In this light, it is worth mentioning that there are few cases of developing countries which have succeeded in the consolidation of manufacturing technologies (see Chapter 8).

Another distinction between the analysis of Lee and Lim (2001) and Lee (2005) and this thesis is that they understand the capability of manufacturing technology and new product development as a design technology for existing products. In contrast, this thesis argues that this kind of capability is not a pure design capability. It is a common aspect between manufacturing and design capabilities. In this stage (as explained in Section 6.6.3) firms practice re-engineering and product improvement activities. The ultimate goal of this stage is to improve the functionality of existing products. However, the required capabilities are in a close interrelationship between manufacturing and design capabilities. This stage is referred to as product engineering in this thesis, and its details were explained in Section 6.6.3.

6.7 How Did MAPNA Acquire Capabilities?

The previous sections have analysed MAPNA's technological capabilities as well as the processes through which it has acquired knowledge in a number of phases. The next step is to understand the methods, channels and dynamics of technology acquisition processes. This section elucidates how MAPNA acquired those technological capabilities. The approaches and methods will be explained and analysed.

6.7.1 MAPNA's Strategy

As explained in the above sections, MAPNA has greatly benefited from overseas technology transfer projects. However, fieldwork data analysis reveals that the technology acquisition process of MAPNA from overseas suppliers has a number of salient features.

Firstly, MAPNA's foreign technology transfer activities have been based on construction and/or manufacturing projects. The company managers set two specific objectives: construction of power plants to respond to domestic electricity demands, and supplying, in collaboration with foreign partners, power plant equipment for these construction projects. Therefore, technology transfer activities were implemented in a context in which intensive learning-by-doing dominated. This was particularly the case for the first and the second stages of MAPNA's development. In the first phase, MAPNA implemented power plant construction projects with foreign partners, and during this period, MAPNA acquired power plant construction and design know-how. MAPNA worked with domestic universities and established its own divisions in order to acquire power plant design, construction and installation know-how. Similarly, in the second phase, as MAPNA implemented power plant construction projects using its own in-house capabilities, it tried to absorb main equipment assembly and manufacturing knowledge. This was realised by establishing in-house manufacturing plants and transferring manufacturing knowledge from foreign partners. Learning throughout project implementation created a context in which

MAPNA was able to absorb practical know-how easier and faster. The MAPNA Senior Vice President commented that:[81]

"The difference between MAPNA and other companies is that other companies often make a technology transfer project contract while MAPNA has transferred technology through project implementation, and this is the reputation of MAPNA. Peripheral objectives are generally ignored in Iran, but MAPNA, with the support of the Ministry of Energy while constructing power plants on one hand, has taken this as an opportunity to transfer technological knowledge on the other. This is MAPNA's craft and this is the whole story of MAPNA."

Another eminent feature of foreign technology transfer in MAPNA and in particular in the second phase was the definition and implementation of fleets of projects. As explained in Chapter 5, OEM companies today are reluctant to transfer gas turbine technology to other companies. The major issue for MAPNA in communication and collaboration with foreign partners has been how to engage with and motivate foreign companies to transfer know-how to the Iranian side. MAPNA, with the support of the Ministry of Energy, put together a number of projects and proposed a fleet of power projects which are designed to be attractive to foreign companies. The main project was a contract to manufacture 30 gas turbines (Siemens V94.2) for Iranian power plants in which the share of localisation was gradually increasing. This project was set up in 1999 between MAPNA and Ansaldo Energia and had five phases, as follows:

- Phase one (1999-2001): local manufacturing of air intake system, filtering system, exhaust system, heat and noise isolating systems (enclosure) and fire fighting systems, which include about 11% of all gas turbine parts.
- Phase two (2001-2002): local manufacturing of auxiliaries and skids and gas piping systems, which include about 27% of all gas turbine parts.
- Phase three (2002-2003): local manufacturing of intermediate shaft, bearing pedestal centre and exhaust casing, which include about 37% of all gas turbine parts.

[81] Interview with MAPNA's Senior Vice President and Member of Board (25 June 2009).

- Phase four (2003-2004): local manufacturing of inner and outer shell, mixing chamber, casing, flame tube and burners, which include about 55% of all gas turbine parts.
- Phase five (2004-2005): local manufacturing of rotating compressor blades, turbine shafts and rotor disc, which include about 71% of all gas turbine parts.

Today, all the remaining parts, such as stationary and rotary blades and vanes, have been localised in MAPNA. The projects within the above model helped MAPNA to have close interactions with foreign partners and elevate its technological capabilities through learning-by-doing and absorbing codified as well as tacit knowledge.

The third part of MAPNA's specific technology acquisition was the initial determination of localisation, which strategically motivated managers towards learning and know-how transfer. While MAPNA had committed itself to constructing power plants across the country, it had envisioned the localisation of power generation equipment technologies such as gas turbines. Interview data reveals that localisation of manufacturing and know-how transfer has been prioritised in project planning and project implementation. Project definition (see Chapter 7, Section 7.3.1 and Figure 7.1) and team organisation was formed in ways that enabled technology transfer and the absorption of manufacturing knowledge. For the different parts of the projects, the local employees had the mission to work closely with foreign experts in Iran or abroad. Furthermore, MAPNA, as will be explained in the next section, tried to be actively involved in technology transfer processes. The evidence shows that MAPNA managers in their long-term strategic plans were not satisfied with localisation; rather, they envisioned capability building in the company through indigenous efforts and transferring knowledge from abroad. They recognised power plant construction projects as learning-by-doing opportunities and project implementation with foreign partners as a way in which MAPNA staff were able to absorb tacit elements of technological knowledge. During these processes, MAPNA enabled indigenous capability building sources such as reverse engineering.

6.7.2 Reverse Engineering: Internalising Technological Knowledge or Enhancing Bargaining Power?

Reverse engineering is often cited as a technology transfer channel to latecomer firms (Bell and Pavitt 1993; Pack and Saggi 1997; Radosevic 1999; Mathews 2002). These studies argue that reverse engineering is possible where a product technology has become standardized and thus it is possible for some technologies and it may not be possible for other technologies such as ICT technologies. Apart from feasibility, the interesting question is to what extent reverse engineering can help latecomer firm in technological catching-up process? A few studies have argued that in reverse engineering methods, tacit elements of technology are not transferred and hence it is a passive process of technology transfer (Pack and Saggi 1997). However, other studies have argued that reverse engineering can be an important channel for indigenous capability building. Bell and Pavitt (1993) believe that reverse engineering in Japan complemented technology imports, and they argue that "tie-ups with foreign firms (involving know-how licensing and direct foreign investment) were necessary, but localized reverse engineering was also a major channel for accumulation of product design and development capabilities once local firms had mastered production and component technologies" (p. 172). The MAPNA case supports the latter argument and reveals that reverse engineering has played two significant roles.

Firstly, this method has enhanced both MAPNA's technological capability to manufacture gas turbine parts and its absorptive capacity to assimilate foreign technologies. Reverse engineering in MAPNA occurred before foreign technology import and developed a level of indigenous capability to absorb foreign knowledge – an argument that has often been cited in the literature (Freeman and Hagedoorn 1994; Pack and Saggi 1997). MAPNA employed reverse engineering in the manufacturing of turbine blades[82] and succeeded in manufacturing GE Frame 9E gas turbine blades. This capability helped MAPNA to become a licensee for Siemens to manufacture V94.2 gas turbine blades. The CEO of PARTO commented that:[83]

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[82] MAPNA managers perceive reverse engineering as a method which does facilitate the absorption of some technological knowledge, but which is not suitable for the whole system.

[83] Interview with PARTO's CEO (22 August 2009).

"We started reverse engineering activities earlier than licensing. Deepening our knowledge in this case considerably helped us in the absorption of licensing knowledge. However, being a licensee speed up our technological growth and answered our questions."

Reverse engineering has produced deep manufacturing knowledge and capabilities for PARTO. The company has used foreign technology transfer to fill its possible technological gaps and now PARTO is capable of manufacturing most kinds of gas turbine blades via reverse engineering methods. In 2009, PARTO's CEO reported that the company had had a failure report in licensed gas turbine blades, but had had no failure reports in reverse engineered blades. PARTO employees have often mentioned one common aspect in reverse engineering; that is, they have the freedom to choose manufacturing methods and procedures in reverse engineering, compared to licensing, in which they have to follow certain methods and techniques. Although the case study reveals that those rare failure cases were mainly because of fuel impurities, one important outcome is proven: in PARTO, reverse engineering has greatly contributed to the development of manufacturing capabilities in gas and steam turbine blades and has also extensively helped PARTO in absorbing foreign technologies.

The case of gas turbine blades in MAPNA shows that the company has synthesised indigenous technology development efforts and overseas technology transfer in a dynamic manner. Reverse engineering helped PARTO to absorb imported technology, while imported technology improved the company's capabilities and answered its technical questions. In the case of gas turbine blades, there has often been an interaction between these two kinds of technology sources (indigenous and overseas).

The second point revealed by the MAPNA case is that acquiring technological knowledge through reverse engineering enhanced the company's bargaining power in international collaborations. The evidence suggests that the acquisition of manufacturing capabilities by local firms affected the level of prices offered by foreign companies. The foreign suppliers offered lower prices for gas turbine parts for the period in which the technologies had not been shaped in MAPNA. Furthermore, PARTO's capabilities helped the company to become a licensee for manufacturing Siemens V94.2 gas turbine blades. Interview data shows that Siemens was reluctant to sell the license to MAPNA and its subsidiaries (particularly regarding the manufacturing of hot sections of gas turbines, which are the most high-tech parts). Siemens was more inclined to collaborate in the assembling area. Nevertheless, the licensing agreement was made because of two main reasons. Firstly, Siemens was alarmed by the presence of another competitor in the Iranian market, Ansaldo Energia, which had made collaboration agreements with MAPNA (this will be explained in the next section). Secondly, Siemens observed the formation of manufacturing capabilities of gas turbine parts through reverse engineering in MAPNA and its subsidiaries. The extent to which Siemens observed the manufacturing of its original parts by an Iranian company without Siemens's involvement caused more alarm for Siemens. Accordingly, Siemens agreed to collaborate with MAPNA under licensing conditions. Therefore, it is reasonable to conclude that reverse engineering activities improved MAPNA's bargaining power in its international collaborations.

6.7.3 Licensing

In the literature, licensing implies a technology transfer channel in which a licensee is allowed to produce a specific product in accordance with its original specifications, provided that they pay a license fee to the technology owner (licensor). In these agreements the product is manufactured under the parent enterprise's brand and quality control procedures, and hence the original manufacturing equipment and procedures should be transferred within the license. Therefore, it is often recognised as an opportunity in which the licensee can acquire both explicit and tacit forms of technological knowledge (Pack and Saggi 1997; Kim 1998), thus improving their technological capabilities as well as their R&D capacity (Freeman and Hagedoorn 1994; Pack and Saggi 1997). Past government policies in Japan and Korea encouraged local firms to make licensing contracts with foreign partners rather than make use of FDI. This was partly because of nationalistic concerns but largely due to the enhancement of the possibility of the local firms' access to technological knowledge (Pack and Saggi 1997).

On the other side of the coin, licensing agreements, in the view of the licensor, embed the risk of the sale of the original product by the licensee to other markets.

Therefore, licensing contracts often involve a number of restrictions in terms of exports to third markets, rights of ownership of any improvements the licensee may make to the licensed technology, and the purchase of inputs produced by the licensor (Pack and Saggi 1997). The risk of technological knowledge leakage from the licensor to the licensee means that licensing agreements are not appropriate in all circumstances and in all technologies. Empirical evidence shows that firms are reluctant to transfer their best technologies under licensing agreements; instead, they prefer to make licensing agreements for older technologies. This is particularly the case in the gas turbine industry, where the oligopolistic nature of the gas turbine market (see Chapter 5, Sections 5.4.4 and 5.4.5) has confined the licensing agreements to a small proportion of the total agreements, and where OEMs prefer a small number of players in the market. In contrast in some other industries and in particular low-tech industries, such as metalworking, licensing has been the choice for technology-owning firms (Mytelka 1979). Therefore, the appropriateness of licensing for either licensors or licensees should be discussed in a specific context.

MAPNA tried to acquire licenses from leading OEMs. However, US-led sanctions obstructed any collaboration with GE, and thus MAPNA switched to Siemens. However, Siemens and MAPNA did not compromise in contractual terms, mainly with regard to know-how transfer. MAPNA negotiated with other technology owners with centralised transferral of technology at the core of its negotiations. Finally, MAPNA was able to conclude a large project (manufacturing 30 gas turbines) with Ansaldo Energia. This project helped MAPNA to gradually enhance its technological capability and led to know-how acquisition by MAPNA. In these circumstances, Siemens was alarmed at the loss of a large and growing market in Iran. In addition, Siemens observed the acquisition of technical know-how by MAPNA without Siemens playing any role and thus agreed to make a licensing contract with MAPNA.

This licensing contract has had two main benefits for MAPNA. Firstly, MAPNA sees the licensor as a 'reliable' knowledge source through which MAPNA and its subsidiaries are able to benefit from the licensor's experience and technological knowledge, as well as their consultancy in building technological capabilities. Construction of manufacturing plants, machinery selection, designing manufacturing procedures and upgrading products and machines are all areas in which MAPNA can benefit from the licensor's consultancy. Secondly, the licensing agreement entails 'credibility' for MAPNA when selling its products. The Siemens gas turbine brand and its credibility are important in the market, and power plant constructors often prefer to use credible and reliable products. Interview data shows that one of the major motivations of the MAPNA Company with regard to licensing agreements was to obtain credibility in the domestic and overseas markets.

6.7.4 Indigenous Development of Management Systems

MAPNA has implemented various domestic as well as international projects. The growth of the companies like MAPNA depends on their ability to learn from these projects and to convert the acquired knowledge into organisational capability, the integration of systems and improving core capabilities (Davis and Hobday 2005). Furthermore, MAPNA as an EPC and also as a power plant equipment manufacturer often works with a complex and broad range of knowledge. Such an position requires high-level management skills including organising, managing resources, planning, financing and project management.

Since 1973, Monenco Agra[84] has had a joint venture in Iran. Until 1997, Monenco Iran was managed by the government, but in that year the government sold its share to MAPNA and to MIR Investment Company. In acquiring this company, MAPNA was able to access management skills and subsequently tried to contextualise these skills and knowledge in power plant construction and the power plant equipment manufacturing industry. MAPNA then indigenously developed management systems such as project management, information management, logistics and technical contracts. MAPNA also developed software for management systems.

[84] Monenco Agra was a Canadian Company. In 1999, AMEC acquired Monenco Agra and became a shareholder in Monenco Iran. MAPNA is now the main shareholder of Monenco Iran, though AMEC and MIR (Cooperation of Monenco Iran employees) have about 6% of the total share.

6.7.5 Indigenous and Overseas Capabilities Are Synthesised

In the MAPNA case, as discussed, two main knowledge sources have been drawn upon: indigenous capabilities, including intra-firm capabilities, domestic universities and research centres, and overseas technology sources, including OEM companies, non-OEM companies and foreign consultant companies. However, the managing of these two sources has involved challenges with different considerations.

The first source requires human resource development, investment in R&D, and interacting with domestic universities in order to build technological capabilities. Although these measures could greatly enhance MAPNA's technological capabilities, their impacts are not necessarily short-term. However MAPNA, as previously mentioned, had a commitment to construct power plants across the country in accordance with particular timescales.

The second source requires development of constructive cross-border partnerships. However, this has been heavily influenced by the oligopolistic structure of the gas turbine market. The industry structure and market characteristics operate in such a way that latecomer firms face significant barriers to acquiring technologies and to entering into the market (see Chapter 5, Section 5.4). Beyond this, the US-led sanctions jeopardised the 'accessibility' of some technologies for MAPNA Group (see Chapter 7, Section 7.4). These sanctions, which were due to political tensions, have had fluctuating effects.

The MAPNA case analysis shows that the company has dynamically benefited from both indigenous and overseas technology sources. The company built its initial capabilities, acquired technology from abroad, mobilised indigenous people to master these technologies, tried to improve them, and upgraded its capabilities very close to the design stage. Throughout these processes, the company has acted in a context in which various considerations coexist and at the same time indigenous capabilities have coevolved with overseas technology inflows. MAPNA's Senior Vice President commented that:[85]

> "We have tried to synthesise imported technologies with indigenous capabilities. We localised manufacturing technologies and then we activated R&D. Our strategy has been building initial capability before entering technology transfer activities."

[85] Interview with MAPNA's Senior Vice President and Member of Board (25 June 2009).

MAPNA's entry into gas turbine manufacturing was preceded by power plant construction, the acquisition of assembly know-how, and active engagement in learning-by-doing steps. These initial efforts fit closely with the complementary idea in technological catch-up studies, where scholars highlight that the process of importing technology could be preceded, not just followed by local investment in related technological capabilities (Bell and Pavitt 1993; Freeman and Hagedoorn 1994). Therefore, two important aspects made MAPNA a 'smart importer': a strategy for learning, and initial capability building (as explained in Section 6.7.1).

However, initial efforts do not necessarily entail technology acquisition by the transferee. Another important aspect is how to transfer the technology. In 1999, when MAPNA embarked on gas turbine manufacturing, the first idea was to benchmark Siemens's manufacturing lines and establish a similar plant in Iran. A consideration emerged once the managers recognised that some of the Siemens manufacturing processes as well as their machining lines were relatively old. MAPNA hired local experts and university researchers to advise on plant construction. These consultants advised the managers to use new manufacturing machines and procedures. On one hand, some of the managers were keen to start manufacturing activities at the earliest possible time simply by directly copying Siemens machines and procedures in Iran. On the other, the consultants advised the installation of new techniques and the establishment of a modern plant. Eventually, MAPNA established an advanced plant based on its own needs. TUGA's Engineering Deputy Manager commented that:[86]

> "We had some experts to consult in purchasing, operation and maintenance of machines. We should have a deep manufacturing knowledge before purchasing machines and equipment. We didn't purchase Siemens's machines. We ordered based on our own needs and then we developed the technologies, and now manufacturing is our competitive advantage."

MAPNA envisioned mastering gas turbine manufacturing technologies not only based on one specific model, but also wanted to be capable of manufacturing other types of gas turbines. The interview data shows that the managers were not thinking to establish a manufacturing plant for one specific model of gas turbine, and that they preferred to master

[86] Interview with TUGA's Engineering Deputy Manager (16 July 2009).

manufacturing technologies instead. Therefore, they weren't concerned with technical specifications; rather they returned to the question of what kinds of capabilities and knowledge they needed and then tried to acquire them. However, the realisation of such thinking needed the engagement of domestic universities, experts and intra-firm capabilities in the process, as explained above. The engagement of domestic universities in technology transfer processes has had two benefits for MAPNA. Firstly, the company was able to install new manufacturing machines and techniques. Secondly, the universities played a constructive role in human resource development for MAPNA. They introduced capable graduates to the company who were gradually engaged in technology transfer processes and, after some years' experience, they are now key individuals in the company. Therefore, MAPNA's plant establishment had already been complemented by indigenous technology development efforts.

A similar challenge has been the case in gas turbine blade manufacturing. When PARTO Company started to transfer blade manufacturing technologies, a number of problematic situations emerged. The first challenge was in adapting casting technologies. PARTO collaborated with Doncaster[87] Company in a casting technology transfer project. The machines and techniques were adapted from Doncaster; however, techniques and procedures were improved for Iran's climatic conditions, since temperature and humidity are influential factors in casting. PARTO's CEO commented that:[88]

> "We transferred the basis of casting but we changed it in accordance with our own needs. We localised procedures and improved on a number of cases. In one specific model of blade, we even totally changed the casting process".

The second challenge was in the development of machining procedures. Siemens provided the final machining drawings and technical specifications for PARTO, but PARTO developed its own manufacturing techniques. In some cases, updated techniques were developed and deployed by PARTO.[89] These changes were partly because of the advent of new manufacturing techniques at the time of PARTO's establishment while

[87] Doncaster is a British company specialising in casting.
[88] Interview with PARTO's CEO (1 September 2009).
[89] For example, machining of cooling holes upgraded by electrical machining techniques. Similarly, for machining the stationary blades PARTO used a 'single piece grinding' method, which is a new and flexible technique, instead of 'ring turning'.

Siemens's manufacturing machines and techniques were relatively old, and partly because of the indigenous efforts of PARTO to adapt and localise manufacturing technologies. Transferring machining technologies was synthesised with indigenous technology development efforts.

The third problematic situation for PARTO was in transferring coating technologies. The companies collaborating with Siemens in the coating of blades were American companies and thus collaboration between these companies and Iranian firms was not possible. Siemens could only provide the final specifications; that is to say the 'acceptance criteria'. However, reverse engineering activities had enhanced the technological coating capabilities in PARTO. The company decided to activate both indigenous technology development efforts and possible foreign technology consultants and then draw on both of these knowledge sources. PARTO dynamically interacted with indigenous and foreign knowledge sources and thus acquired coating technologies.

The above efforts have all been aimed at the acquisition of technological knowledge through a synthesis of domestic and foreign sources. However, while multiple sources of technological knowledge had given PARTO a broad scope for spillovers, the issue was the integration of the knowledge, and in particular its codification. Technical documents were provided in a diverse range of languages and to a variety of standards. For example, if PARTO manufactures 20 types of products and each product has its own casting, machining and coating documents, the overall number of documents required will be 60, each of which could be based on different standards or in different languages. Therefore, the next step was to codify and standardise these documents in accordance with domestic routines. These efforts resulted in serious indigenous efforts to codify, standardise and localise technical knowledge for PARTO.

The PARTO case clearly demonstrated a dynamic progression of capabilities; that is to say, constant interactions with indigenous and foreign knowledge sources and the evolution of capabilities. A dynamic approach provided an efficient knowledge acquisition process for the managers who prioritised knowledge acquisition, learning in their interactions, and dealing with problematic situations. From this perspective, indigenous research projects and efforts, even in cases of failure, provide spillovers for the firm, through which the firm's capabilities will grow faster. PARTO's Head of R&D commented that:

"Synthesising indigenous and foreign knowledge channels is very important, as neither of these alone helps us to catch-up, and there should be a constant engagement between the two. Our rig test project with the Niroo Research Institute failed, but the spillovers helped us in our interaction with Ansalso Energia."[90]

The case of PARTO shows that indigenous efforts, including reverse engineering activities, university engagement in technology transfer processes, adaptation and improvement of imported technologies based on local conditions and activating R&D projects have been synthesised with foreign knowledge sources including technology transfer projects and consultancy and licensing agreements. In some circumstances, the existence of external factors (such as US-led sanctions) has jeopardised foreign knowledge inflows, but PARTO intensified its indigenous efforts in order to compensate, while benefiting from foreign consultants. Thus, the intensity or moderation of the two technology sources (indigenous and foreign) has dynamically varied at each stage of development. However, constant engagement of the two sources and their synthesis has produced richer expertise.

MAPNA's approach can be seen in its other subsidiaries. MECO has tried to acquire capabilities related to power plants' electrical and control systems. However, MECO has relied heavily on licensing know-how and subsequently activated indigenous technology development to internalise these technologies. It is worth mentioning that repairing and assembling knowledge (during the early phases of MAPNA's evolution) have helped MECO in absorbing technologies in its licensing contracts. MECO, as explained above, has gradually increased the localisation of gas turbine control and electrical system manufacturing. MECO decoded the existing software and mastered its know-how. Furthermore, MECO has had technology upgrading contracts with Siemens and ABB in order to renew its know-how. In the case of MECO, indigenous technology development efforts have been progressively enhanced. These efforts have synthesised with licensing technologies and have recently reached R&D projects.

[90] Interview with PARTO's Head of R&D (20 June 2009).

The NYAM project (see Section 6.6.3) was a serious effort in the MAPNA group to internalise power plant construction and power plant equipment manufacturing technologies. In this project, all imported and indigenously generated forms of knowledge were revisited. This included the codification and standardisation of power plant equipment in the MAPNA Group and led to the identification of possible technological gaps and attempts to fill them accordingly. The project engaged all subsidiaries and integrated various fields of knowledge. The project was followed by the implementation of R&D projects in collaboration with domestic universities and research institutes. MAPNA aimed to benefit from the spillovers of these projects, even in cases of failure.

The large and step-by-step projects of MAPNA with foreign partners have provided an opportunity by which transferred foreign knowledge has been 'complemented' by indigenous capability building efforts. The evidence suggests that in most circumstances, foreign technology transfer was 'preceded' by initial indigenous efforts. In the case of gas turbine blades, reverse engineering had enhanced the firm's absorptive capacity and made the firm a 'smart importer'. Technology transfer processes had also been accompanied by the 'active involvement' of domestic firms. These aspects fit closely with the literature of complementarity (Chapter 3, for instance: Bell and Pavitt 1993; Freeman and Hagedoorn 1994; Pack and Saggi 1997; Radosevic 1999). However, in-depth analysis of this case reveals that in a technological catch-up context a complementary perspective which only reflects the 'type' of relationship between indigenous technology development and overseas technology transfer does not suffice in interpreting the dynamics. In fact, in the process of technological catch-up, a latecomer firm often encounters problematic situations and the interaction between these two main knowledge sources cannot be simply reduced to a description of the type of relationship. Instead, a dynamic perspective suggests firstly that the process includes the coexistence of many considerations as well as influencing factors (see Chapter 7) that might be beyond the will or power of managers; and secondly, such a perspective provides a basis from which a firm's technology development efforts are dynamically synthesised with foreign technology transfer. Therefore, the MAPNA case reveals how the acquisition of technologies from one of these sources sometimes acts as a platform for acquisition from the other, and how these two sources are synthesised during the technological catch-up process. Figure 6.2 demonstrates the dynamics of MAPNA's technological development based on the two main elements of the dynamic approach: (a) time dimensions and sequencing (b) changing resource allocation between importing and local technology development.

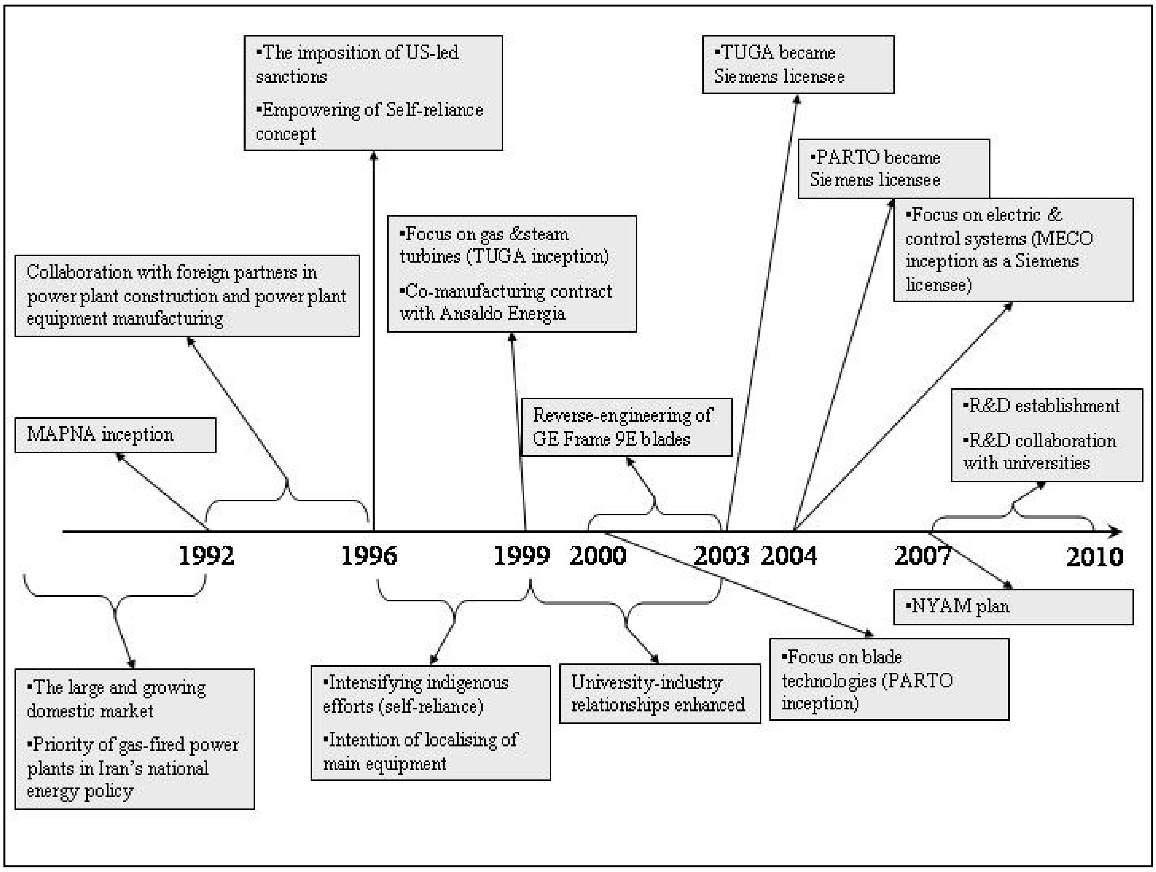

Figure 6.2: The Dynamics of MAPNA's Technological Development

Source: Author

Figure 6.2 provides a summary of the dynamism of MAPNA's technological growth process. The policy drivers of MAPNA's inception as well as MAPNA's collaborations with foreign partners between 1992 and 1996 are illustrated in the figure. The policy drivers will be explained in detail in Chapter 7, Section 7.3. It will be also explained how government procurement policies (Section 7.3.1) have facilitated MAPNA's interactions with foreign companies and have provided an excellent learning-by-doing opportunity for MAPNA and its subsidiaries. The imposition of US-led sanctions (Chapter 7, Section 7.4), in 1996, led to the empowering of 'self-reliance concept' and would lead to intensifying indigenous technology development efforts by MAPNA. It means the importance of the capability of indigenous manufacturing of industrial goods with minimum dependency on foreign sources. The existence of a big and growing domestic market (Chapter 7, Section 7.5) has motivated MAPNA to acquire advanced technologies. In 1999, MAPNA established TUGA to focus specifically on gas and steam turbine technologies. Since its inception, it had a close relationship with domestic universities. Since 1999, TUGA initiated its collaborations with European suppliers (Siemens and Ansaldo Energia) and in 2000 TUGA and MAPNA established PARTO company to focus on blade technologies. The PARTO Company started its activities with reverse engineering of GE blades and was able to become Siemens licensee to manufacture V94.2 blades in 2004. MAPNA then established MECO, in 2004, to acquire control and electronic systems. In 2007, MAPNA introduced a big project to all its subsidiaries (NYAM Plan) to integrate and standardize different technological knowledge (Section 6.6.3.1). In 2007, MAPNA established R&D department and entered into R&D collaborations with foreign companies as well as domestic universities. Figure 6.2 clearly demonstrates a dynamic progression of capabilities in which the latecomer firm, based on circumstances, benefits from indigenous and foreign knowledge sources. The process of technological catch-up by latecomer firm and its interactions with domestic and foreign knowledge sources depend upon different micro, meso and macro level factors which will be discussed in Chapter 7.

6.8 Conclusions

This chapter has discussed the products, the markets and the evolution of Iran's gas turbine industry. The main actors in the industry are MAPNA and its subsidiaries. MAPNA Group is in both the power plant engineering and procurement construction (EPC) and the power plant equipment manufacturing (OEM and non-OEM) businesses.

The analysis of MAPNA and its subsidiaries clarifies that the capabilities have grown from repairing and assembling knowledge almost to design capabilities. Throughout the evolution process, MAPNA and its subsidiaries carried out many in-house and international projects and have tried to synthesise knowledge and spillovers converting them into organisational capabilities. MAPNA's paradigm was based on the implementation of a fleet of projects, active involvement in learning-by-doing projects, initial determination to localise, and constant engagement with both indigenous technology development efforts and overseas technology transfer.

This chapter has also discussed the difficulties and the challenges faced by MAPNA Group in the technology acquisition processes. It argues that although in these processes MAPNA has benefited from both indigenous and overseas technology sources and the two sources have complemented each other, the interaction between these two sources is a complex process and is beyond that of what the complementary perspective says. MAPNA and its subsidiaries have faced various problematic situations and considerations during the technology development processes. Throughout these processes, the company has acted in a context in which various considerations coexist, and at the same time indigenous capabilities have coevolved with overseas technology inflows. MAPNA has constantly interacted with indigenous and overseas technology sources and synthesised them to produce richer expertise. The dynamic perspective, by going into greater depth, is able to shed light on the complexity of the evolution of technological capabilities. It also contributes to understanding the influencing factors on these processes – an issue that will be scrutinised in the next chapter.

Chapter 7 : Influences on MAPNA's Technological Development Process

7.1 Introduction

This chapter analyses the dynamics of interactions between MAPNA's technology development efforts, such as in-house R&D and interactions with domestic universities, and foreign technology inflows. It explains what factors influenced these processes and how they have affected the technological catch-up of MAPNA Group. This chapter discusses whether these influences facilitate interactions between indigenous and overseas capabilities or whether they act as barriers. At the same time, this chapter compares the findings with the existing literature and shows which parts fit with the literature and which parts are dissimilar. The theoretical framework in Chapter 3 provides a matrix (Table 3.2) which was re-produced, based on the scope of this thesis, in Chapter 4 (Table 4.1). This matrix provides a platform from which to compare the findings of this thesis with the existing literature. Such a comparison reveals whether those influences are important in the Iranian case or not. Furthermore, it enables this thesis to suggest new influences which have not been mentioned in the literature so far.

This chapter comprises 11 sections. Section 2 explains the enhancement of MAPNA's absorptive capacity as an important factor in MAPNA's technological development. Section 3 discusses the Iranian government's policies in the context of the gas turbine industry and explains how these policies influenced MAPNA's technological evolution. Due to the ownership of MAPNA by the state, these policies clearly show the influence of government policies on the interaction between domestic and foreign technological capabilities. This section also analyses the influence of Iran's energy policy on the evolution of Iran's gas turbine industry. Section 4 elucidates the influence of the US-led sanctions on MAPNA and explains how the sanction regime has overshadowed MAPNA's evolution. One of the salient features of this thesis is the existence of this influence on the technological catch-up process, which demarcates it from other similar studies. Section 5 explains how Iran's domestic market has played an important role in the development of MAPNA's technological capabilities. Section 6 investigates the influence of geographical agglomeration in MAPNA's evolution. Section 7 shows how the complexity of gas turbine technologies and the special market structure have influenced the interactions of indigenous and foreign technology sources in the Iranian context. Sections 8 explain that in the evolution of MAPNA, interactions with domestic universities and the enhancement of absorptive capacity have been major factors. Section 9 analyses whether the status of intellectual property rights regimes have influenced the development of Iran's gas turbine industry. Section 10 suggests a framework for all the discussed influences in a matrix and compares the findings of this thesis with the literature. Section 11 draws the conclusions of this chapter.

7.2 Absorptive Capacity

In the technological catch-up context, and in examining interaction processes between indigenous and overseas knowledge sources, the essential question is how much the domestic firm is able to absorb foreign technologies. Assimilated knowledge can complement indigenous efforts and may stimulate further technological capability building efforts. In fact, as discussed in Chapter 3, the complementary literature is based on the absorptive capacity concept, and the authors have presented successful catch-up evidence confirming the role of absorptive capacity in the process. In these cases, absorptive capacity is described based on its two elements: prior knowledge base (or threshold effect), and intensity of effort.

In the Iranian case, absorptive capacity – with these two important elements – has played a significant role in technological development processes. The strategy of MAPNA was to develop a level of technological capability before attempting technology transfer projects. For some important and high-tech parts, such as turbine blades, MAPNA's technology transfer was preceded by reverse engineering activities. Prior technology capability building efforts turned MAPNA into a smart importer (see Chapter 6, Section 6.7.5), and the subsidiaries were able to fill their technological gaps through foreign interactions. Concurrently, MAPNA increased its indigenous technology capability building efforts by escalating university-industry linkages and developing R&D activities. In the meantime, while the US-led sanctions have limited MAPNA Group's interactions with US sources of technology (such as GE), they have stimulated indigenous capability building efforts. Thus, intensity of efforts both in technology transfer projects and in domestic efforts has increased. The evolution of MAPNA's capabilities and its absorptive capacity was analysed in detail in Chapter 6; however, this section emphasises the role of absorptive capacity and technological capabilities in the interaction processes between indigenous and overseas knowledge in the Iranian case.

This section argues that the technological capability of MAPNA and its subsidiaries has evolved over time, as they currently intend to collaborate in cross-border R&D projects rather than ordinary machinery equipment contracts. They are now capable of producing gas turbines locally, though they are now striving to manufacture new models. Their absorptive capacity has also been enhanced, as the interview data suggests that they can now better assimilate foreign knowledge than they could before. This case also confirms that the high level of absorptive capacity will enhance the knowledge inflows from foreign sources to domestic companies and facilitate both sides' interactions.

7.3 Government Policies

Government policies have been continually discussed as an important influencing factor in technological catch-up and in latecomer firms' growth processes (Bell and Pavitt 1993; Hobday 1994; Lee 1996; Pack and Saggi 1997; Katrak 1997; Kim 1998; Radosevic 1999; Lee 2005; Malerba and Nelson 2007). The role has been highlighted particularly at the early stages of development (Fagerberg and Godinho, 2005). However, recent studies have revealed that the type of government policies and the methods of government interventions in the processes differ significantly from one country to another (Fagerberg and Godinho 2005; Lee 2005; Malerba and Nelson 2007). These issues were discussed in Chapter 3.

The case of Iran’s gas turbine industry shows that government policies and their associated drivers have some similarities as well as dissimilarities with the existing literature. This section elucidates how the government policies have influenced the interaction processes between indigenous technology development efforts and overseas technology transfer in Iran’s gas turbine industry.

7.3.1 Public Procurement

The main objective of MAPNA’s inception by the state, as explained in Chapter 6, was the establishment of a local company that is capable of power plant construction. Since its inception, the Ministry of Energy has granted the majority of power plant construction projects to MAPNA in order to offer opportunities of learning-by-doing for the domestic company. Furthermore, domestic utility companies have been obliged to order power plant projects from MAPNA. Meanwhile, MAPNA has been authorised and even motivated to acquire technology from various domestic and foreign sources. The Senior Deputy Minister of Energy commented that:[91]

> “The government has greatly supported MAPNA. Sometimes we gave some projects to MAPNA without any tendering. We aggregated domestic demands and ordered them from MAPNA altogether. These are unique supports for a domestic firm.”

The government has not only granted power plant construction projects to MAPNA but also tried to support and activate the power plant equipment industry. The state-owned power plants have often ordered their required equipment, such as gas turbines and their parts, from MAPNA instead of from foreign companies. Hence, the government and utility companies typically have not interacted directly with any foreign companies; rather, they have dealt with MAPNA and made contracts with it. Therefore, on one hand MAPNA has been responsible for establishing power plants in accordance with a certain timescale, agreed between MAPNA and the state, while on the other, the company has been

[91] Interview with Senior Deputy of the Ministry of Energy (16 June 2009).

authorised to interact with any domestic or foreign companies in any form of contract. However, as explained in Chapter 6, MAPNA has tried to learn during these projects and has not only focused on power plant construction. By establishing its subsidiaries and linking these companies with foreign and domestic partners, MAPNA has approached technology acquisition in tandem with power plant construction projects. In the fleet of projects, which were granted by the state to MAPNA, the main contracts between the state and MAPNA included power plant construction. However, MAPNA was also the buyer of power plant equipment, such as gas turbines, from foreign suppliers. Thus, there was another contract between MAPNA and the foreign supplier regarding the supply of the required equipment. However, one of the key contractual terms between MAPNA and the foreign supplier was the supply of at least 51% of gas turbine parts from MAPNA's subsidiaries. Therefore, another sub-supply contract was made between the foreign supplier and MAPNA's subsidiaries. In fact, power plant construction projects were broken into specific subcontracts, each of which had different contractors and different objectives. Figure 7.1 demonstrates the process and hierarchy of power plant construction projects.

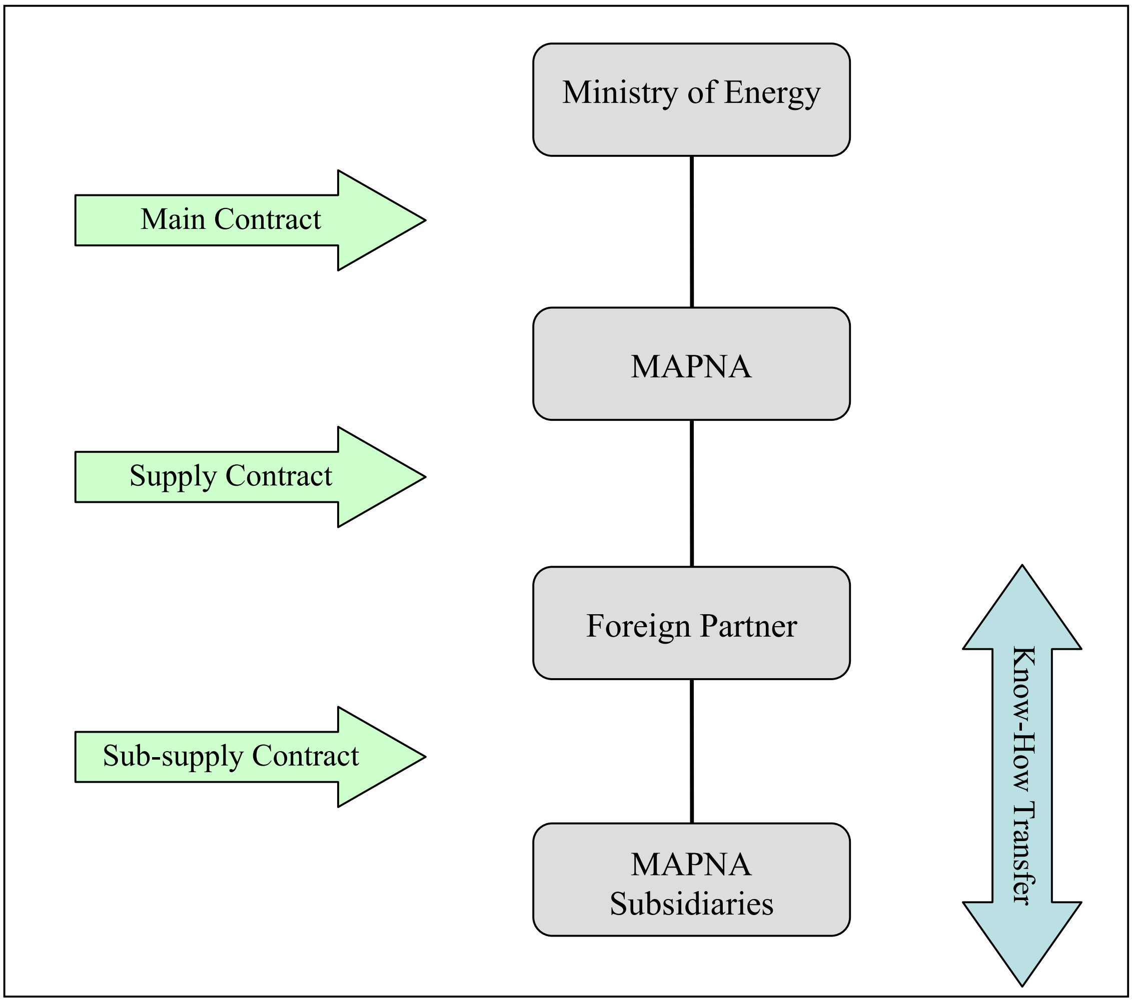

Figure 7.1: The Process and the Hierarchy of Contracts for MAPNA's Fleet of Projects

Source: Author's elaboration on interview data[92]

In the process demonstrated above, the parent enterprise (MAPNA) focuses on the management issues, such as financing and project management, to meet the project deadlines. On the other side of the coin, its subsidiaries closely collaborate with foreign suppliers in order to assimilate manufacturing technologies. They are effectively learning by manufacturing. However, it should be noted that the above process is only valid for the fleet of projects and not for licensing agreements between MAPNA Group and foreign suppliers. The licensing agreement is an independent type of collaboration between MAPNA Group and foreign suppliers (such as Siemens) in which the state-level players do

[92] Interview with TUGA's Technology Transfer and Licensing Manager (16 July 2009).

not play any role. Furthermore, in licensing agreements the foreign supplier is at the top of the contract in terms of hierarchy.

By following public procurement policies, the government secured a market for MAPNA's products. These policies, by aggregating domestic power projects, also enhanced MAPNA's bargaining power in collaboration with foreign firms. It is clear that the definition of such large projects is not feasible without government support. Therefore, MAPNA was better able to deal with foreign companies in terms of know-how transfer. Such a 'state-led demand' provided an opportunity for MAPNA in which the company and its subsidiaries were able to engage in technology transfer projects. In fact, these policies hastened MAPNA technological growth. Therefore, it can be argued that public procurement policies may facilitate the interaction of indigenous technology development efforts with overseas technology transfer.

Public procurement policies in the Iranian case show a relatively good fit with other experiences of technological change. Mowery (1995) argues that the Japanese and many Western European governments used "procurement policy to advance national technological capabilities. This strategy generally includes restrictions on foreign enterprises' access to domestic markets and the payment by public enterprises of premium prices for new equipment" (p 535). He also comments that "public procurement can support demand for advanced technologies, accelerating their development and wider application" (p 535). Lee (2005) also argues that procurement of national products is one of the ways to overcome the risk of initial market creation in the technological catch-up process.

The MAPNA Group is a monopoly (in fossil fuel power plant construction) in Iran and the industrial managers have been reluctant, particularly in MAPNA's early phases, to establish any competitor for MAPNA. The main reason for this was to support the company's growth and the consolidation of its capabilities. However, in recent years the policy makers have sought ways to foster competition in Iran's power plant industry. For instance, although procurement has been inclined towards domestic suppliers, the import tariffs for gas turbines and their parts have been maintained at a relatively low level. In 2009, the import tariff for gas turbines was only 4%.[93] Similarly, in recent years, the Ministry of Energy has authorised the private sector to import new versions of gas turbines

[93] Interview with MAPNA's Senior Vice President and Member of Board (25 June 2009).

in order to give a competition shock to MAPNA. The Ministry of Energy believes that a critical mass had been built in MAPNA and thus MAPNA is becoming a powerful monopoly in Iran which may become costly to order gas turbine and other main equipment from MAPNA in future. Furthermore, Government advisors believe that Government should make a competitive climate in order to stimulate MAPNA in acquiring advanced technologies. The competition shock has been implemented in the case of those power plants which have been ceded to the private sector in recent years. For instance, the construction of the 2162 MW Rudeshur simple-cycle power plant was begun in summer 2004 by The Mahtaab Company. This company is an IPP[94] in the electric power generation, distribution and energy sale industry. Rudeshur power plant was operationalized in 2007. It is based on a V94.3A Siemens gas turbine. While MAPNA is currently manufacturing V94.2 gas turbines, the policy makers believe that these measures constitute a competition shock to MAPNA. The interview data suggests that although MAPNA managers were unhappy about such measures, they felt the serious need to acquire new gas turbine technologies.

7.3.2 Investment in Learning and Education

Fostering of learning and education has been one of the salient features of government policies in Iran's power plant industry. Due to the strategic importance of gas-fired power plants and subsequently the gas turbine industry in Iran's energy policy (see Chapter 2, Section 2.4.2, and Chapter 8, Section 8.4), the managers in the Ministry of Energy have constantly supported any education and learning activities. This policy has been realised through two main channels. Firstly, the government has supported the establishment of any kind of research centre to make close interactions and connections with MAPNA and its subsidiaries. These institutes play an intermediary role between universities and industry to foster applied research. As explained in Chapter 2, Niroo Research Institute, which is a research organisation affiliated to the Ministry of Energy, has

[94] Independent Power Producer

had many R&D projects with MAPNA and its subsidiaries. These projects have enhanced indigenous technological capabilities. Similarly, government policies in the Ministry of Science, Research and Technology and the Ministry of Energy have supported joint research programmes. MAPNA has recently established a research institute in collaboration with the University of Tehran in which technological demands as well as financial support are provided by MAPNA, while knowledge and education of young researchers is undertaken by the university. In spite of this, the managers within the Ministry of Energy believe that these efforts have been inadequate and that the power plant industry is in a far from ideal situation.

Secondly, government authorities have always been favourable to MAPNA Group in terms of fostering training programmes. As explained in Chapter 6, MAPNA has prioritised training of its staff either in collaboration with domestic sources or with foreign consultants. MAPNA has implemented a relatively high standard training programme, and has annually held 50 to 70 hours of education programmes for its employees.[95]

In the literature, public research institutions (Mazzoleni and Nelson 2007) and government policies in stimulating and fostering learning processes (Malerba and Nelson 2007) and the expansion of education (Fagerberg and Godinho 2005) have been emphasised in the technological catch-up of latecomer firms. The Iranian case confirms these arguments. In analysing the Iranian case, it can be argued that government education policies can foster and stimulate the learning of domestic firms. These policies can provide required finance in education and research. The outcomes are the formation and development of human capital and the close interaction between firms and universities and research centres. Thus, these government policies indirectly enhance indigenous capabilities in their interactions with overseas technology sources.

7.3.3 Management Stability

Aside from the currently ongoing privatisation process in Iran, MAPNA, since its inception, has been a state-owned company. Although it is governed not as a state entity but

[95] Interview with the Vice President of Systems and Quality, MAPNA (1 July 2009).

as a private company in terms of its rules and regulations, since the majority of its shares belong to the state, it still counts as a state-owned company. One of the consequences of being a state-owned company could be management instability as managers and boards might change from one government to another. Once a different party wins the presidential election, other people may be substituted for previously appointed managers and boards. Consequently, not only may government policies change, but the firm's strategies might turn in other directions. Furthermore, transferral of experience and knowledge from a group of managers to another group is an issue. Such instabilities may incur negative consequences for the firm's technological development. This typically happens in certain industrial sectors in Iran where the companies are governed and controlled by the state. The obvious example is Iran's automotive industry, which has experienced a variety of managers from one governing party to another. However, MAPNA has been excluded from these instabilities. In order to respond to increasing domestic electricity demands, infrastructural development such as electricity network development has been a top priority for all governing parties. In fact, power plant construction has been a common thread in governments' energy and industrial policies. However, the interview data shows that despite such consensus, the state authorities have had some disputes regarding the localisation of main power plant equipment such as gas turbines.[96] Despite this, the increasing pressure by the US-led sanctions has empowered the localisation concept among politicians (see Section 7.4.2).

Due to its management stability, MAPNA's managers have tried to deal with political controversies. While they have been more inclined towards technological acquisition, they have represented the company as a non-political entity. This could also be interpreted by way of the technocratic characteristics of MAPNA managers, who have tried to stay far from political struggles and have instead focused on technology development issues. The management composition of MAPNA has never been influenced by national political struggles such as changes in the governing party.[97] The various governing parties have not disturbed the industry and have had a consensus to support it. This case study

[96]Interview with the CEO, Engineering and Manufacturing Division, MAPNA (17 June 2009).

[97]Interview with Engineering Deputy, Engineering and Manufacturing, MAPNA, and interview with RPP Manager, MAPNA (5 July 2009).

shows that management stability in MAPNA Group has functioned as a positive influence in the development of gas turbine technologies.

The CEO of PARTO Company commented that:[98]

> "MAPNA has not been destabilised as a result of the change of governments. However, if the change of government had resulted in a change of management, this influence would have definitely destabilised MAPNA, because the group who established MAPNA and managed its initial technological developments were well aware of MAPNA's objectives and understood the workings of the wider group. Their removal from the company would have become a barrier to MAPNA achieving its aims."

7.3.4 Energy Policies

In Chapter 2, it was explained that fostering natural gas utilisation has become central in Iran's energy policies. The industrial sectors, such as the power generation industry, have been directed towards the use of natural gas rather than other fossil fuels. This has been a common thread among all governing parties. Recent energy policies in Iran emphasise the importance of gas-fired power plants, in particular CCGTs, as a strategic option in the power generation industry. The main rationales are the existence of huge natural gas reserves in Iran, environmental advantages compared to other fossil fuel power plants, low capital investment compared to most other electricity generating options, low operating and maintenance costs, rapid construction times, small visual impact, high efficiency, and fitting with the global paradigm shift towards CCGTs (see Chapter 2, Section 2.4.2).

Iranian energy policy makers seek to increase national installed capacity by roughly 10% annually, keeping in line with the projected annual growth of national demand of 7-9% (EIA 2010). The large and growing domestic market and the environmental friendliness of gas-fired power plants are the economic and environmental rationales for the fostering of gas-fired power plants. This is particularly the case now that policy makers understand that the gas turbine is the most technologically advanced and capital-intensive part of a gas-

[98]Interview with PARTO's CEO (22 August 2009).

fired power plant. Hence, energy policy makers and industrial managers have always been inclined towards localisation of gas turbines. All governing parties have also agreed to create jobs by establishing local manufacturing plants.

Beyond the economic and environmental rationales, the specific political situation of Iran in terms of international relations has enhanced the motivation of Iran's politicians towards localisation. This influence will be discussed in detail in the next section. However, there has been a consensus between MAPNA's managers and state-level authorities on the strategic importance of gas turbines.

In the literature, national energy policies in industrialised countries, such as the US and the UK (see Chapter 5, Section 5.4), have influenced the evolution of land-based gas turbine technologies. Chapter 8 will also discuss the fact that these policies play a crucial role in the development of the gas turbine industry in the context of industrialising countries. There is also some evidence in the literature that governments have supported the technological growth of an industry because of its importance in the energy policy agenda (e.g. solar and wind energy in Spain: Zubi et al 2009; Dusonchet and Telaretti 2010; coal-fired power plants in India and China: IEA 2007). However, this thesis is examining this subject in the context of technological catch-up and specifically in the context of interaction processes between indigenous knowledge acquisition and overseas technology transfer.

It can be argued that in the Iranian case, energy policies, as a part of government policies, have provided economic, environmental and political rationales for government officials to support the gas turbine industry. The orientation of Iran's energy policy approach has created a background against which the acquisition of gas turbine technologies is recognised as a strategic option. The industrial as well as energy policy makers have had sympathy with the case of gas turbine industry development. The supportive policies have indirectly facilitated the interaction between indigenous technology development efforts and overseas technology transfer.

7.4 US-led Sanctions and their aftermath

The relationship between Iran and the US has increasingly deteriorated over the last 30 years. The conflicts began after Iran's Islamic Revolution in 1979, when diplomatic clashes were initiated. The Iran-Iraq war (1980-1988), during which Iran accused the US of supporting Iraq, intensified these conflicts. There were even some battles during the eight year war period in the Persian Gulf oil-fields.[99] After 1988, the conflicts moved back to the diplomatic arena. In 1992, "Iran filed an application with the International Court of Justice (ICJ) requesting that the United States be held responsible for a series of attacks by the U.S. Navy against certain Iranian offshore oil platforms in the Persian Gulf in October 1987 and April 1988, and claiming reparation" (Bekker 2004, p 550). Likewise, in December 1993, the United States fielded a preliminary objection seeking dismissal of the case, which was rejected by the ICJ in 1996, finding that the destruction of the Iranian oil platforms could have an adverse effect upon the freedom of commerce (Bekker 2004). Similar claims and counterclaims by both sides repeatedly took place after the Iran-Iraq war.[100] However, the diplomatic conflicts have had their ups and downs, as in some periods both sides have given positive signals to mending the relationship (Tarock 1999; Wright and Bakhash 1997). Nevertheless, one of the consequences of these diplomatic stresses has been the legislation of sanctions against Iran.

Effective March 16, 1995, President Clinton issued Executive Order 12957 prohibiting US involvement with petroleum development in Iran (US Department of the Treasury).[101] On May 6, 1995, he signed another Executive Order (12959) substantially tightening sanctions against Iran under which all trade transactions with Iran were prohibited. On 8 September 1995, Alfonse D'Amato, the former US senator, introduced a

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[99] For instance, the US Navy targeted Iranian oil fields in 1987 and an Iranian passenger aeroplane in 1988.

[100] In 2003, the ICJ rejected the US counterclaims again. However, it ruled that although the US attacks on the Iranian oil platforms constituted recourse to armed force that did not qualify, under the United Nations Charter and customary international law, as acts of self-defence and were not justifiable as measures necessary to protect the essential security interests of the United States as permitted by Article XX (1) (d) of the 1955 Treaty, the United States had not violated the Treaty since the attacks did not adversely affect freedom of commerce between the territories of Iran and the United States (Bekker 2004). This was a controversial decision for Iranian politicians.

[101] US Department of the Treasury, Iran Sanctions, Available at: http://www.treas.gov/offices/enforcement/ofac/programs/iran/iran.shtml

new comprehensive bill in which he broadened the scope of the sanctions to non-US corporations that have transactions with Iran (Alikhani 2000). A similar bill was subsequently put forward by Senator Benjamin Gilman. These two bills were amended and finally issued by President Clinton on 4 August 1996, under the name of the Iran and Libya Sanctions Act of 1996.[102] This law, however, is recognised as The D'Amoto Act. On August 19, 1997, the President signed Executive Order 13059 clarifying Executive Orders 12957 and 12959 and confirming that virtually all trade and investment activities with Iran by US persons, wherever located, were prohibited (US Department of the Treasury). On March 17, 2000, the Secretary of State announced that sanctions against Iran would be eased to allow US persons to purchase and import carpets and food products such as dried fruits, nuts and caviar from Iran. This change was implemented at the end of April 2000 (US Department of the Treasury).

From 1996, when the D'Amato Act against Iran came into force, the country faced increasing challenges and hardships in international interactions and in particular in technology transfer. The D'Amato Act purports to limit access to Iran and the transfer of advanced technologies by restricting Iran's ability to explore, extract, refine or transport by pipeline petroleum reserves. This sanction not only limits the business scope of US firms, but also allows the US government to withhold US financing and contracts from foreign companies that trade with Iran. Despite the serious diplomatic efforts of the US to include other countries in the Iran embargo, other Western and East Asian countries were reluctant to take part in these unilateral sanction regimes. It was difficult to convince the world's giant oil companies to abandon transactions and investment in Iran's huge gas and oil reserves. Likewise, the large and growing energy market in Iran (Chapter 2) cannot be easily underestimated by international companies. However, the circumstances of the sanctions have jeopardised the access of Iranian companies to foreign technologies. This has been particularly the case for the US firms and also those foreign companies which have had strong connections to or affiliations with the US. In Iran's gas turbine industry, MAPNA and its subsidiaries could not work with US firms and tried to look for other international partners. The Engineering Deputy of MAPNA commented that:[103]

[102] On September 30, 2006, the act no longer applied to Libya and thus it renamed as Iran Sanctions Act.
[103] Interview with the Engineering Deputy, Engineering and Manufacturing, MAPNA (5 July 2009).

"Compared to other foreign companies, GE's products had higher quality and lower prices but we couldn't work with them due to US-led sanctions."

In these circumstances, MAPNA Group searched for other foreign companies, such as European companies, to collaborate with. However, the sanctions overshadowed the negotiating processes and led to the weakening of domestic firms' bargaining power. The channel of GE, as one of the main technology sources, was blocked and other European companies were cautious about taking over risky transactions with Iranian firms. Thus, the sanctions acted as barriers in the interactions between foreign and indigenous capabilities. In the same way, they had a similar role in the technological catch-up process, because access to foreign knowledge, which plays a vital role in the technological catch-up process, was substantially at risk. Nevertheless, MAPNA tried to cope with this problem in two main ways.

Firstly, as discussed in Chapter 6, MAPNA proposed a fleet of projects to attract foreign companies and marginalise the sanctions' impacts. Such packages reduced the risk of projects for foreign companies and motivated them to collaborate with MAPNA Group. Furthermore, the sanction regimes had some specific characteristics. They were mainly effective with regard to US firms rather than other international companies. The evidence suggests that despite the legislation of the D'Amato Act, non-US companies understood sanction regimes as a barrier for their business and they were reluctant that they be applied. The sanctions were also in response to political tensions and have had some corresponding fluctuations. MAPNA actively observed the sanctions, and when sanctions were lighter it mobilised technology transfer teams and tried to fill its technological gaps. Moreover, MAPNA has tried to underpin its international networking with sub-suppliers and consultant companies in particular. This group of companies has helped MAPNA to enhance its technological capabilities.

Secondly, MAPNA was determined to acquire technology in its organisation and recognised each technology transfer project as a valuable opportunity to acquire technological knowledge. Therefore, at each stage MAPNA tried to actively become involved in the process. Accordingly, MAPNA intensified indigenous technology development efforts and tried to compensate in a number of knowledge areas by strengthening university-industry linkages, which will be discussed in the next sections. Its manifesto has been: ‘the greater the determination, the greater the efforts’.

7.4.1 Advocacy of Self-Reliance

After 1979, political conditions and in particular the Iran-Iraq war cultivated an idea of self-reliance; that is to say, the importance of the capability of indigenous manufacturing of industrial goods with minimum dependency on foreign sources. This period corresponded with very low international oil prices. As discussed in Chapter 2, the national economy is dependent on oil export income and thus the recession of the oil market in the 1980s resulted in budget deficits in the national economy. Consequently, the low level of government income, war expenses and the political conflicts between Iran and the US led to the development of the self-reliance concept among Iranian politicians and officials. In fact, policy makers perceived in-house manufacturing of industrial goods as a remedy for the economy as well as leading to political and economic independence. Thus, the industrial managers prioritised investment in local industries and accordingly intended local procurement, despite its poorer quality. The idea was to protect infant industries and to develop indigenous technological capabilities. This concept was applied in a number of industrial sectors such as the automotive industry and the agricultural machine industry. However, in power plant industry there was no major company in Iran to undertake power plant equipment manufacturing. The scope of domestic activities in power plant equipment manufacturing was limited to repairing a number of types of power plant equipment.

The post-war period (after 1988) was distinguished by reparation and construction. MAPNA was incepted in this period. Despite the existence of the concept of self-reliance, the industrial managers were still seeking collaboration with foreign partners, as political conflicts between Iran and the US had slightly softened after the end of the Iran-Iraq war. In this period, industrial collaborations between domestic and foreign sources were expanded. Nevertheless, the D'Amato Act in 1996 jeopardised such industrial collaborations. This Act gradually overshadowed MAPNA’s international collaborations and had a potentially negative impact on relations with international companies. The D'Amato Act had been preceded by similar sanction regimes, though they had recently become tougher. In fact, gradually increasing sanctions evolved in tandem with the wartime self-reliance concept and progressively empowered this concept. The Senior Deputy of the Ministry of Energy commented that:[104]

"US-led sanctions created a huge potential and a huge motivation for us to develop indigenous capabilities. In fact, there was a sense of self-reliance and these sanctions empowered it."

The case study analysis has revealed that the self-reliance doctrine was well-accepted amongst state-level authorities as they supported the growth of the gas turbine industry. This can be interpreted as one of the motivations of policy makers in support of the industry.

7.4.2 The Sanctions: Limitation or Driver?

Obviously, the direct effect of sanctions on domestic industries has been to limit their access to foreign knowledge and expertise. This factor has hindered the speed of the technological catch-up process, as the interaction between indigenous and foreign expertise were not as easy as under normal conditions. As explained in the preceding sections, US-led sanctions have incrementally influenced Iran's gas turbine industry, though the sanctions have fluctuated. Collaboration of industry actors with US suppliers had been blocked, and thus Iranian firms switched to European/Asian sources.

The second drawback of the sanctions on Iranian firms has been the additional cost of technological acquisition. As interview data has shown in the above sections, MAPNA managers believe that GE's prices are lower than other suppliers and that GE's quality is better in some technological areas. Furthermore, according to the interview data and in view of the fact that the lead companies in the gas turbine industry are limited in number

[104] Interview with the Senior Deputy of the Ministry of Energy (16 June 2009).

(see Chapter 5), and since US-led sanctions prevented GE from collaborating with MAPNA Group, the bargaining power of MAPNA Group was weakened. The evidence shows that MAPNA Group offered attractive projects to foreign suppliers.

These two factors were observed in the Iranian case as the negative consequences on the industry of the US-led sanctions. They can be clearly interpreted as unconstructive influences on technological catch-up as they are in contrast with the general assumption of the technological catch-up concept in which successful cases have greatly benefited from overseas knowledge. The analysis of the Iranian case definitely does not refute this general idea; however, it reveals a different type of access to foreign knowledge with a different perspective and in a dissimilar influential context. Furthermore, this case has shown that the sanction situation has had other consequences which might be interpreted as positive outcomes. The sanctions strengthened the determination of the industry authorities. They enacted further supportive policies and inspired such determination in the firms' managers. Accordingly, MAPNA activated indigenous technology developments and made serious efforts to reinforce university-industry linkages. Likewise, MAPNA and its subsidiaries intensified intra-firm knowledge acquisition processes. Reverse engineering, as discussed in Chapter 6, was activated for two main reasons. Firstly, due to initial capability building, firms were given a readiness in technology transfer projects. Secondly, since the majority of Iran's power plants had been built based on GE technology before the US-led sanctions, repairing and maintenance of these power plants was needed. Therefore, domestic firms tried to acquire manufacturing knowledge and to supply the parts locally.

Similarly, the sanctions led to the formation of R&D in MAPNA and its subsidiaries. The interview data show that R&D establishment in MAPNA Group has had two main motivations: firstly, the differentiation between design and manufacturing knowledge; and secondly, the sanctions which made access to foreign knowledge difficult. The R&D Head of MAPNA commented that:[105]

"In terms of design, technology transfer is not an appropriate means because the nature of design and manufacturing capabilities are different. Design capabilities are more tacit and no companies intend to train you. This is particularly the case in the gas turbine industry where the companies prefer a limited number of players. This is, however, a

[105] Interview with MAPNA's R&D Head (2 August 2009).

general issue, but we have had a specific situation, namely the circumstances of sanctions. So we activated the universities.”

In the catch-up literature there have been some few studies that aim to examine the role of a crisis in a technological catch-up process. Kim (1998), in the case of the Korean automotive industry, argues that the technological catch-up process of Hyundai has been significantly influenced by crisis circumstances. He contends that the policy makers as well the firm’s managers believed in crisis construction as a strategic means of intensifying learning efforts. He explains that in the Korean case, the crises were constructed in the two levels. Firstly, the industrial policy makers initiated a step-by-step protection plan for the firm’s managers. They identified a number of deadlines by which the firms should enhance their technological capabilities, otherwise the government would remove market protection and other financial support. These provisional supports stimulated the firm’s managers to intensify indigenous learning efforts. Secondly, the managers constructed intra-firm crises by which the employees were stimulated to intensify their technological capability building efforts. However, the crises in Hyundai were all deliberately and domestically constructed. The main rationale for constructing these crises was to intensify the indigenous efforts (hence enhancing absorptive capacity) to acquire technologies and catch up.

In contrast, in the Iranian case the crisis is due to sanctions. The sanction regime is one of the most decisive influences on the industry, and is not under the control or the will of the industry managers. In these circumstances, firms not only had to intensify indigenous efforts, but also deal with the difficulty of access to foreign knowledge. As explained, they have faced numerous challenges to cope with this dilemma and have tried to deal with problematic situations.

The case analysis has revealed that it is not easy or straightforward to judge whether the sanctions hamper or hasten the technological catch-up process. Instead, it is more accurate to conclude that while sanctions have undoubtedly jeopardised access to foreign knowledge and may have imposed additional costs, they may simultaneously stimulate motivations to intensify indigenous efforts to acquire technology. In fact, the Iranian case has shown that the US-led sanctions have acted as a double-edged sword. On one hand, the sanctions have jeopardised access to foreign knowledge and have imposed extra costs for domestic companies in dealing with foreign technology sources. On the other hand, they have stimulated a degree of enthusiasm and energy devoted to capability building and acquiring as much technology as possible due to the great motivation of local parties. These sanctions have stimulated policy makers' determination and empowered the self-reliance doctrine amongst them. Consequently, local firms have intensified their indigenous technology development efforts.

7.5 Size and Orientation of Market

In the catch-up literature, demand has been put forward as a significant driver for catching-up, though differentiated between export-oriented and domestic market-oriented demand. The majority of studies have provided evidence in which export markets have been crucial in latecomer firms' catch-up (Hobday 1994; Kim 1998; Radosevic 1999). These studies, which are mostly focused on the new Asian industrialised countries, have shown that latecomer firms enhance their technological capabilities by exporting. Through this, they learn a great deal from export markets. This model is recognised in the traditional literature as export-led growth; this literature also assumes that the size of domestic market is too small to stimulate catch-up. It thereby often underestimates the role of the domestic market in the technological catch-up processes.

The second demand orientation in the catch-up literature addresses the domestic market and contends that this market is potentially able to grow the industry. In these circumstances, domestic firms, often with the support of the government, supply the domestic market and enhance their technological capabilities to the point at which they can compete internationally. This is particularly the case for countries that have large domestic markets such as China, India and Brazil. In these countries, a large domestic market has been a major driver for learning and for the accumulation of capabilities (Malerba and Nelson 2007). Fagerberg and Godinho (2005) also believe that technological development in the USA, Germany and Japan was firstly geared towards the home market, while for the new Asian caught-up countries exports played a similar role.

However, among the recent catch-up cases, there has been only minor evidence showing catch-up resulting from the domestic-oriented market. Recent research has taken place in the Korean context, in the mobile handset industry (Whang 2009). Generally, in all past Korean catch-up models the domestic market was not seen as able to trigger innovation in the industry. In these models, foreign companies ordered the manufacture of specific parts by the Korean suppliers, mostly through OEM-type contracts. Subsequently, the Korean suppliers tried to assimilate the manufacturing technologies. In the next step of technological catch-up they entered into design activities, specifically as ODMs (see Chapter 3, Section 3.2.2). However, the analysis of Whang (2009) shows a different process. She demonstrates that in the case of the mobile handset industry in South Korea, the domestic market has played a crucial role in the technological catch-up, a dimension which has been neglected in the traditional literature. Whang and Hobday (2010) published their findings in a paper. They argue that the reasons for the technological catch-up of the mobile handset industry in South Korea lie in the quality and dynamics of the local market. They believe that the local market, which they refer to as a 'test bed' for technological development, enabled technological development and triggered innovation in the industry.

The Iranian case shares many features with the above model. MAPNA Group, with the support of government policies, supplied the domestic market and gradually enhanced its technological capabilities. The government had an economic rationale for supporting the industry: the national electricity demand has been increasing considerably, requiring industrial policy makers to increase national installed capacity by roughly 10% annually. As explained in Chapter 2, fostering the use of natural gas has been one of the main Iranian energy policies, under which gas-fired power plants have been encouraged. Thus, the large and growing domestic market has been the economic rationale for government officials to support the industry. Furthermore, industrial policy makers have perceived such a market as an opportunity for technological catch-up by domestic firms. MAPNA and its subsidiaries have accordingly tried to enhance their technological capabilities through supplying the domestic market. In these circumstances, MAPNA and its subsidiaries have been able to demonstrate an attractive market for the collaboration of foreign companies. The market includes both power plant construction and power plant equipment manufacturing. Therefore, MAPNA activated its subsidiaries to acquire manufacturing technologies while supplying the parts in collaboration with foreign companies. This was particularly the case for some capital-intensive parts such as gas turbines. Even if the domestic market becomes saturated with gas-fired power plants, the maintenance of these power plants will regularly require the supply of gas turbine parts.[106]

Supplying the domestic market has gradually increased MAPNA Group's technological capabilities to the extent that the company has recently entered foreign markets. MAPNA and its subsidiaries have recently expanded their market to Middle Eastern countries, such as Iraq, Syria and Lebanon. These new foreign markets have contributed to MAPNA's product improvement as the company needs to respond to particular forms of demand which might be different from domestic models due to different geographical and climatic conditions.

The case of Iran's gas turbine industry accounts for a domestic-oriented market model. However, it differs from the recent Korean model (regarding the mobile handset industry). The difference is that in the Korean case, the size of the domestic market was not large, but it acted as a test bed for the transition of the industry to a leadership position. However, in the Iranian case both the size and orientation of the domestic market have been important. Thus, the size of the domestic market may be comparable with countries such as India and China (see Chapter 8).

In the Iranian case, the large and growing domestic market contributed to improved interaction between indigenous and overseas knowledge sources. The existence of such a market enhanced the company's bargaining power in collaboration with foreign companies and facilitated knowledge flows from abroad. Furthermore, responding to the domestic market not only enhanced MAPNA's technological capabilities but also stimulated the export of both power generation equipment and power plant construction.

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[106] Interview with PARTO's R&D Head (20 June 2009).

7.6 Geographical Agglomeration

The studies of technological catch-up, to date, have not specifically examined the role of physical proximity of latecomer firms in the technological catch-up process.[107] This could be due to two main reasons. Firstly, in-depth analysis of technological catch-up cases has only recently increased in the literature. A recent catch-up project over six different sectors and across different countries has lately been finished, and there are not yet any publications based on it (except for one paper in the Globelics Conference 2007 by Malerba and Nelson). Secondly, the cases studied so far have been in sectors which have not tended towards clustering. In spite of this, the Iranian case shows that the physical proximity of the subsidiaries was an important issue in MAPNA's success.

In the context of this thesis, cluster means the geographical agglomeration of firms operating in the same industry (Swann and Prevezer 1996; Giuliani 2005). There are often three main factors that attract firms to a particular location: specialised labour, specialised intermediate inputs, and spillovers of knowledge (Marshall 1920; Swann and Prevezer 1996). Spillovers of knowledge is the most important factor that attract firms in high-technology industries to be clustered (Krugman 1991; Swann and Prevezer 1996). Swann and Prevezer (1996) added two other benefits of clustering to those mentioned: "the infrastructure benefits of locating in a cluster (e.g. access to major communications networks) and informational externalities that accrue to the new entrant from seeing an established firm producing successfully at a particular location" (p. 1142).

MAPNA's subsidiaries, those manufacturing primary equipment such as turbines, generators and boilers, are agglomerated geographically. They are basically located in the same place and are very close to each other. The case study shows that physical proximity among the main gas turbine equipment manufacturers – TUGA, PARTO and MECO – has facilitated their interactions. Physical proximity has contributed to the technological development of the industry in different ways. Firstly, the companies frequently interact with each other by holding regular seminars, meetings and training courses. Due to their physical proximity, the arrangement of these events is not difficult. These events are

[107] Although Amsden and Chu (2003) and Lee (2005) mention that in the electronics industry in Taiwan the firms are geographically agglomerated.

opportunities allowing people from various companies to share their knowledge and experience through face-to-face interaction. Thus knowledge flows among all parties are facilitated by their physical proximity.

Furthermore, in big projects, which are often defined by the head company, MAPNA, these agglomerated companies can effectively work together. The NYAM project, as discussed in Chapter 6 (Section 6.6.3), was a major project in MAPNA Group in which the majority of subsidiaries have been involved. The interview data show that how the physical proximity helped the companies to respond quickly and effectively to MAPNA.

Moreover, such proximity has resulted in important local externalities by which each company is able to use these spillovers. Engineering knowledge sharing from one company to another is much easier than when companies are physically far away. The interview data show that the clustered companies often share their experiences of working with domestic and overseas sources. The relationship of one company with domestic universities or foreign companies can be useful and insightful for the other companies. Therefore, they can better deal with foreign companies and the interaction of indigenous and overseas sources is facilitated.

Thus, the facilitation of knowledge flows, spillovers of knowledge and infrastructural benefits such as networking are the main benefits of geographical agglomeration in the Iranian case. The above line of reasoning leads to a precise and neat conclusion that although geographical agglomeration of latecomer firms may not have a direct influence on the decision to import technology and knowledge or to develop indigenously, it promotes an interactive atmosphere among latecomer firms by which they can better deal with the challenges and difficulties of technological catch-up process. Furthermore, this section argues that the literature of the technological catch-up process, to date, has paid inadequate attention to the influence of geographical agglomeration on technological catch-up processes and in particular on the interaction processes between indigenous and overseas technology/knowledge sources.

7.7 Type of Technology

Chapter 5 scrutinised the technological and marketing dimensions of the gas turbine industry. It was explained that the application as well as the technological evolution of gas turbines in the power generation industry originated from aircraft jet engines. Even outstanding innovations, such as material and coating technologies in gas turbines, first occurred in the aircraft jet engine industry. Likewise, Chapter 5 elucidated the market dimensions for land-based gas turbines and explained that the market has been entered by newcomers which have either transferred technologies from established companies or have been working under license. Nevertheless, as argued in Chapter 5 (Section 5.4.2), the market still tends towards being an oligopoly, where OEM companies have recently established a new policy in order to keep their superior position in the market: they try to acquire competent non-OEM companies, and if they have already sold a license to a newcomer company, they have now become reluctant to renew the agreement, occasionally even terminating these licensing agreements. Similarly, in number of cases, the OEM companies have attempted to acquire some production units of other OEMs in order to keep their leadership position while enhancing their competitiveness in the market.

In these circumstances, it is bound to be difficult to deal with foreign suppliers regarding technology transfer. The analysis of the Iranian case confirms this. Foreign companies have been, in most cases, interested in making turnkey agreements with Iranian companies, but have been unwilling to transfer know-how to the Iranian side. This is clearer when MAPNA Group’s contracts in different technology areas are compared. For instance, the case study analysis shows that transferring technologies for steam turbines is not as challenging as for gas turbines. Steam turbines, in contrast to gas turbines, typically operate at low temperatures, and manufacturing technologies are not as advanced as for gas turbines. Likewise, interview data suggests that the transferring of other power plant equipment, such as boilers, was not as difficult as for gas turbines for MAPNA Group. Therefore, the analysis of the Iranian case shows that, other influences aside, the type of technology has influenced the interaction processes between indigenous and overseas capabilities to the extent to which transferring various technologies has not been at the same level of difficulty. In fact, amongst types of power plant equipment, gas turbines have been the most difficult parts with regard to foreign technology transfers. Beyond this, the transferral of all technologies existing in the gas turbine industry has not been at the same level. As explained in Chapter 5, gas turbine blades involve advanced and sophisticated techniques of casting and coating. The main lead companies have perceived these techniques as their competitive advantages and thus are reluctant to transfer them.

As discussed in Chapter 6, as well as in Section 7.3.1 of this chapter, MAPNA, with the support of the government, has tried to deal with this problem as well as with sanction conditions by proposing large power plant construction projects and large power plant equipment manufacturing projects to encourage foreign partners to collaborate. In fact, as shown in Chapter 6, MAPNA has used a particular strategy in its interactions with foreign companies. MAPNA's subsidiaries have also intensified indigenous technology development efforts and have tried to build strong connections with domestic universities to acquire a number of technologies. This has been particularly the case in recent years during which period MAPNA has introduced itself to international markets, particularly in the Middle East. Foreign companies have an apprehension of a growing competitor in the market and therefore avoid transferring new technologies[108] to MAPNA Group. It can be argued that in the case of Iran's gas turbine industry, the type of technology and the global market structure have acted as negative influences and have made a problematic situation for the industry managers. This argument shares some characteristics with the argument of Radosevic (1999), who argues that firms in industrialised countries are inclined to transfer older technologies to the industrialising world. However, the Iranian case shows that the difficulty of transferral in the gas turbine industry is not about the age of technology but about the type of technology. The evolution of land-based gas turbines (see Chapter 5, Section 5.3) shows that the technologies are at a mature stage.

[108] For instance, foreign partners have recently rejected collaboration in TBC coating and direct solidification (as explained in Chapter 5), and thus PARTO has intensified indigenous efforts to acquire these technologies.

7.8 University-Industry Linkages

Universities and public research institutes have always been recognised as a significant factor in the catch-up of developing countries (Hobday 1994; Fagerberg and Godinho 2005; Lee 2005; Malerba and Nelson 2007; Mazzoleni and Nelson 2007). Today's literature highlights indigenous technology development efforts, including the active role of universities and public research institutes (Mazzoleni and Nelson 2007) (see Chapter 3, Section 3.2.3.1). The analysis of the Iranian case confirms this trend and argues that university-industry relationships have influenced the interaction between indigenous and overseas capabilities. This case shows the relationships between MAPNA Group and domestic universities (and also other public research institutes) have contributed to the hastening of technological acquisition. The relationships have functioned for technological development in different ways, as follows:

<u>Contribution in technology transfer processes</u>

As discussed in Chapter 6, MAPNA and its subsidiaries hired domestic university experts on technology transfer projects at two stages of the process: firstly, *ex-ante* transfers, when companies hired consultants in purchasing machining lines and designing manufacturing processes. Secondly, in the post-transfer phase when the companies escalated bilateral projects with domestic research institutions, domestic universities and public research institutes conducted research and helped MAPNA Group to master the imported technologies. MAPNA and its subsidiaries invited many local universities to explain their expertise and then evaluated their potentials to help MAPNA in building technological capabilities. Then, they hired university experts and benefited from their knowledge and expertise in technology transfer projects. Through engagement of local universities, the MAPNA Group enhanced its absorptive capacity and was able to better assimilate foreign knowledge. This thesis has clarified the detailed role of public research agents in supporting indigenous firms to assimilate foreign technology inflows. However, due to confidentiality, this thesis was not able to explore the number and the name of the universities which had close interactions with MAPNA. Likewise, the list of the projects between MAPNA and local universities was not explored in this thesis for the same reason. Nevertheless, this thesis found that the engagement of domestic universities in technology transfer projects have been one of the main elements in MAPNA's technological growth.

Supplying human resources

Engagement of universities in MAPNA's activities has resulted in ever more attention of universities being given to educating and training young talented people for the companies. The majority of educated graduates working for MAPNA Group have been trained by domestic universities. As explained in Chapter 4 (Section 4.3.1) , some managers interviewed were not only active in the industry, but were also affiliated to universities and other R&D institutions. Double-affiliation of the managers has helped MAPNA in two ways: firstly, these managers have helped MAPNA in identifying and recruiting talented students from Iranian universities. Secondly, MAPNA was able to outsource some of its technological priorities as research projects to local universities. In this circumstance, the managers who were also affiliated to universities made a close connection between university and industry.

Development of peripheral institutions

Along with indigenous capability building efforts, MAPNA, in collaboration with domestic universities, has recently established other research institutes, as discussed in Section 6.2.2. In fact, one of the consequences of collaboration between universities and the gas turbine industry has been the development of research institutes in which the research is guided by the industry and implemented by university graduates.

The relationship between MAPNA and its subsidiaries with domestic universities increased the companies' absorptive capacity to better assimilate foreign technologies. It has supported domestic companies by supplying educated people. It has also helped strengthen indigenous technology development efforts by escalating bilateral projects between MAPNA Group and universities.

7.9 Intellectual Property Rights Regimes

The status of intellectual property rights (IPR) regimes has not been important in the development of Iran's gas turbine industry. The case study shows that neither in overseas technology transfer nor in domestic technology developments did IPR status play any role. This could be because of two main reasons.

Firstly, as explained in Chapter 5, gas turbines are the product of many technological advances and interrelated technologies, some of which have evolved from their roots in the aircraft jet engine industry. The gas turbine is also the most capital intensive part of a gas-fired power plant. In these circumstance, brand plays a significant role. Utility manufacturers do not take the risk of installing unknown and unproven products because any failure leads to high levels of damage. The CEO of the Engineering and Manufacturing Division of MAPNA commented that:[109]

"In the area of business in which MAPNA operates, IPR regimes have not been the subject of much discussion. Power plants require huge investments in which brand plays a crucial role. For instance, the failure of one blade would damage the whole turbine and could cause the power plant stop to working. The consequential damage could stop the power plant from operating. Having connections with well-known suppliers, such as licensing agreements, ensures we have access to reputable brands."

In a similar way, MAPNA's Senior Vice President and Board Member commented that:[110]

"Credibility is an important issue. We need to maintain a good reputation so that Tavanir or the Ministry of Energy can trust our products. This is a common issue. People care about the brand when they want to buy a biscuit, so what about a capital intensive product such as a gas turbine?"

Therefore, brand has become important in the context of the gas turbine industry because manufacturing and supplying gas turbines requires taking on a high risk for the manufacturer. Local suppliers share the responsibility with well-known foreign suppliers through collaborations. IPR regimes are considered in these collaborations.

[109] Interview with the CEO of the Engineering and Manufacturing Division, MAPNA (17 June 2009).
[110] Interview with MAPNA's Senior Vice President and Member of Board (25 June 2009).

The second argument is about those parts which are made through reverse engineering methods. As explained in Chapter 6 (Section 6.7.2), PARTO has made serious efforts to manufacture turbine blades which are the most highly advanced and sophisticated parts of a gas turbine. Reverse engineering has applied to only GE’s Frame 9E gas turbine blades. In PARTO’s technological evolution, they have synthesised their indigenous efforts with the knowledge of overseas consultants. Since the sensitivity of operation for turbine blades is much higher than for other parts of gas turbines, PARTO has gone a long way towards consolidating these technological capabilities. They have implemented many validation tests on the gas turbine blades. However, they have not violated any international rules, because, as explained in Chapter 5 (Section 5.4.2), there are many non-OEM manufacturers worldwide which are manufacturing gas turbine parts through reverse engineering and which supply the non-OEM market. As discussed, in accordance with international laws, each company is allowed to manufacture parts similar to OEM parts provided they do not directly use the OEM’s documents and drawings. The CEO of PARTO Company commented that:[111]

“Reverse engineering and re-engineering of turbine blades is common worldwide and most non-OEM companies engage in this area of business. We did not use any GE documents simply because we did not have any access to them. We created our own documents and developed manufacturing technologies indigenously, and we even changed their designs.”

7.10 The Comparative Framework of the Influences

The framework of influences in the context of this thesis was shown in Chapter 3, Table 3.2. The matrix was reproduced in Chapter 4 based on the methodological principles of this thesis and then operationalized during the fieldwork. This section charts the findings and shows the framework of the explored influences in the Iranian context (Table 7.1). The final matrix compares the findings of this thesis with the literature.

[111] Interview with PARTO’s CEO (22 August 2009).

As Table 7.1 shows, a number of influences confirm the findings of the literature, while others contribute new insights to the literature. Sanction regimes, self-reliance, energy policy aspects of government policies, the type of technology and geographical agglomeration are new insights that have been introduced by this thesis to technological catch-up and in particular to the substitution/complementary literature. Furthermore, the distinctive features of MAPNA's contractual terms with foreign companies as well as the size and orientation of the domestic market are influences that have rarely been touched upon in the literature. The remaining influences have been discussed in the literature, and the findings of this thesis confirm them. However, the status of intellectual property rights regimes is the only influence discussed in the literature which was not observed as an important factor in the development of Iran's gas turbine industry.

The Iranian case shows that there is a dynamic relationship between these influences. For instance, government policies on one hand have provided a domestic market, and supplying such a large market has enhanced MAPNA's technological capabilities. On the other hand, these policies have been indirectly related to MAPNA's interactions with domestic universities. This argument confirms the existence of a dynamic relationship among the factors in technological catch-up, as Malerba and Nelson comment: "often one factor alone cannot trigger catch-up unless other factors are present, and they feedback on each other" (2007, p 19).

Table 7.1: The Framework of Explored Influences in the Iranian Context

	Influences in the Iranian Case	Comparison with the Literature
Internal Influences (Firm Level)	Technological capability and absorptive capacity	Confirms findings of the literature
	Continuous interactions with foreign players	Confirms findings of the literature
	Type of contract	Confirms findings of the literature. Contributes new insights to the literature
External Influences (Industry, National and Global Level)	Government policies including national energy policies	Confirms findings of the literature. Adds energy policy influences to the literature
	Sanctions	Contributes new insights to the literature
	Self-reliance	Contributes new insights to the literature
	Size and orientation of markets	Confirms the few findings of the literature in which domestic market plays a crucial role. Contributes new insights to the literature
	Geographical agglomeration	Contributes new insights to the literature
	Type of technology	Confirms findings of the literature. Contributes new insights to the literature
	Universities and public research institutes	Confirms findings of the literature

Note: Some of influences are at various levels. For instance, self-reliance was observed at the firm, industry, and national levels. However, it originates from national policies and thus it is shown at the industry and national levels in the table. University-industry linkage is also an influence at all levels, though it is shown at the industry and national levels influences.

7.11 Conclusions

This chapter has discussed the dynamics and influences of the interaction processes between indigenous technology development efforts and overseas technology transfer in the context of Iran's gas turbine industry. These influences show that technological catch-up and in particular the interaction between indigenous and overseas technology sources is a very complex issue that takes a multiplicity of forms and directions. Dealing with multiple levels of influences often requires different angles of vision in different periods of history. These influences form the context, in that latecomer firms act in a highly sophisticated, changeable, and unpredictable context. The analysed influences also clearly explain how a latecomer firm may face various situations within which many external influences exist which might be beyond the will or power of managers. However, these influences should still be recognised, understood and dealt with. The corollary of this position is that the interaction processes between indigenous and overseas technology sources cannot be reduced to the study of the type of relationship. Today, it is not enough to argue that there is a complementary relationship between these two technology or knowledge sources; instead, understanding the dynamics and the complexity is much more important. Far more attention needs to be devoted to what influences are important in the different contexts and how these influences affect the technological development of different firms across different industries and in different countries.

Chapter 8 : India and China Insights

8.1 Introduction

The purpose of this chapter is to provide a comparative analysis between Iran's gas turbine industry and that of China and India. The reasons for choosing these two countries are: (1) similar to Iran, both India and China have undertaken some licensed activities in relation to gas turbines, (2) the gas turbine manufacturers in Iran, India, and China are state-owned companies and are monopolies in Iran and India and thus they should be able to reveal the influence of government policies in technological catching-up processes (3) in the 'large power' segment, both India and China are more or less alone in the developing countries (except Russian Federation) in having an indigenous gas turbine industry.

This chapter helps to put the Iranian case into context by contrasting Iran's strategy and the development of MAPNA's capabilities with the national strategies and corporate capabilities in the two largest emerging economies. Such a comparison helps to generalise the findings of the Iranian case. This chapter also helps to understand the similarities and the differences between the industries of these three countries as well as their evolutionary paths and policy drivers.

According to a broad literature review, which was presented in the previous chapters, and benefiting from the database of the Sussex Energy Group, the gas turbine industries of developing countries, to date, have not been systematically examined. This could be because the of specific industry characteristics which were discussed in Chapter 5 (Section 5.4). Therefore, this thesis has strategically focused on what documentary evidence does exist for China and India (primarily reports such as those produced by the IEA, journal papers, and reliable websites) and secondary interview data, which were explained in detail in Chapter 4 (Section 4.3.1).

This chapter is composed of four sections. Section 2 discusses the Indian gas turbine industry and analyses its evolution as well as its policy drivers. Similarly, Section 3 provides such discussions in the Chinese context and thus facilitates to compare the three countries. Section 4 draws the conclusions of the chapter.

8.2 Indian Gas Turbine Industry

8.2.1 Indian Companies

Bharat Heavy Electricals Limited (BHEL) is the only company in India which manufactures power plant equipment such as gas turbines. BHEL is the main supplier of power plants in India and it is likely to maintain its dominant position in the future (IEA 2007). This state-owned company was established in the 1960s and since the 1970s its business scope has diversified into the power industry and other industries including transmission, transportation, telecommunications, renewable energy and defence. BHEL has installed more than 100,000 MW of power generation for utilities and industrial users. In fact BHEL focuses on power plant construction (mostly fossil fuelled power plants, but also renewables) rather than just manufacturing power plant equipment. However, in order to procure power plant equipment, BHEL has established indigenous manufacturing plants in collaboration with foreign partners. BHEL's Heavy Electrical Equipment Plant (HEEP) is a subsidiary of BHEL which was established in 1963 in Haridwar. BHEL Haridwar signed a collaboration contract with Kraftwerk Union AG[112] of West Germany for manufacturing large sized steam turbines and turbo-generators. In 1989, the company started manufacturing Siemens V94.2 gas turbines in collaboration with Siemens under a licensing agreement.[113] Today, BHEL manufactures and assembles various models of Siemens and GE gas turbines as explained in Table 6.2.

In gas turbines, BHEL's technological capabilities have been confined to manufacturing static sections such as air intake systems and inlet casings. The manufacture of dynamic sections, in particular casting and coating of high-technology parts, is implemented at Siemens's German site. For instance, the blades are manufactured at Siemens's German site and dispatched to BHEL's Indian site for final assembly. BHEL's Indian site mainly implements two stages of gas turbine manufacturing: manufacturing static sections and final assembly.

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[112] Kraftwerk Union AG (KWU) was originally created by a merger of the power plant divisions of Siemens and AEG in 1969 and was later absorbed into Siemens in 1990 when AEG faced some problems (Watson 1997; p292).

[113] This information is based on documents which were gathered during the fieldwork.

BHEL, in collaboration with foreign partners, particularly Siemens, established a manufacturing plant to supply Siemens gas turbines. In this collaboration, the Indian company has been able to benefit from access to foreign technology, increased employment of local labour and economic benefits. On the other side of the coin, Siemens has been able to benefit from a cheap labour force, penetration of India's large market and economic benefits. Recently, the collaboration has been expanded to foreign markets. For instance, Siemens supplied three V94.2 gas turbines to Italy, Vietnam and Iraq which were produced in India.[114]

According to the classification of Chapter 6 (see Section 6.4.3), BHEL is recognised as an EPC company with the major task of designing and constructing power plants. However, BHEL has established a number of manufacturing plants such as BHEL Haridwar. Although BHEL Haridwar manufactures some models of gas turbines, manufacturers from industrialised countries are more prominent in the provision of gas turbines (IEA 2007). BHEL's sales are much higher than its production levels, while MAPNA's sales and production are almost the same. This is because MAPNA procures power plant equipment locally while BHEL procures partly from foreign suppliers and partly locally. As will be explained in the next section, the policy drivers in the Indian context have shaped BHEL's strategy in the way in which, and the extent to which, the company has prioritised quick construction of power plants rather than the localisation of all power plant equipment. BHEL Hardiwar only manufactures static sections of gas turbines and most of the high-tech parts such as turbine blades are imported. Instead, it has focused on constructing power plants and quickly responding to the highly undeveloped domestic demand, and has preferred to procure the latest versions of main pieces of equipment such as gas turbines from third parties.[115] Therefore, BHEL has had a different development path. It can be categorised as one of the largest EPC companies in the world in terms of turnover (see Chapter 6 Table 6.2). In contrast, its technological capabilities in gas turbine manufacturing are far behind the lead companies.

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[114] BHEL Haridwar catalogue.
[115] Interview with PARTO's CEO (1st September 2009).

8.2.2 Policy Drivers in the Indian Context

The evolution and the direction of development of BHEL may be due to a number of key influences. The first influence, which is similar to the Iranian context, is the existence of a large domestic market in power plants. “India has the fifth-largest installed power-generating capacity in the world, with 146 GW in 2005, including utilities and industrial autoproducers of electricity” (IEA 2007, p 510). According to IEA (2007), total electricity generation in India had an annual increase of 6.1% per year between 1990 and 2005 and will increase by 6.6% per year in the period 2005-2015. The size of the Indian electricity market is about four times larger than the Iranian market;[116] however, the annual increase in Iran is projected to be 7% to 9%, as explained in Chapter 2, which is higher than the Indian market. Both countries have recently prioritised the need to respond to increasing national demand. However, the shortage of electricity supply in India is much greater than in Iran. India suffers from a severe shortage of electric capacity, as roughly 40% of residences in India are without electricity (EIA 2009). In order to address this shortfall the government of India has set the goal of adding 90,000 MW of additional electric generation capacity by 2012 (EIA 2009). In this context, the role of BHEL is crucial. “The 11th Five-Year Plan calls for BHEL's manufacturing capacity to expand from 6000 MW a year now to around 10000 MW” (IEA 2007, p.512). Over the last 40 years, responding to such a large market has enabled BHEL to develop as an EPC company and today it has a vast amount of turnover. The company now has capabilities in power plant design and construction, in particular fossil fuel power plants.

Although BHEL, with the support of the Indian government, has tried to respond to the national electricity demand, there is still a huge gap and thus the government is looking for other suppliers. Many uncertainties exist, such as whether BHEL will be able to expand its manufacturing capacity and when it will be in a position to produce more efficient power plants (IEA 2007). The analysis of the BHEL Company shows that while the company has had a large market, it has been strained by a shortage of supply. Despite the fact that BHEL’s managers have tried to build initial manufacturing capabilities, the

[116] According to the BP Statistical Review (2009) electricity generation in India in 2008 was 834.3 TWh, while Iran’s figure stands at 206.3 TWh.

priority has been the quick construction of national power plants. Hence, the shortage of supply has influenced the approach of BHEL managers regarding the way in which, and the extent to which, they have mainly undertaken power plant construction rather than localisation of power plant equipment manufacturing.

Furthermore, BHEL's business context has been another significant difference from MAPNA's. In contrast to MAPNA, the business of BHEL has not been overshadowed by embargo circumstances in which the fear of inaccessibility of foreign technologies has intensified indigenous technological development efforts. The Indian managers have always had access to foreign technologies and high-tech parts have always been readily available for power plant construction purposes.

The Indian gas turbine industry has had another influence which originates from India's national energy policy. According to IEA (2007), coal constituted 33% of primary energy demand in India in 1990, and it is projected to rise to 48% in 2030, while the gas figures for the same period are 3% and 7% respectively. Figure 8.1 shows total primary energy demand by fuel in India between 1990 and 2030.

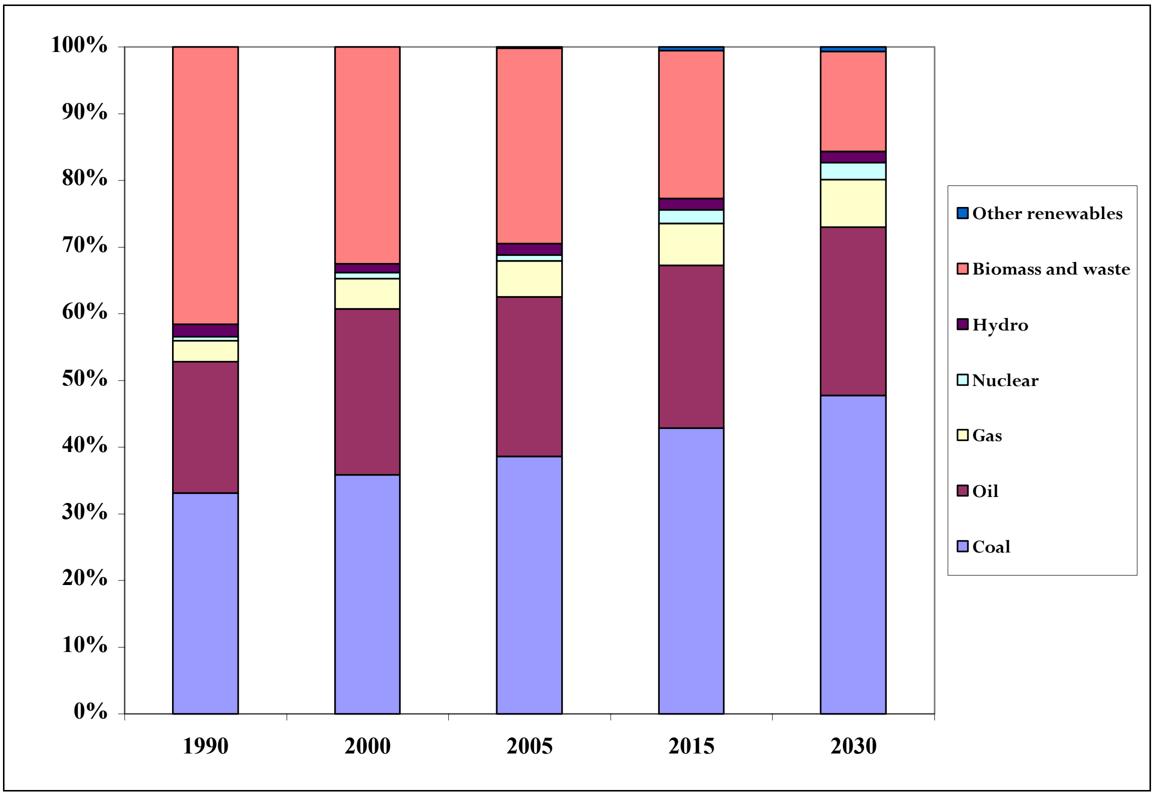

Figure 8.1: India's Primary Energy Demand by fuel across 1990 to 2030

Source: IEA (2007)

Analysis of India's primary energy demand indicates that coal has been and will remain the main fuel. In fact, the share of coal will even increase by 2030 and the Indian economy remains heavily dependent on coal, mostly produced indigenously (IEA 2007). India's current reserves of coal are 58600 million tonnes, which stands at 7.1% of all the coal reserves in the world (BP Statistical review 2009). However, due to the projected increase in demand, it is predicted that coal imports will rise markedly in India from 12% of demand in 2005 to 28% in 2030 (IEA 2007). Based on this prediction, total coal imports to India in 2030 will be more than 10% above that of the entire European Union (IEA 2007). In contrast to coal, gas retains a very small share of total primary energy demand in India. India possesses a negligible amount of natural gas reserves (0.6% of world reserves) (BP Statistical review 2009). However, gas production and imports are expected to increase over the next decades to satisfy national demands, though the share of gas in India's energy supply is negligible compared to coal.

The importance of coal in the power plant sector is much higher than in other sectors in India, as the figures confirm the dominance of coal in electricity generation. IEA predictions[117] show coal remaining the dominant fuel (accounting for over two-thirds of total electricity produced) by 2030 (IEA 2007). Figure 8.2 demonstrates the electricity generation mix and associated changes in India between 1990 and 2030.

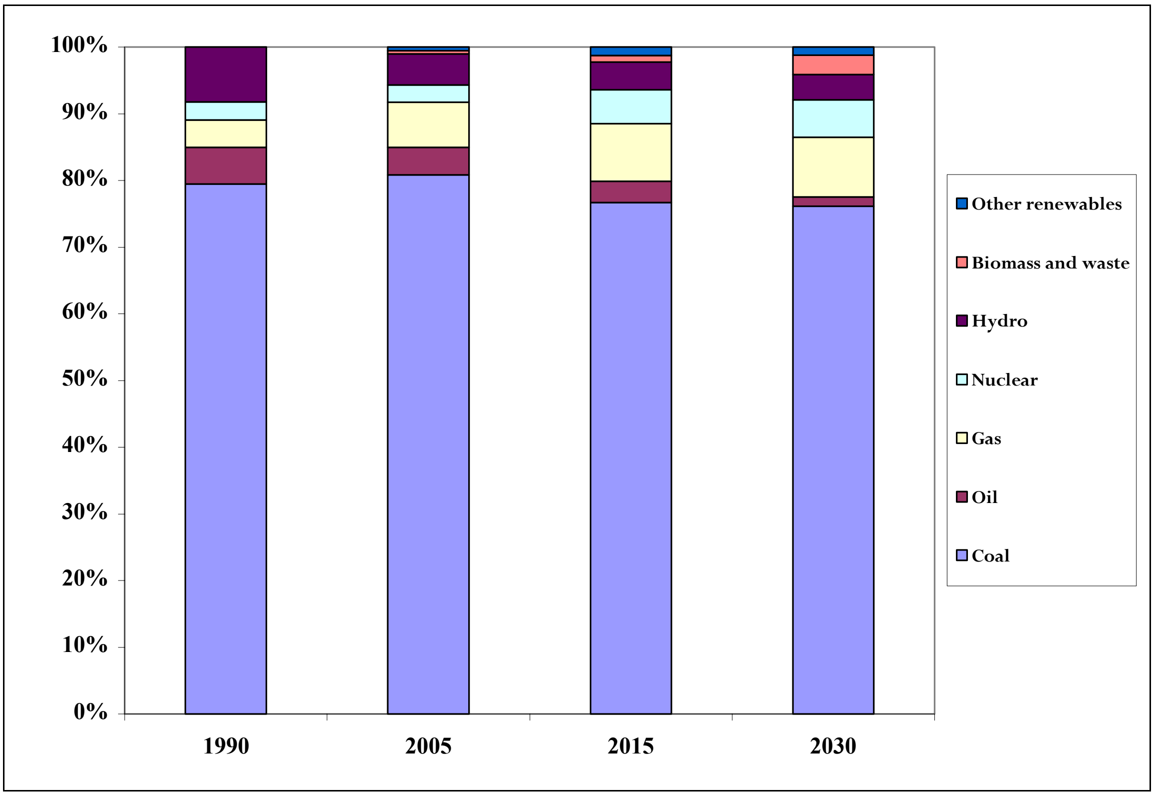

Figure 8.2: India's Power Generation Mix across 1990 to 2030

Source: IEA (2007)

India's national energy policy and specifically its electricity mix show that coal-fired power plants are likely to remain the main source of electricity generation by 2030.

[117] IEA has more than one scenario; however, in this chapter the Reference Scenario, in which government policies are assumed to remain unchanged from mid 2007, is used.

However, India's coal-fired power plants suffer from low efficiency levels as they are among the least efficient power plants in the world. The average conversion efficiency fluctuates between 27% and 30%, while the OECD number is about 37% (IEA 2007). The main negative factors are the poor quality of the coal available and inadequate maintenance of power plants (IEA 2007). The pressure of responding to huge domestic demands as well as environmental considerations has recently initiated new policy measures in India. India's current plans intend to establish large and efficient power plants and thus the efficiency of its power plants is expected to increase to 38% by 2030. India's government is also encouraging R&D in the power plant sector. Research is carried out mainly by BHEL[118] and the National Thermal Power Corporation (NTPC[119]) and mainly focuses on fluidised bed-based integrated gasification combined-cycle (IGCC[120]) (IEA 2007). BHEL has recently initiated collaborative projects to construct IGCC plants in which GE Frame 9F and GE Frame 6F gas turbines are being used (SPRU and TERI 2009).

India was an early adopter of gas turbine power plants back in the 1980s, which were mainly supported by the World Bank (World Bank 1991). Recently, the number of gas-fired power plants has been growing in the Indian electricity sector due to environmental considerations, quality concerns pertaining to the steel industry, and supply constraints surrounding coal (EIA 2009). Reliance Industries is building the world's largest natural gas-fired power plant at Dadri in Uttar Pradesh, which is expected to have a capacity of 3,500 MW (EIA 2009). Gas-fired power plants are developing particularly on the east coast as well as the west coast of India, which holds its main natural gas reserves.

Despite the recent activities to foster gas-fired power plants, India's national energy policy and specifically its electricity mix show that the share of gas-fired power plants in India's total electricity network remains marginal and in contrast coal-fired power plants

[118] BHEL's R&D expenditure is around 1% of sales. This ratio is between 1.8 and 6 internationally (IEA 2007).

[119] NTPC is the single largest company, with an installed capacity of about 26 GW and annual generation exceeding 180 TWh. It is majority owned by the central government. This company has a similar role to TAVANIR in Iran.

[120] IGCC: combines coal gasification with a combined-cycle power plant. Coal is gasified under pressure with air or oxygen to produce fuel gas which, after cleaning, is burned in a gas turbine to produce power. IGCC on coal can't thermodynamically be as efficient as a CCGT because of the need for a gasifier which has a big efficiency penalty. IGCC has not been able to compete with CCGT technology in terms of efficiency, environmental friendliness, cost and some other factors (Watson 1997; Watson 2004*a*).Only six successful IGCC plants have so far been built: three in the United States, two in Europe and one in Japan. China is also planning to build a number of IGCC plants.

are likely to remain the main source of electricity generation by 2030. According to IEA's reference scenario (2007), gas-fired generation will account for 11% of total generation in 2030 while coal-fired power plants will be more than 70% in 2030. Lack of noteworthy natural gas reserves, the existence of considerable coal reserves, and issues with natural gas imports are the main drivers of India's energy policy to keep coal as the dominant fuel.

In fact, the above influences, and in particular the huge domestic demand and shortage of supply have led BHEL to evolve in a different direction from MAPNA. BHEL's capabilities have evolved in the construction of power plants, and now the company is a big EPC rather than a main equipment manufacturer. BHEL has preferred to respond to such a market swiftly by procuring the main equipment from OEMs and increasing its economic benefit. There have also not been any serious incentives from the government for the acquisition of gas turbine technologies. The low level of import tariffs (1.75%) and the high quality of OEMs' gas turbines accounts for the reasons why BHEL does not put itself at the risk of acquisition of gas turbine technology, which counts as advanced and sophisticated technologies. Similarly, due to the dominance of coal in India's energy mix, coal-fired technologies are prioritised over gas-fired technologies.

8.3 Chinese Gas Turbine Industry

8.3.1 Chinese Companies

The Chinese power plant equipment manufacturing companies were established in the 1950s and 1960s as state-owned enterprises. They initiated a number of collaboration agreements with former Soviet Union companies for manufacturing steam turbines. They achieved fairly good success in steam turbine manufacturing and today they are able to manufacture steam turbines in the ranges of 300, 600, and 1000 MW. The Chinese steam turbine industry was established based on Russian technology, though they have recently tried to improve their products.[121] With respect to gas turbine technology, there are three

[121] For instance, Shanghai Power Generation Equipment Company had an agreement with Westinghouse in the 1990s.

main power plant equipment manufacturers in China: Shanghai Electric Power Generation Group (SECPG),[122] Dongfang Electric Corporation (DEC), and Nanjing Turbine and Electric Machinery Group (NTC), which are all state-owned companies. These companies often manufacture gas turbines in the form of co-manufacturing; that is to say, they manufacture static parts of gas turbines such as air inlet housing, but the dynamic parts such as blades, shafts and rotors are imported.[123]

The Chinese government has recently fostered competition among domestic and foreign companies in China's steam and gas turbine market. The government has tried to link the three domestic companies with the three main OEMs: Siemens, GE and Mitsubishi Heavy Industries (MHI). Each of the Chinese companies collaborates with one of the main OEMs: Siemens with SECPG, MHI with DEC, and GE with NTC.

SECPG is one of the largest power plant equipment manufacturers in China. The main business of SECPG includes the design and manufacture of steam turbines for fossil fuelled power plants, nuclear power plant turbines and heavy duty gas turbines. SECPG has joint venture agreement with Siemens to manufacture steam and gas turbines.[124] In steam turbines the company is able to produce turbines in the range of 300 to 1000 MW. SECPG has recently developed a 1200 MW steam turbine. Conversely, in the area of gas turbines the agreement is limited to V94.3 A and V94.2 Siemens gas turbines.[125] The plant in Shanghai only undertakes the machining of static parts as well as final assembly. The dynamic parts such as turbine blades are manufactured in Berlin and then are dispatched to the Shanghai plant for final assembly. The knowledge of manufacturing processes is also provided by Siemens to SECPG.

Dongfang Electric Corporation (DEC), established in 1984, is another enterprise in China undertaking the manufacturing of power plant equipment and at present occupying about 30% of the domestic market for large thermal power stations, and up to 40% of the

[122] It is sometimes called SEC because SECPG is a subsidiary of the Shanghai Electric Group Co., Ltd., (SEC).
[123] Interview with PARTO's CEO (1 September 2009); interview with MAPNA's R&D Head (24 August 2009).
[124] In 2010, Siemens increased its share from 33.7% to 40% (PowerGen; 28 June 2008).
[125] Through its cooperation with Shanghai Electric Power Generation Co., Ltd. (SEPG) since 2004, Siemens Energy has secured orders for fifteen F-class and six E-class gas turbines (Siemens Press 2010; available at http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2010/fossil_power_generation/EFP201004057.htm)

hydropower market (DEC 2010). DEC focuses on steam turbine technologies and does not actively undertake gas turbine manufacturing. Technologies were developed through collaborations with former Soviet Union companies in the 1960s. However, the evidence suggests that the company has recently started collaboration with Alstom in the area of large sized steam turbines. In contrast, gas turbine technology has remained in its preliminary stages, despite recent collaborations with Mitsubishi Heavy Industries. DEC is able to manufacture six M701F Hitachi gas turbines[126] annually, for which the advanced parts, such as blades, rotors and control systems, are supplied by MHI. Only the combustors are supplied by Mitsubishi Heavy Industries Dongfang Gas Turbine (Guangzhou) Co., Ltd., which was jointly established by MHI and DEC in 2005.[127] The evidence suggests that DEC only undertakes limited manufacturing and assembling processes of gas turbines.

Nanjing Turbine and Electric Machinery Group (NTC) manufactures gas turbines, steam turbines, generators and large/medium sized motors. NTC, founded in 1956, is the main gas turbine manufacturer in China. Since the 1980s, NTC has been manufacturing GE Frame 6B[128] gas turbines in a co-manufacturing process, in which component kits, namely turbine rotors, nozzles, combustion systems, control panels and some accessories, are provided by GE and other parts, mostly static parts, are made in a Chinese plant based on GE's drawings and documents (NTC 2010). Along with China's new national energy policies, which support the construction of gas-fired power plants, NTC has recently expanded its business into heavy duty gas turbines. In 2004, NTC made a technology transfer agreement for the GE gas turbine Frame 9E (125MW) with GE, in order to supply the domestic market. In 2006, NTC dispatched its first GE Frame 9E gas turbine which was assembled in China. NTC mainly undertakes machining as well as final assembly of gas turbines and annually produces 10 GE Frame 6E and Frame 9E gas turbines.[129]

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[126] Based on documents which were gathered during the fieldwork.
[127] Japan's Corporate News (JCN) Network, available at: http://japancorp.net/Article.Asp?Art_ID=13579
[128] According to the classification in Chapter 5, GE Frame 6 with output power of 40 – 49 MW is recognised as an industrial gas turbine.
[129] Interview with MAPNA's R&D Head (24 August 2009).

8.3.2 Policy Drivers in the Chinese Context

The evolution and the direction of the three main power plant equipment manufacturers in China have been influenced by a number of factors. The large and growing domestic market for electricity is the factor which is similar to the Iranian and Indian contexts. China has the second-largest electricity market in the world, behind the United States (IEA 2007). In 2008, total electricity generation in China reached over 3433 TWh, which is about fourfold that of India and sixteen fold that of Iran (BP Statistical Review 2009). According to IEA (2007), total electricity generation in China in 2005-2015 is projected to grow by 7.8% per year, much faster than the 3.1% average annual rate projected for the period 2015-2030. Therefore, the annual increase of total electricity generation in China in the period 2005-2015 is akin to Iran's growth and slightly higher than that of India. Furthermore, as Iran's electricity generation is projected to increase by 3.2% over the period to 2030 (IEA 2005), the trend in both China and Iran is similar.

Chinese power plant equipment manufacturers have been influenced by the structure of the Chinese electricity generation sector. In 2002, the Chinese government partly deregulated the electricity sector, in which the monopoly State Power Corporation (SPC) was dismantled into separate generation, transmission and service units (EIA 2009). The generation sector is now dominated by five state-owned holding companies;[130] these generate about half of China's electricity (EIA 2009). The rest of its electricity is generated by independent power producers (IPPs), often in partnership with the privately-listed arms of the state-owned companies (EIA 2009). It is expected that private finance will play an increasing role in generation investment, but transmission and distribution remain the responsibility of the central government (IEA 2007).

The Chinese companies which are in the gas turbine industry are organised differently compared to Iran and India. In Iran and India, MAPNA and BHEL are the main power plant constructors and at the same time are the main power plant equipment manufacturers. In contrast, in China, power plant construction and power plant equipment manufacture are implemented by different organisations, though all are state-owned companies. In fact, the three key power plant equipment manufacturers in China are not

[130] China Huaneng Group, China Datang Group, China Huandian, Guodian Power and China Power Investment.

EPC companies, whilst in Iran and India the companies are EPC companies as well as power plant equipment manufacturers.

The businesses of the three main power plant equipment manufacturers in China are also influenced by China's national energy policy. According to IEA's reference scenario (2007), coal was about 61% of China's total primary energy demand in 1990 and is projected to grow to 63% in 2030, while the gas figures for the same period are 1.5% and 5.2% respectively. Figure 8.3 shows total primary energy demand by fuel in China between 1990 and 2030.

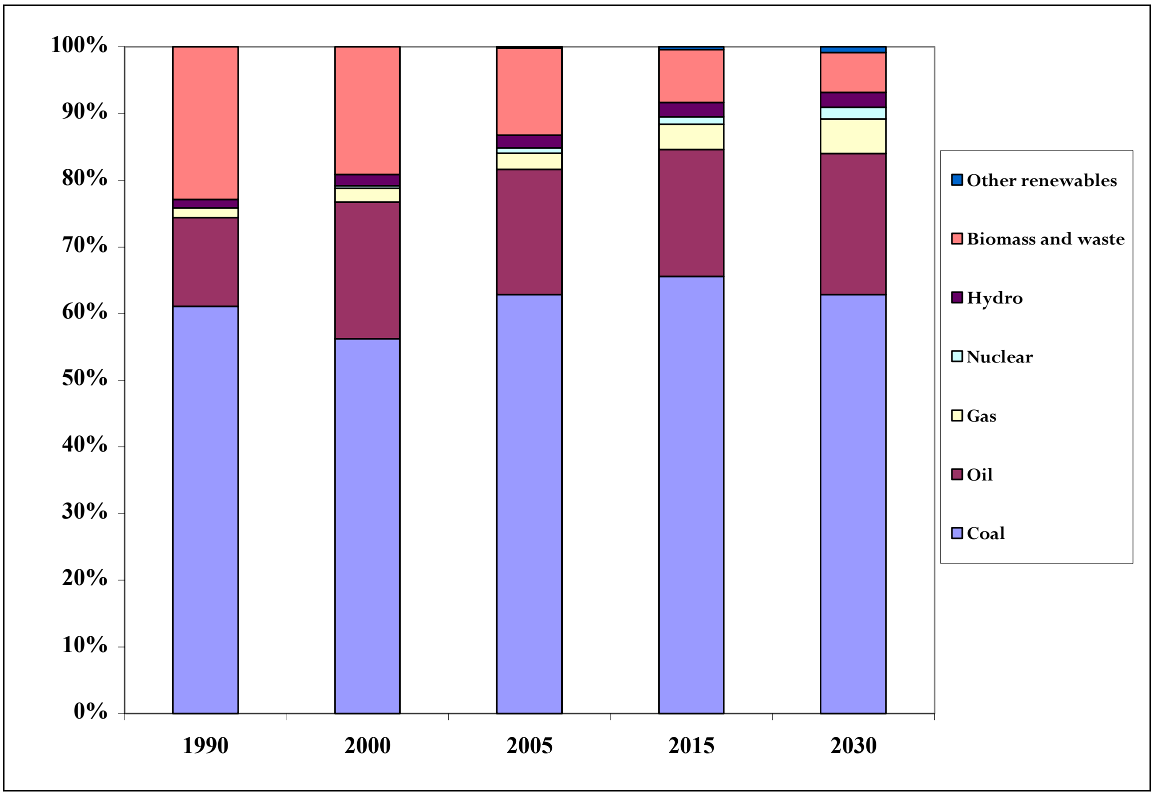

Figure 8.3: China's Primary Energy Demand by Fuel across 1990 to 2030

Source: IEA (2007)

The trend of China's total primary energy demand in the past and in the future consolidates the position of coal as the dominant fuel. The importance of coal in China's energy mix is even more significant than in India. The projections from IEA (2007) show that from 1990 to 2015, coal demand in China remains more than fivefold that of India. Likewise, China's coal reserves are larger than India's. According to the BP Statistical review (2009), Chinese coal reserves amount to 114500 million tonnes, which is 13.9% of all the world's coal reserves. China has historically been self-sufficient in coal and thus the national energy policies have been and will continue to be set up based on coal (IEA 2007). However, due to a drastic increase in domestic demand, China became a net importer of coal in 2007, and is predicted to import 3% of its demand by 2030 (IEA 2007). The above figures all confirm coal as the dominant fuel in China's energy policy.

The crucial role of coal in the electricity sector is even higher than in other sectors. Coal constitutes roughly three-quarters of the power generation feedstock and according to EIA forecasts it will maintain this market share through 2030 (EIA 2009). While in 2030 coal will be more than 73% of power generation fuels, natural gas will be just above 3% (IEA 2007). Figure 8.4 demonstrates the electricity generation mix and its changes in China between 1990 and 2030.

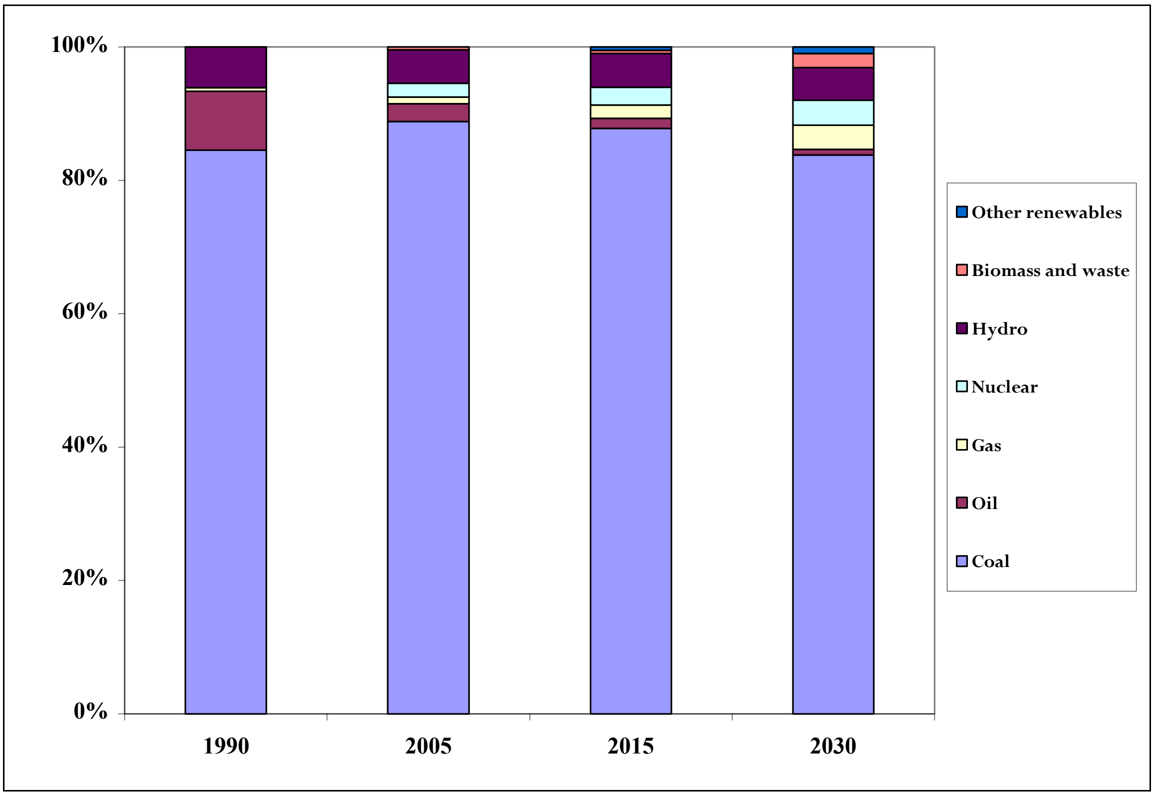

Figure 8.4: China's Power Generation Mix across 1990 to 2030

Source: IEA(2007)

The expansion of coal-fired generation in China will continue to be based on pulverised coal, with supercritical[131] steam cycle technology because of its efficiency and emissions advantages (IEA 2007). China has recently made considerable progress in the implementation of state-of-the-art coal-fired generation technologies (IEA 2007). The average efficiency of coal-fired generation was 32% in 2005 which is higher than India, and it is expected to rise to 39% by 2030 (IEA 2007). There is also some focus on IGCC. This may have implications for gas turbine technology in future. However, as explained

[131] Supercritical pulverised coal combustion: The efficiency of a steam cycle is largely a function of steam pressure and temperature. Typical subcritical steam cycles, as in the vast majority of today's power plants, operate at 163 bar pressure and 538°C. With supercritical designs, pressure is typically 245 bar and temperature is in excess of 550°C (the critical point at which water turns to steam without boiling). Supercritical technology has become the norm for new plants in OECD countries and is increasing in China (IEA 2007).

above, IGCCs, due to their lower efficiency and higher costs, are not able to compete with CCGTs (Watson 1997; Watson 2004a) and thus there are still few IGCC plants in the world.

The dominance of coal in China's energy mix is a major concern for Chinese government officials. The Chinese government has recently pursued changing the consumption structure of coal-based energy toward a diversified energy mix in which natural gas utilisation is fostered. The move to natural gas is likely driven by two main influences: local air quality concerns in cities, and the wish to diversity away from coal at the margins in some coastal provinces.[132] Therefore, local air quality and energy security are the two main issues in fostering the use of natural gas in China. In order to address these issues, the Chinese government has recently followed policies such as the development of natural gas fuelled vehicles, encouragement to construct gas-fired power plants, and collaboration with international organisations.[133] Despite such measures, predictions indicate that the share of gas-fired power plants will still be very marginal by 2030. The critical issues are as follows (Chun Ni 2007):

- Lack of gas fuel for gas-fired power plants: there has been unexpected escalating gas demand from residential as well as large industrial users. Due to the lack of natural gas supply in Shanghai, gas-fired power plants with a total capacity of 4 GW in 2005 and 6 GW in 2006 failed to generate electricity and play a role in the expected peak-shaving in the region. The rise in natural gas prices in 2007 worsened the situation.[134]
- Lack of competitiveness of gas-fired power plants compared to coal-fired power plants: the price for natural gas is much higher than that of coal and thus gas-fired power plants are not competitive against coal-fired ones from a cost perspective.

[132] According to the draft of an unpublished working paper by Sussex Energy Group (still pending).

[133] One of the major measures in China's energy policy is the implementation of Clean Development Mechanisms (CDM) which call for sustainable means of energy supply. CDM is one of the three flexible mechanisms put forward through the Kyoto Protocol for the mitigation of greenhouse gases (Gao et al 2007; Yan et al 2009). "The purpose of CDMs is to assist developing countries in achieving sustainable development by providing environmentally friendly investment opportunities initiated from developed countries" (Gao et al 2007, p1). A number of gas-fired power plants are being established in China under the CDM framework.

[134] Chinadaily, China lifts natural gas prices sharply 2007-11-14, available at: http://www.chinadaily.com.cn/business/2007-11/14/content_6254160.htm

- Irrational Electricity Pricing System: the pricing system does not take into account efficiency and environmental performance even among the same types of power plants. Given that the government intends to raise the price of natural gas by 8% per annum, gas-fired power generators will have difficulty competing with coal-fired generators and there is little incentive for companies to build more environmentally-friendly power plants with higher efficiency rates.

All the above influences have guided Chinese power plant equipment manufacturers towards coal-fired power plant technologies and in particular steam turbines. As explained, although the three main companies have recently started gas turbine development collaborations with foreign partners, due to the lack of notable demand, the capabilities have been confined to assembly, limited casting and limited machining technologies. The hot sections of gas turbines are all imported by the companies. However, the evidence suggests that Chinese companies have made more efforts in comparison with BHEL in India, and they are planning to localise other manufacturing processes in future.

8.4 The Comparison with the Iranian Context

In contrast to India and China, Iran's energy policy has been increasingly structured based on natural gas. A comparison of the electricity sector trends between India and China on one side and Iran on the other indicates that natural gas in Iran has the same dominant role as coal has in India and China. Figure 8.5 demonstrates the past and future trend of Iran's power generation mix.

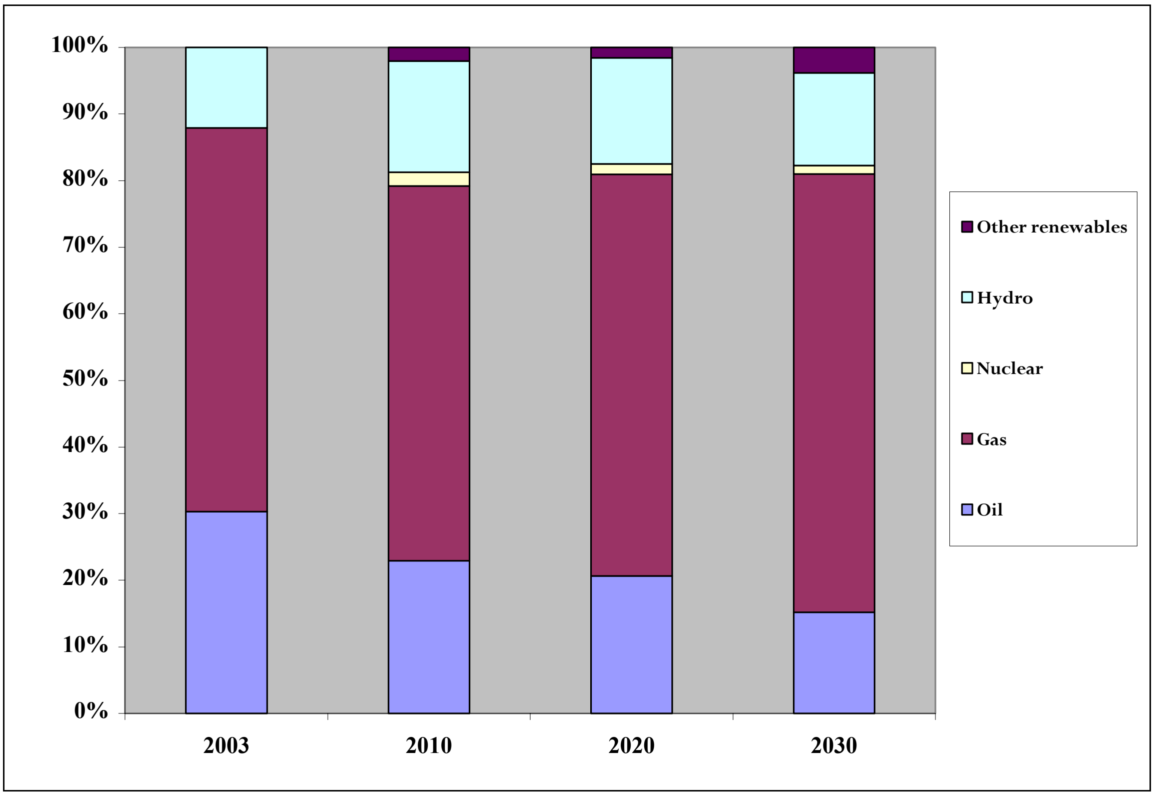

Figure 8.5: Iran's Power Generation Mix across 2003 to 2030

Source: IEA (2005)

Therefore, gas turbine technology, as explained in Chapter 2, is a strategic choice in Iran's electricity sector whereas for India and China, steam turbine technology is strategically important. Accordingly, while India and China envision acquiring coal-fired plant technologies, Iran foresees developing gas-fired power plant technologies, particularly CCGTs.

The influences in the land-based gas turbine industries in Iran, India and China have led to different evolutionary paths. However, the comparison reveals some similarities as well as differences. First of all, all companies in the three countries are state-owned, though in Iran MAPNA is in a transition stage and to date a small share of the company has been sold to the private sector. Due to their ownership, the Iranian, Indian and Chinese companies in the power plant equipment industry are greatly influenced by state policies. The state policies in the three countries mainly originate from national energy policies. While in India and China the national energy policies have focused on coal, and natural gas has had a negligible effect, in Iran the emphasis has moved in the opposite direction. Iran is now focusing on a transition to natural gas.

Government policies in the three countries have all supported the industry but in different directions and different ways. While India and China have supported the development of steam turbines, Iran has encouraged gas turbine technology development. Furthermore, in China the three companies have a mission to interact with the three OEMs, whereas in Iran the company has shifted towards different sources to acquire technologies. In India the government policies have been towards power plant construction rather than power plant equipment manufacturing. Thus BHEL has preferred to procure gas turbines through foreign OEMs and carry out the construction process as quickly as possible, although the local plants still undertake a number of manufacturing processes. Moreover, the types of government support are different in the three countries. In Iran and India the main responsibility of MAPNA and BHEL has been power plant construction and the supply of a large domestic market, as demanded by the state. In this context, MAPNA took the advantage and tried to acquire gas turbine technology throughout the construction process while BHEL has preferred outsourcing. In contrast, in China the power plant constructors have had to order the required equipment from the three local power plant equipment manufacturing companies, and these three companies tend to supply the market via collaborations with foreign partners. Therefore, while in Iran and India the power plant constructors and power plant equipment manufacturers are the same, in China they are different.

The large and growing domestic market for electricity has been another common thread in the three countries. While the size of the domestic market in China is bigger than that of India and much bigger than that of Iran, the growth rate in Iran and China is almost the same and is slightly higher than that of India. However, the market for gas turbines in Iran is much bigger than in China and India. This is because the electricity market in Iran has been directed towards gas-fired power plants while in China and India the market has been oriented towards coal-based technologies. Furthermore, supplying the domestic market has influenced the evolution of each of the three countries' power plant equipment manufacturers. The Iranian and the Chinese companies have tried to enhance their technological capabilities in gas turbine and steam turbine technologies respectively, whereas the Indian company has prioritised power plant construction to meet rapidly growing demand and thus acquisition of gas turbine technologies has remained marginal.

Finally, the evolution of the Iranian company has been influenced by a factor which has not existed in the Chinese and Indian contexts. US-led sanctions have limited the Iranian company's access to foreign knowledge. Therefore, as discussed in Chapter 7 (Section 7.4), the Iranian company has intensified indigenous technology development efforts, thus approaching any technology transfer projects with enthusiasm to acquire the technologies, and trying to combine them with their indigenous efforts. In these circumstances, the Iranian company has increasingly activated domestic universities and strengthened university-industry linkages. Similarly, the limited evidence gathered in this thesis suggests that Chinese companies have also recently expanded their interactions with domestic universities, while this area has not yet been fostered fruitfully in India. Summarising the discussions above, Table 8.1 compares the gas turbine industry and its associated policy drivers in Iran, India and China.

Table 8.1: Comparison of the Gas Turbine Industry in Iran, India and China

Country/Company		Business Area	Ownership	GT Models	Technological Capabilities in GT	Policy Drivers
Iran	MAPNA	EPC and PPEM	State-owned (privatisation is in process)	V94.2, GE Fr-9E (some spare parts)	Manufacturing all gas turbine parts, final assembly	Natural gas reserves, security of supply, the large domestic market, rapid growth of electricity demand, environmental issues, US-led sanctions
India	BHEL	EPC and PPEM	State-owned	V94.2,V94.3A, V64.3, Fr-6FA, Fr-9E, Fr-9FA	Manufacturing static parts, final assembly	Coal reserves, security of supply and lack of reliable and economic sources of natural gas, the large domestic market, rapid growth of electricity demand, electricity supply shortages
China	SECPG	PPEM	State-owned	V94.2, V94.3A	Casting and machining of static parts, final assembly	Coal reserves, the large domestic market, rapid growth of electricity demand, security of supply and lack of reliable and economic sources of natural gas, IGCC forecast*
	DEC	PPEM	State-owned	M701F	Limited machining, final assembly	
	NTC	PPEM	State-owned	Fr-9E	Casting and machining of static parts, Final assembly	

Source: Author's elaboration (see text).

Note: This table demonstrates only mid and heavy duty gas turbines for power plants – industrial gas turbines are excluded due to the thesis scope.

Abbreviations: EPC = Engineering Procurement and Construction; PPEM = Power Plant Equipment Manufacturing

* China envisions the acquisition of IGCC technologies, despite their considerable technological and economic limitations. Thus, this may, to some extent, influence gas turbine industry development in China.

8.5 Conclusions

This section has discussed the Indian and Chinese companies in the gas turbine industry and has compared them with the Iranian companies. It has explained that in all three countries the companies are state-owned companies and are greatly influenced by the states' policies. The Chinese and Indian companies have undertaken some limited stages of manufacturing, mostly of cold and static sections, while the Iranian company, as discussed in Chapter 6, has localised the whole manufacturing process. In contrast, due to India and China's national energy policies, the centre of gravity of the power plant industry in these countries is coal-based technologies and in particular steam turbines. Meanwhile, the Indian company has prioritised power plant construction and thus the development of gas turbine technologies have become the secondary goal.

The common threads of the Iranian, Indian and Chinese companies are their ownership by states, their supply of large and growing domestic markets, governments' supportive policies, and last but not least, their evolutions which have been influenced by national energy policies. Meanwhile, the salient feature of the Iranian context has been the existence of US-led sanctions. The contribution of indigenous efforts in technology development in Iran has been observed to be higher than in India and China. Furthermore, the common thread between the Iranian and Indian companies is that both operate as EPCs as well as power plant equipment manufacturers. Similarly, the common thread between the Indian and Chinese companies is their orientation toward coal-fired power plant technologies, which is an unsustainable energy path due to its environmental impacts.

Chapter 9 : Conclusions

9.1 Introduction

This thesis has aimed to understand the dynamics of interaction between indigenous technology development efforts and overseas technology transfer in technological catch-up process. Confirming the complementary relationship, this research has introduced a different mode of thinking than that of the existing literature. This thesis has suggested the dynamic approach to study the interaction processes between these two main knowledge sources. It argues that technological catch-up is an extraordinarily complex process within which the interaction processes between indigenous and overseas knowledge sources are influenced by various national-, industry- and firm-level influences, and thus it often requires different angles of vision for different industries as well as for different countries. Hence, understanding the interaction processes between these two main knowledge sources cannot be reduced to examining only the type of relationship. Instead, far more attention needs to be devoted to understanding the dynamics. This thesis has examined the above concept in Iran's gas turbine industry. In this light, four research questions were posed. In the following sections, I shall first recall the research questions and then answer them accordingly:

1) *What types of gas turbines are manufactured in Iran by MAPNA, and how do they compare to the technological leaders?*

Chapter 5 clarified the gas turbine industry's dimensions both in terms of technologies and in terms of the market. The most recently developed and popular gas turbines used in today's power plant construction worldwide are summarised in Table 5.2. Chapter 5 (Section 5.3.5) explained that MAPNA Group, as the only gas turbine manufacturer in Iran, undertakes the manufacture of Siemens V94.2 and some spare parts for GE Frame 9E gas turbines. Both Siemens V94.2 and GE Frame 9E are 'E' class vintage, which were introduced in the 1980s and upgraded in 1990s (see Chapter 5 Section 5.3.3). V94.2 is the highest-sold product among Siemens gas turbines.

Availability, reliability and low specific operating costs are major salient features of Siemens V94.2 gas turbines. Further to these factors, long market history and proven maturity make V94.2 gas turbines highly attractive for simple or combined-cycle processes, with or without combined heat and power, and for all load ranges, particularly peak-load operation. Despite this, MAPNA does not manufacture class F gas turbines, which are more efficient and slightly more expensive. Therefore, it can be argued that V94.3A and GE Frame 9F gas turbines (both counting as F class gas turbines) are the main technological gaps of MAPNA in mid and heavy duty gas turbine manufacturing, compared to GE and Siemens – the two lead suppliers in the market. The main characteristics and differences between various vintages of Siemens and GE gas turbines were discussed in Section 5.3.

Furthermore, Chapter 6 explained that the market for MAPNA's products and services can be divided into three main areas: (a) MAPNA as an EPC, in which the company designs the power plant, procures the required equipment, and finally completes the construction; (b) the OEM market; and (c) the non-OEM market. The characteristics of OEM and non-OEM markets were analysed in Chapter 5 (Section 5.4) and then contextualised in the context of Iran's gas turbine industry in Chapter 6 (Section 6.4).

2) *How has the MAPNA Group acquired gas turbine technologies? To what extent has the MAPNA Group included imported and in-house technology?*

The analysis of MAPNA and its subsidiaries reveals that the technological capabilities have evolved from the assimilation of repairing and assembling knowledge to the development of manufacturing capabilities and product engineering, and finally to design capabilities. Figure 6.1 depicts the gas turbine technology development phases in MAPNA. With the support of government procurement policies, MAPNA had the opportunity of supplying the large domestic market. In these circumstances, MAPNA was able to offer large and step-by-step projects to foreign companies in order to acquire know-how from the lead suppliers. The details and hierarchy of these projects were explained in Chapter 7, Figure 7.1. In these projects, MAPNA and its subsidiaries collaborated with foreign suppliers in the construction of power plants as well as in the manufacturing of power plant equipment. At the same time, MAPNA enabled indigenous capability building efforts such as reverse engineering, collaboration with domestic universities, and the establishment of local R&D. In fact, MAPNA's technological development has been realised through constant engagement of indigenous efforts in tandem with foreign technology inflows. As explained in Chapter 6 (Section 6.6.2), MAPNA from the early phases of its development has hired university scholars and experienced people to advise on purchasing production lines and devising manufacturing procedures. They consulted MAPNA to select appropriate technologies and machines (which is not perceived as simple knowledge in the gas turbine industry as explained in Chapter 5, Section 5.5.2). MAPNA did not simply copy the lead suppliers' manufacturing equipment; rather, it established its plant based on its own needs. The machines of the production lines were selected in accordance with cutting-edge manufacturing techniques and procedures. At the same time, MAPNA benefited from the experience and knowledge of foreign suppliers. In addition to co-construction and co-manufacturing projects with foreign suppliers, MAPNA acquired a license from Siemens. This channel of technology transfer also helped MAPNA to enhance its technological capabilities (see Chapter 6, Section 6.7.3).

In some circumstances, the process of importing technology was preceded, not just followed, by local investment in related technological capabilities. This was particularly the case in the development of turbine blade manufacturing capabilities in MAPNA (see Chapter 6, Section 6.7.2).

Throughout the evolutionary process, MAPNA and its subsidiaries have carried out many in-house and international projects and have tried to synthesise knowledge and spillovers, converting them into organisational capabilities. MAPNA's paradigm was based on the implementation of fleet of projects, active involvement in learning-by-doing projects, initial determination of localisation, and constant engagement with both indigenous technology development efforts and overseas technology inflows. The details of these processes were set out in Chapter 6 (Sections 6.6 and 6.7).

3) *Why has the MAPNA Group embodied this combination of indigenous and imported technologies, and what factors have influenced the interactions between the two knowledge sources?*

The combination of indigenous and overseas technology sources in the technological development of MAPNA originates from the worldwide gas turbine industry structure, the company's strategies, and influences such as government policies, national energy policies and US-led sanctions.

Focusing on know-how transfer, MAPNA has used different kinds of foreign technology transfer channels. Licensing has been one of the favoured choices of MAPNA for two main reasons. Firstly, the company perceived the licensor as a 'reliable' knowledge source through which MAPNA and its subsidiaries were able to benefit from the licensor's experience and technological knowledge as well as their consultancy in building technological capabilities. Construction of manufacturing plants, machinery selection, designing manufacturing procedures, and upgrading products and machines are all issues in which MAPNA can benefit from the licensor's consultancy. Secondly, the licensing agreement entails 'credibility'[135] for MAPNA to sell its products. This is particularly the case in the gas turbine industry where the market has an oligopolistic shape and where technologies are advanced (see Chapter 5, Section 5.4).

However, the US-led sanctions obstructed any collaboration with GE and thus MAPNA switched to European suppliers such as Siemens. The sanctions were due to political tensions and as such have had ups and downs (see Chapter 7, Section 7.4). Although the sanctions overshadowed technology transfer processes from European companies, MAPNA developed strategies for dealing with the sanctions' vicissitudes (see Chapter 7, Section 7.4). The sanctions also motivated MAPNA's subsidiaries to intensify indigenous technology development efforts (see Chapter 7, Section 7.4.2) such as reverse engineering (see Chapter 6, Section 6.7.2). Thus, the intensity or moderation of two technology sources (indigenous and foreign knowledge) has varied dynamically at each stage of development. The case of Iran's gas turbine industry reveals that in the process of technological catch-up, a latecomer firm often encounters a number of problematic situations and the interaction between these two main sources cannot simply be reduced to a description of the type of relationship. Instead, the dynamic perspective suggests that firstly, the process involves the coexistence of many influencing factors (see Chapter 7), which might be beyond the will or power of managers, and secondly, such a perspective provides a ground in which a firm's

[135] In order to understand the perception of MAPNA's managers about credibility, refer to the interviews mentioned in Chapter 7, Section 7.9

technology development efforts are dynamically synthesised with foreign technology transfer.

In order to identify and analyse the influencing factors, this thesis has comprehensively analysed the influences, which have, explicitly or implicitly, been discussed in the literature. Chapter 3 reviewed the majority of the technological catch-up and substitution/complementarity literature and prepared a framework, which is summarised as Table 3.2. The table incorporates the literature to develop a structured framework for operationalizing the study. In Chapter 4, the matrix, based on the methodological principles of this thesis, was reproduced and then operationalized during the fieldwork. The summary of findings was shown in Chapter 7 as Table 7.1. It charts the main findings of this thesis and shows the framework of the explored influences in the Iranian context. The influences are shown and categorised based on the distinction criteria, that is to say internal or external to the firm (see Chapter 3, Section 3.3.3). Table 7.1 also compares the findings of this thesis with the literature and shows that a number of influences confirm the findings of the literature, while others contribute new insights to the literature.

4) *How do MAPNA's capabilities compare to those in other developing countries?*

As the first systematic study on the gas turbine industry in the context of developing countries, this research has aimed to understand the insights into gas turbine industries in other developing countries, particularly in China and India – both of which have also undertaken some licensed activities in the gas turbine industry. This thesis strategically focused on what documentary evidence does exist for China and India and on conducting secondary interviews (see Chapter 4, Sections 4.3.1.1 and 4.3.2).

This thesis has emphasised the importance of the industry's structure in terms of concentration. The industry has a pyramid shape (see Chapter 5, Section 5.4.3), in which there are often two or three lead suppliers worldwide, and other suppliers are recognised as followers or latecomers. This thesis argues that such a concentration is one of the main influences on technological acquisition in the gas turbine industry. The industry requires advanced and sophisticated technologies, and while technological catch-up is not impossible, it is a very challenging process. This thesis also suggests that although firms in China and India manufacture a broader range of gas turbines compared to MAPNA, their technological capabilities are confined to assembly and limited areas of manufacturing technologies. In contrast, the gas turbines manufactured by the Iranian company are confined to a limited range of products but all the manufacturing technologies are localised. This thesis also argues that the evolution of technological capability building in Iran, China and India is extensively influenced by their national energy policies (see Chapter 8). With these findings, this thesis, for the first time, contributes to the study of the gas turbine industry in developing countries.

9.2 The Main Findings

As mentioned in the introduction to the thesis, this study mainly contributes to the two bodies of knowledge: (a) the technological catch-up concept and in particular the substitution/complementarity literature; and (b) the case of the gas turbine industry in both developed and developing countries' contexts. This section clearly summarises the theoretical and empirical issues tackled in the thesis. It also explains how the findings can be extended to other contexts.

9.2.1 The Theoretical Argument

As Chapter 3 explained in detail, two important concepts, namely the national/sectoral innovation system and international technology transfer, have contributed to the evolution of the literature about technological catch-up processes of latecomer firms. The innovation/learning system literature sheds light on the role of indigenous technology development efforts, learning systems, institutions and engaged organisations. Meanwhile, the international technology transfer literature has contributed to the technological catch-up concept by highlighting the roles and channels of foreign knowledge sources. The corollary point of these basic concepts has been the emergence of the substitution/complementarity literature, to which this thesis has contributed. The literature aims to understand the relationships as well as the interactions between indigenous and overseas technology sources. The findings of this thesis confirm the validity of the complementarity concept in a number of ways.

Firstly, this study shows that MAPNA and its subsidiaries have benefited from both indigenous and overseas technology sources at all stages of development. In some circumstances, MAPNA and its subsidiaries have acquired technologies through reverse engineering (see Chapter 6, Section 6.7.2) and collaboration with domestic universities (see Chapter 7, Section 7.8). These activities have enhanced the absorptive capacity of MAPNA Group in collaboration with foreign partners. Under other circumstances, MAPNA has also acquired technologies from foreign technology sources through various know-how transfer agreements. Licensing has provided MAPNA with a reliable means of access to lead suppliers' technologies (see Chapter 6, Section 6.7.3). Beyond this, MAPNA has had a fleet of projects with other European suppliers in which the local companies have greatly benefited from foreign knowledge inflows (see Chapter 6, Section 6.7.1, and Chapter 7, Section 7.3.1). The MAPNA case reveals how the acquisition of technologies from one of these sources often acts as a platform for acquisition from the other, and how these two sources are synthesised during the technological catch-up process.

Secondly, MAPNA's entry into gas turbine manufacturing was preceded by power plant construction, the acquisition of assembly know-how, and active engagement in learning-by-doing (see Chapter 6, Section 6.7). MAPNA also had a strategy for technological catch-up (see Chapter 6, Section 6.7.1) in which local experts and university scholars were engaged from the early phases of MAPNA's development. These initial efforts fit closely with the complementarity idea in technological catch-up studies, in which scholars highlight that the process of importing technology could be preceded, not just followed, by local investment in related technological capabilities (Bell and Pavitt 1993; Freeman and Hagedoorn 1994). This was particularly the case in the acquisition of gas turbine blade technologies where PARTO Company extensively activated indigenous sources of technology development such as reverse engineering and domestic R&D projects. These efforts have considerably increased PARTO's absorptive capacity in its interactions with various foreign technology sources. With respect to this evidence, this thesis argues that two important aspects have made MAPNA a 'smart importer': a strategy for learning, and initial capability building.

Thirdly, technology transfer processes have also been accompanied by the active involvement of domestic firms. The construction of domestic power plants and supplying power plant equipment had learning-by-doing benefits for MAPNA. These aspects also fit well with the literature of complementarity (as elucidated in Chapter 3, for instance Bell and Pavitt 1993; Freeman and Hagedoorn 1994; Pack and Saggi 1997; Radosevic 1999).

Despite the good fit between the research results and the complementarity idea, this thesis has identified some shortcomings of the technological catch-up and in particular the substitution/complementary literature. It has shown that the substitution/complementarity literature on developing countries context is confined to a small proportion of developing countries (India: Katrak 1997 and Lall 1985, Brazil: Braga and Willmore 1991, and Korea Lee, 1996; Kim, 1998). The majority of these studies have focused on analysing the type of relationship between indigenous technological efforts and foreign technology transfer. These studies have paid inadequate attention to the dynamics of interaction between indigenous technology development and overseas technology inflows. The majority of researchers have been preoccupied with assessing the correctness of one or other of the substitution/complementarity ideas. In other words, they have tried to prove one side and reject the other side while a dynamic perspective in the analysis has been largely absent. The literature has also paid inadequate attention to the complexity of the process, problematic situations, and the coexistence of influencing factors.

This thesis would argue that although a complementary relationship between indigenous and overseas technology sources is still valid in the case of Iran's gas turbine industry, the synthesis process is not as simple as a Lego building. It is a very complex process and many influences are engaged within. A closer look at the findings of the substitution/complementarity studies and the successful catch-up cases reveals that despite the complementarities between indigenous and overseas technology sources, they have an interchangeable role. In other words, catch-up firms choose both of the two knowledge sources, but partially. This means that in acquiring a specific technology firms do not merely rely on one or other of the technology or knowledge sources, because the firm, due to its prior knowledge base and its contemporary efforts, is not only able to absorb transferred technology also to become actively involved in the transfer process. The acquisition of gas turbine blade technologies by PARTO clearly explains this argument. Moreover, at some stages, the need for foreign knowledge may be much higher than at others. MAPNA's efforts to acquire the license of Siemens demonstrates the validity of this argument. Therefore, although in-house and foreign knowledge sources complement each other and the importance of both sides is emphasised in the literature, the evidence shows that firms often dynamically change the contribution of both knowledge sources in terms of resource allocation (financial and human resources). In some circumstances they may invest more in indigenous capability building than in foreign knowledge sources, and vice versa. The extent to which domestic and overseas technology sources contribute to the technological catch-up process depends upon international-, national-, sectoral- and firm-level influences. These influences may be present simultaneously – beyond the will or power of managers and policy makers – and have to be recognised, analysed and dealt with.

The thesis has emphasised that in order to have a deeper understanding of the interaction processes between the two main knowledge sources, a new perspective should be developed. This thesis suggests the dynamic approach, which is a different mode of thinking than that of the traditional literature. 'Dynamic approach' in this thesis refers to a synthesis of indigenous expertise and imported knowledge in a dynamic manner; that is to say, the two parts of this tango should constantly interact with each other to produce richer expertise to deal with the ongoing development of technological methods and procedures as well as the materials and ways of shaping them. In this way, the practitioners who invoke this approach constantly try to improve their own technical knowledge in the light of what they learn from the imported know-how, as well as through the experiences and enlightenment they gain from their own indigenous tradition. Therefore, the best way forward is in constant interaction with the latest developments while synthesising them with indigenous ideas. This process is certainly an ongoing and never-ending process, which should be passed from one generation of indigenous experts to another. However, this process is a very complex one and depends upon various influencing factors. The dynamic approach suggests focusing on challenges and difficulties and analysing influencing factors rather than examining the type of relationship. The details of the dynamic approach were explained in Chapter 3 (Section 3.3.2).

The dynamic approach affected the research design, in which the methods were specified for the research. Most previous studies have used quantitative approaches, mostly through survey analysis. However, in order to reach a deep understanding of the phenomena, the methods should be different from the traditional literature, which has focused on studying the type of relationship between indigenous and overseas technology sources. In this light, the methodological argument is that the case study method, by going into great depth in one case, is able to study the dynamics present within single settings as well as to investigate important topics not easily covered by other methods (Eisenhardt 1989; Yin, 2006). However, in this thesis, the case study method needed to be be designed based on a dynamic perspective in which the researcher was able to undertake highly qualitative interviews as well as gathering supplementary documents in order to reach a deeper understanding of the interaction processes between the two main knowledge sources, as explained in Chapter 4 (Section 4.2.1). It also needed to be able to reveal the influences across international, national, sectoral and firm levels. Thus, this thesis identified the methodological principles (see Chapter 4, Section 4.2.1) and prepared a preliminary framework before attempting to operationalize the research (see Chapter 4, Table 4.1). Such a framework provides a platform to design the data collection methods.

The above line of reasoning leads to the point that throughout the technological catch-up process, the capabilities of latecomer firms have grown by constant interaction with indigenous and foreign technology sources. Consequently, while such a dynamic progression confirms a complementary relationship between these two main technology sources, it reflects the dynamic nature of this process in which the interaction of the two technology sources is influenced by a number of factors. This argument can be extended to other contexts where the interaction processes between indigenous and overseas technology sources are questioned.

This thesis identified and analysed the influencing factors in Iran’s gas turbine industry. While some influences fit with the literature, others are different. Furthermore, this thesis adds a number of new influences which have not yet been discussed in the literature. Table 7.1 in Chapter 7 demonstrates the framework of the explored influences in the Iranian context.

This thesis argues that government policies have played a significant role in the evolution of Iran’s gas turbine industry. The findings confirm the vital role of these policies in the early stages of development, as argued in the literature. However, this thesis has analysed the government policies in detail. Unlike in other Asian contexts, tax privileges and R&D subsidies were not core aspects of the government’s policies. The government in Iran has granted the majority of power plant construction projects to MAPNA in order to offer an opportunity of learning-by-doing to the domestic company. Furthermore, domestic utility companies have been obliged to order power plant projects from MAPNA. Meanwhile, MAPNA has been authorised and even motivated to acquire technology from various domestic and foreign sources. Thus, by following public procurement policies, the government has secured a market for MAPNA's products and also enhanced MAPNA's bargaining power by aggregating domestic power projects. Such a state-led demand provided an opportunity, particularly in its early phases, for MAPNA, in which the company and its subsidiaries were able to engage in technology transfer projects. In fact, these policies hastened MAPNA's technological growth. Therefore, it can be argued that public procurement policies may facilitate the interaction of indigenous technology development efforts and overseas technology transfer. These results can be extended to those industries that are engaged in technological catch-up processes and are characterised by a considerable size of domestic market. Furthermore, these results can be insightful for state-owned companies, on which government procurement policies can have direct effects.

This thesis has also revealed that management stability in the MAPNA Group has helped managers to consistently follow technological catch-up strategies. One of the consequences of being a state-owned company could be management instability as the managers and boards might change from one government to another. Once a different party wins the presidential election, the appointed managers and boards may be substituted for other people. However, in the Iranian case the industry has not been destabilised as a result of changes in government. These results can also be extended to other state-owned companies where destabilisation of the companies is an issue.

The study has also shown that national energy policies have influenced the direction and development of the gas turbine industry in Iran. Industrial sectors in Iran, such as the power generation industry, have been directed towards the use of natural gas among other fossil fuels. Recent energy policies in Iran focus on gas-fired power plants, and in particular CCGTs, as a strategic option in the power generation industry. This thesis has compared the results with two other developing countries in which the companies are state-owned. The results suggest that in India and China steam turbine technologies have reached higher capabilities than have gas turbine technologies. This is because in India and China, energy policies have been directed towards coal-fired power plants, as discussed in Chapter 8. These results may be extended to other energy sector industries in other developing countries.

Government policies and energy policies in Iran, India and China have economic rationales, as each of the three countries has a large domestic market for electricity as well as for power plant equipment. The thesis argues that in the Iranian case, the large and growing domestic market has contributed to better interaction of indigenous and overseas knowledge sources. The existence of such a market has enhanced MAPNA's bargaining power in collaboration with foreign companies and facilitated knowledge flows from outside. Furthermore, responding to the domestic market has not only enhanced MAPNA's technological capabilities but also stimulated exports in both power generation equipment and power plant construction. MAPNA and its subsidiaries have recently expanded into the markets of other Middle Eastern countries, such as Iraq, Syria and Lebanon. This thesis supports similar arguments in the Chinese and Indian contexts. In China and India, supplying the large domestic market has enhanced the capabilities of local power plant equipment manufacturers. This, however, contrasts with the traditional literature which underestimates the role of the domestic market in technological catch-up processes (see Chapter 7, Section 7.5).

This thesis has also contributed to the debate on the influence of sanctions on technological catch-up process. The sanction regime is one of the most important influences in the case of Iran, which is not under the control or the will of industry managers. The Iranian case has shown that the US-led sanctions have acted as a double-edged sword. On one hand, the sanctions jeopardised access to foreign knowledge and imposed extra costs for domestic companies in dealing with foreign sources. On the other hand, they provided a degree of enthusiasm, strengthened the self-reliance concept, and led to energy devoted to capability building and acquiring as much technology as possible with great motivation of local parties. It is not easy and straightforward to judge whether sanctions hamper or hasten technological catch-up process. Instead, it is more accurate to conclude that while sanctions undoubtedly jeopardise access to foreign knowledge and may impose additional costs, they may simultaneously stimulate motivation to continue indigenous efforts to acquire technology. These efforts may include strengthening university-industry linkages, empowering local R&D activities and networking with other small companies. These findings can be extended to other Iranian industries, which do business under in the context of sanctions.

The thesis has found that domestic universities can play an essential role in the technological catch-up of a latecomer firm in three different ways: contribution to technology transfer processes, supplying human resources, and developing peripheral institutions. The relationship between MAPNA Group and domestic universities increased the company's absorptive capacity to better assimilate foreign technologies. It has supported domestic companies by supplying educated people. It has also helped the strengthening of indigenous technology development efforts by escalating bilateral projects between MAPNA Group and universities.

Therefore, in the theoretical sense, the research has made two main contributions. Firstly, it has introduced the dynamic approach to the technological catch-up and in particular to the substitution/complementarity literature, which goes beyond the investigation of the type of relationship between indigenous technology development efforts and overseas technology transfer. The new perspective offers new insights for future studies. Secondly, the research has discussed the influencing factors in the Iranian context and has added a number of new influences to the literature which have not yet been discussed (see Chapter 7, Table 7.1).

9.2.2 The Empirical Insights

This thesis is the first systematic study on the gas turbine industry in the context of developing countries. It allows an understanding of the technological capabilities, industry structure and governance, and challenges of technological catch-up in developing countries. It also sheds light on the similarities and differences between the gas turbine industry in the contexts of developed and developing countries. The two main empirical findings of this thesis can be framed as follows.

Technological catch-up in gas turbine industry is a very challenging process

Gas turbines are the product of many technologically advanced, interrelated and sophisticated technologies. The gas turbine is the main machine and the most technologically advanced part of a gas-fired power plant. The required technologies for manufacturing gas turbines have incrementally evolved over the last 50 years. Some gas turbine technologies have evolved from their roots in aircraft jet engines (see Chapter 5, Section 5.3). Technologies such as superalloys, single crystal, direct solidification and advanced coating methods have all been transferred from the aircraft jet engine industry. The transfer of these advanced technologies has greatly influenced the survival of some companies and the shakeout of others (see Chapter 5, Sections 5.3.3 and 5.3.4). Companies today compete to manufacture efficient, durable, and less fuel-consuming gas turbines. The computerisation of manufacturing technologies such as CAD/CAM and CNC machines (see Chapter 5, Section5.2) has enabled manufacturers to fabricate highly accurate components. Similarly, design technologies have greatly benefited from computer simulations and new material sciences (see Chapter 5, Section 5.3.5).

This thesis has noted the findings of past studies on the oligopolistic structure of the gas turbine market (Watson 1997; Watson 2004*a;* Magnusson et al 2005). Over most of the past two decades, the number of suppliers has been limited to a few multi-billion dollar companies. However, in recent years and within a competitive atmosphere, the market has been entered by newcomers which have either transferred technologies from the leading companies or which have been working under licenses. Nowadays, amongst those countries that have a gas turbine industry (which are limited, particularly in the context of developing countries), the number of suppliers in each country is confined to one or two.

This thesis would argue that gas turbine suppliers in the world have a pyramid shape, in which there are often two or three lead suppliers, while other suppliers are recognised as followers or latecomers. In the global market, GE and Siemens have more than 60% of the total value share of gas turbines in all power output ranges. Other OEM suppliers, such as Alstom and Mitsubishi Heavy Industries, are behind these two lead suppliers. The rest of the suppliers in the world – such as the Iranian, Indian and Chinese companies – are followers which work under the licenses of these lead suppliers.

From a developing country's perspective, this thesis would argue that technology transfer from the lead suppliers to the followers entails significant barriers. As it was argued in Chapter 5 (Section 5.4), in the oligopolistic market for gas turbines, the lead suppliers are reluctant to transfer technical know-how to developing countries' firms. In other words, this thesis has shown that the oligopolistic structure of the gas turbine market is an important influence on catching-up. Companies like MAPNA have faced various kinds of challenges and difficulties in acquiring technologies. The entrance to the gas turbine industry, even when becoming a follower such as a licensee, needs considerable indigenous capability building efforts. The Iranian case has revealed that technological growth of the industry needs extensive indigenous technology development efforts, constant engagement of indigenous efforts with foreign knowledge sources, supportive government policies, and collaboration with national universities.

This thesis would also argue that follower companies are working in different contexts and have different levels of capabilities. The Indian and Chinese companies manufacture a broader range of gas turbines than MAPNA, but their technological capabilities are confined to assembly and limited manufacturing processes. They import advanced and high technology parts from the lead suppliers. In contrast, MAPNA manufactures limited models of gas turbines, but have succeeded in acquiring of the main technologies for their manufacture. The Iranian firms were able to localise the production of all gas turbine parts including gas turbine blades and other hot sections. They have also employed different kinds of indigenous technology development efforts. With respect to this, this thesis argues that reverse engineering activities have substantially improved the Iranian companies' technological capabilities (see Chapter 6, Section 6.7.2). This finding contrasts with the argument of Pack and Saggi (1997) and confirms the argument of Bell and Pavitt (1993).

Despite these efforts by the Iranian firms, this thesis has shown that there are still many gaps in technological capabilities between the Iranian companies and the lead suppliers. The Iranian firms have not yet acquired the new technologies such as single crystal, direct solidification and the new CCGT cycles. In fact, technological catch-up in the gas turbine industry is a special case in terms of technologies and markets. It requires acquiring very sophisticated technologies. For instance, a comparison between the gas turbine and wind turbine industries shows that, although the lead suppliers in the wind turbine industry are strong and hesitant to share cutting-edge technology out of fear of creating new competitors, China and India have succeeded in developing important firms over the last ten years (Barton 2007). Based on the findings of this thesis, it can be argued that although technological catch-up in the gas turbine industry is not impossible, it entails substantial barriers for developing countries' firms.

High level of state involvement in developing countries is a prominent feature

Chapter 5 (Section 5.4) reviewed the influences on the evolution of land-based gas turbines. As it was argued, the evolution of gas turbine technologies originates from multi-billion dollar military and civil programmes and other public R&D budgets (Mowery and Rosenberg 1982). However, both demand pull factors (e.g. demand for peaking/backup plants in the US and the UK in the 1960s or the PURPA Act plants in the US in the 1980s) and supply push factors (e.g. military R&D support) have been important in the evolution of technical skills, knowledge and innovation in the gas turbine industry. Until recently, many gas turbine technologies were readily available from the multi-billion dollar military jet engine programmes of the US Department of Defense and their European counterparts (Watson 2004*a*). The analysis shows that the market for land-based gas turbines has had connections (direct and sometimes indirect) with each country's government policies, including energy policies. Countries like the US the UK and Germany have funded some programmes to research gas turbines (see Chapter 5, Section 5.4).

The analysis in Chapter 5 (Section 5.4) also revealed that the market demand for land-based gas turbines is also attributed to governments' environmental policies. Today, natural gas is recognised as a much cleaner type of fuel compared to other types of fossil fuels and consequently CCGTs are considered a favourable choice in the power plant industry. Furthermore, their short time of construction and low capital costs (in comparison with other types of fossil fuel power plants and also nuclear power plants) adds to the above demand pull factors. Thus, where natural gas is available, governments tend to support the construction of gas-fired power plants in their national energy policies.

The thesis has shown that the market for land-based gas turbines has been heavily influenced by state policies in all countries, though the strength or weakness of this influence depends on whether the industry has been privatised or still state-owned. The customers for these types of products have been or still are states. Although electricity markets as well as power plant equipment manufacturers in the US and the UK have privatised and liberalised over the last two decades, in the majority of countries the electricity generation market structure is still either a private monopoly or a state-owned company. The gas turbine manufacturers in Iran, India and China are state-owned companies (see Chapter 8, Table 8.1). The state policies in these three mainly originate from national energy policies. While in India and China the national energy policies have focused on coal, and natural gas has had a negligible effect, in Iran the emphasis has been in the opposite direction. Iran is now focusing on a transition to natural gas.

Furthermore, this thesis argues that China, India and Iran have large and growing electricity markets in which the states are supporting the local companies in order to supply these domestic markets. It was shown that supplying the domestic market in the cases of India, China and Iran has been a decisive factor regarding the evolution of each country's power generation equipment manufacturers. The Iranian and Chinese companies have tried to enhance their technological capabilities in gas turbine and steam turbine technologies respectively, whereas the Indian company prioritised power plant construction to meet rapidly growing demand and thus acquisition of gas turbine technologies has remained marginal.

Therefore, a high level of state involvement can be distinguished for the development of land-based gas turbine technologies, particularly in developing countries such as Iran, India and China.

9.3 Limitations and Future Research

This thesis has four limitations. Firstly, although it has tried to provide insights into gas turbine industries in other developing countries, particularly in China and India, it has not analysed the Indian and Chinese companies to the same depth as the Iranian companies. This thesis has not directly accessed the Indian and Chinese companies and thus it has used secondary interview data. It has also strategically focused on what documentary evidence does exist for China and India (primarily reports such as those produced by the IEA) as well as articles and reliable websites. This provides a limited opportunity to compare the findings from the Iranian context with the experience of the two other developing countries.

Secondly, this thesis did not assess how foreign partners of MAPNA Group perceive the technological acquisition process of the Iranian side. Although there was some contact made with lead suppliers (particularly with Siemens) about the gas turbine market in general, the thesis research did not conduct interviews with the foreign partners – those who have had technology transfer agreements – of MAPNA Group. This is because this thesis aims to understand the influences and the dynamics of the technological catch-up of an Iranian firm in the Iranian context. However, it is evident that accessing the foreign partners of MAPNA Group could provide further information concerning the two sides' interactions. Interviewing these foreign companies would enhance the chances of understanding the Iranian firms' challenges in acquiring the technologies as well as their degree of contribution to the development of some specific technologies. However, time and resource limits prohibited gathering this additional evidence.

Thirdly, the thesis focused only Iran's gas turbine industry. It is important to understand how other industries in Iran combine indigenous technology development efforts with foreign technology transfer. It is also important to understand how the US-led sanctions influence other industries' technological catch-up in the Iranian context. These aspects were outside the scope of the current research.

Fourthly, the thesis has focused only on the gas turbine industry which is a capital-intensive, low-volume producing, oligopolistic and politicised industry. Although this thesis suggests a new perspective in the substitution/complementarity studies, its findings may offer little to the theory regarding industries recognised as mass-producing, less politicised and highly competitive.

Building on these limitations, a number of potentially fruitful avenues for further research can be suggested.

With respect to the lack of systematic studies on the gas turbine industry in developing countries, future research should aim to analyse the Indian and Chinese companies in depth. The contextual challenges and difficulties of the Indian and Chinese firms towards technological catch-up remain unclear. In-depth analysis of the gas turbine industry in China and India (and any other developing country that has a gas turbine industry) is an interesting issue that warrants further scrutiny.

Introducing the dynamic approach, the thesis research has touched upon the influencing factors as well as the challenges associated with the interaction processes between indigenous and overseas technology sources in the Iranian context. A corroboration of the findings through other case studies would allow a better understanding of the dynamism. Further research should aim to identify and analyse the influencing factors in other sectors and countries. Examining the dynamic approach in technological catch-up in other contexts will lead to a deep, precise and general understanding of the dynamics of interaction between the two main knowledge sources in technological catch-up processes.

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